การทำงานของระบบประสาทและกล้ามเนื้อในการควบคุมการเคลื่อนไหวของข้อเข่าขณะยืนนิ่ง ในประชากรที่มีข้อเข่าแอ่น: การศึกษาจากคลื่นไฟฟ้ากล้ามเนื้อและความสามารถในการรับรู้ตำแหน่งของข้อต่อ

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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NEUROMUSCULAR CONTROL OF KNEE JOINT IN INDIVIDUALS WITH KNEE HYPEREXTENSION DURING QUIET STANCE: RESULTS FROM ELECTROMYOGRAPHIC AND JOINT POSITION SENSE STUDY

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Physical Therapy
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ปวัน ชัยปริญญา : การทำงานของระบบประสาทและกล้ามเนื้อในการควบคุมการเคลื่อนไหวของข้อเข่าขณะยืนนิ่งในประชากรที่มีข้อเข่าแอ่น: การศึกษาจากคลื่นไฟฟ้ากล้ามเนื้อและความสามารถในการรับรู้ตำแหน่งของข้อต่อ. (NEUROMUSCULAR CONTROL OF KNEE JOINT IN INDIVIDUALS WITH KNEE HYPEREXTENSION DURING QUIET STANCE: RESULTS FROM ELECTROMYOGRAPHIC AND JOINT POSITION SENSE STUDY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.จิตอนงค์ ก้าวกสิกรรม, หน้า.

อาสาสมัครที่มีข้อเข่าแอ่นมีความสามารถในการทรงท่าขณะยืนนิ่งน้อยกว่าอาสาสมัครที่มีข้อเข่าปกติ แม้ว่าความสามารถในการปรับการทรงท่าของอาสาสมัครที่มีเข่าแอ่นจะมีลักษณะคล้ายคลึงกับอาสาสมัครที่มีข้อเข่าปกติ แต่ยังไม่มีการศึกษาที่เปรียบเทียบการควบคุมของระบบประสาทและกล้ามเนื้อระหว่างประชากรสองกลุ่มนี้ ทั้งนี้ ความสามารถในการรับรู้ตำแหน่งและการเคลื่อนไหวของข้อเข่า ซึ่งอาจเป็นข้อมูลที่ใช้ในการอธิบายความแตกต่างในการควบคุมการเคลื่อนไหวของข้อเข่าระหว่างประชากรทั้งสองกลุ่มยังไม่สามารถหาข้อสรุปที่แน่ชัดได้ งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาและเปรียบเทียบความสามารถในการปรับการทรงท่าและการทำงานของระบบประสาทและกล้ามเนื้อรอบข้อเข่า รวมถึงความสามารถในการรับรู้ตำแหน่งของข้อเข่าระหว่างอาสาสมัครที่มีข้อเข่าแอ่นกับอาสาสมัครที่มีข้อเข่าปกติ อาสาสมัครหญิงจำนวน 36 คน แบ่งเป็นกลุ่มที่มีข้อเข่าแอ่น 18 คนและข้อเข่าปกติ 18 คนเข้าร่วมในงานวิจัยนี้ โดยทำการบันทึกข้อมูลสัญญาณไฟฟ้ากล้ามเนื้อรอบข้อเข่าด้วยเครื่องบันทึกสัญญาณไฟฟ้ากล้ามเนื้อและบันทึกการเปลี่ยนแปลงมุมของข้อเข่าโดยใช้อุปกรณ์วัดมุมแบบดิจิตอลในขณะที่อาสาสมัครยืนนิ่งหรือยืนในขณะที่มีการรบกวนการทรงท่าโดยให้มีการหลับตาหรือยืนบนพื้นโฟม นอกจากนี้ ผู้วิจัยทำการเก็บข้อมูลความสามารถในการรับรู้ตำแหน่งของข้อเข่าโดยให้อาสาสมัครงอเข่าไปยังมุมที่ให้อาสาสมัครจำไว้ ซึ่งความสามารถนี้จะนำเสนอด้วยค่าความคลาดเคลื่อนสัมบูรณ์ ค่าความคลาดเคลื่อนสัมพัทธ์ และค่าความน่าเชื่อถือในการย่อเข่ามาที่มุมเดิมซ้ำ ข้อมูลทั้งหมดทำการบันทึกจากขาข้างที่ไม่ถนัดของอาสาสมัคร

ผลการศึกษาพบว่าอาสาสมัครทั้งสองกลุ่มมีการตอบสนองต่อการรบกวนการทรงท่าโดยใช้การงอข้อเข่า ยกเว้นกลุ่มอาสาสมัครที่มีข้อเข่าแอ่นซึ่งพบว่ามีการเหยียดข้อเข่ามากขึ้นขณะยืนหลับตาบนพื้นปกติ กล้ามเนื้อ medial hamstrings ในกลุ่มข้อเข่าแอ่นมีการทำงานเพิ่มขึ้นมากกว่าอีกกลุ่มอย่างมีนัยสำคัญทางสถิติ ($p = 0.047$) และอาสาสมัครทั้งสองกลุ่มมีความสามารถในการรับรู้ตำแหน่งของข้อเข่าใกล้เคียงกัน แต่อาสาสมัครในกลุ่มข้อเข่าแอ่นมีความแม่นยำในการทดสอบซ้ำที่น้อยกว่าอย่างมีนัยสำคัญทางสถิติ ($p = 0.017$) อาจสรุปได้ว่า อาสาสมัครที่มีข้อเข่าแอ่นจะมีการควบคุมการทำงานของระบบประสาทและกล้ามเนื้อคล้ายคลึงกับอาสาสมัครที่มีข้อเข่าปกติเมื่อมีข้อมูลจากระบบการมองเห็น การปรับการทรงท่าที่ข้อเข่าของอาสาสมัครทั้งสองกลุ่มมีลักษณะคล้ายกันแม้ว่าลักษณะการทำงานของกล้ามเนื้อจะมีความแตกต่างกัน นอกจากนี้ อาสาสมัครที่มีข้อเข่าแอ่นยังความน่าเชื่อถือของการรับรู้ตำแหน่งของข้อเข่าที่ด้อยกว่าอาสาสมัครที่มีข้อเข่าเป็นปกติ

ภาควิชา กายภาพบำบัด ลายมือชื่อนิสิต ....

สาขาวิชา กายภาพบำบัด ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ปีการศึกษา 2556

5377205837 : MAJOR PHYSICAL THERAPY
KEYWORDS: POSTURAL CONTROL; QUIET STANCE; KNEE HYPEREXTENSION; JOINT POSITION SENSE

PAWAN CHAIPARINYA: NEUROMUSCULAR CONTROL OF KNEE JOINT IN INDIVIDUALS WITH KNEE HYPEREXTENSION DURING QUIET STANCE: RESULTS FROM ELECTROMYOGRAPHIC AND JOINT POSITION SENSE STUDY. ADVISOR: ASST. PROF. CHITANONGK GAOGASIGAM, Ph.D., pp.

The participants with knee hyperextension demonstrated poorer stance stability. Even though the patterns of postural response of the hyperextended knee participants were comparable to normal knee participants, the neuromuscular control was unknown. The ability to detect the knee joint position which could be the explanation why the two groups of participants exhibited different stance stability was still inconclusive. The current study was conducted to investigate and compare the postural and neuromuscular responses at the knee joint between participants with knee hyperextension and normal knee participants. Furthermore, the ability to detect knee joint position was also investigated. Thirty-six healthy female participants were recruited in the study, 18 normal knee and 18 hyperextended knee participants. The activities of the muscle around the knee joint were recorded with the surface electromyography and the knee joint angles were recorded with electrogoniometer while the participants were standing quietly or with the perturbation of either the visual or somatosensory systems, or both. Afterward, the ability to detect knee joint position sense was investigated with the memory-based, ipsilateral active joint position sense matching task. The absolute, relative, and variable errors from the joint matching tasks were then reported. All data were recorded from the non-dominant legs.

The results revealed comparable knee flexion responses to sensory perturbations in both groups except the knee extension response of the knee hyperextension group in the firm eyes-closed condition. Medial hamstrings muscle activity was found significant difference between the two groups in the firm eyes-closed condition ($p = 0.047$). The variable error which reflect the reliability of the joint matching task was found significant difference ($p = 0.017$) while the absolute and relative errors were not. It might be concluded that the neuromuscular control of the hyperextended knee participants were comparable to the normal knee participants only when they could access to the visual information. Despite the different muscle activation patterns, the knee joint postural adjustments were comparable. Lastly, the hyperextended knee participants had lower knee joint position sense reliability.

Department:	Physical Therapy	Student's Signature	....
Field of Study:	Physical Therapy	Advisor's Signature	....
Academic Year:	2013		

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CHAPTER 1
INTRODUCTION

1.1 Background and rationale

Quiet stance, one of the most common tasks used in the daily activities, has been the subject of motor control and biomechanical research for such a long time. It has been modelled as a single inverted pendulum (SIP) as they thought the regulation of body equilibrium was controlled by the ankle musculature (Winter, 1995). However, recent studies have demonstrated that the brain coordinates joints along the body axis to achieve a steady position. The notion was then changed to multi-joint coordination (Hsu et al., 2007) which meant that the knee joint also involved in the control of quiet stance.

Body alignment is thought to have an influence on the control of quiet stance (Shumway-Cook, 2007). Hence, the alignment of the knee joint should affect the stance stability. Knee misalignment was found to be an independent risk factor for progressive knee osteoarthritis (Tanamas et al., 2009) and may lead to the destruction of other knee joint structures (Loudon, Goist, and Loudon, 1998). Knee hyperextension was characterized by the misalignment between the femur and the tibia in the sagittal plane in which the knee range of motion was greater than normal anatomical position. It was found that knee hyperextension correlated with anterior knee joint laxity and anterior cruciate ligament injury (Friden et al., 2001; Loudon et al., 1998; Shultz, Nguyen, and Levine, 2009). Knee hyperextension was found to be more common in females than males and female athletes who had knee joint laxity were more likely to have sustained knee-related injury (Medina McKeon and Hertel, 2009; Shultz, Nguyen, and Schutz, 2008).

Researchers have proposed that proprioception in individuals with joint hypermobility or laxity may be perturbed (Simmonds and Keer, 2007; Stillman, Tully, and McMeeken, 2002). The study by Shultz and colleagues had shown that hamstrings reflex, which helped prevent excessive anterior tibial translation, was delayed (Shultz, Carcia, and Perrin, 2004). Researchers hypothesized that individuals with knee hyperextension might have poor knee joint proprioception due to lax ligament (Simmonds and Keer, 2007; Stillman et al., 2002). However, proprioceptive studies in knee joint laxity yield inconclusive results which might be caused by different testing positions; weight bearing versus non-weight bearing position (Loudon, 2000; Stillman et al., 2002).

Nowadays, there is only one study on postural control in knee hyperextension has been published (Siqueira et al., 2011). To understand the mechanism of knee joint neuromuscular control, an EMG study combine with the results from electrogoniometer and an assessment of knee joint position sense may explain how individuals with knee hyperextension control position of the knee joint. The role of muscle activation in both pathological and normal populations is of interest for understanding central nervous system function. Muscle activation patterns of knee hyperextension may provide insight into physiological changes compared to healthy controls.

1.2 Purposes of the study

The aims of this study were to compare level and pattern of muscle activity between normal knee alignment and hyperextended knee participants during quiet stance. Moreover, the role of knee joint in the control of stance stability and knee joint position sense were also investigated.

1.3 Parameters of the study

1.3.1 Independent variable

Knee hyperextension angle

1.3.2 Dependent variables

1. Level of muscle activity
2. Lower extremity muscle activation pattern
3. Knee joint angle in each standing condition
4. Knee joint position sense

1.4 Scope of the study

The scope of this study was to evaluate and compare: (1) the knee joint postural response, (2) level and patterns of lower extremity muscle activation and (3) knee joint position sense between participants who had normal knee alignment with those who had knee hyperextension greater than 10 degrees beyond anatomical position. The participants were healthy females aged between 18 and 30 years old. All of them did not participate in any sport activity more than 3 times a week.

1.5 Objectives of the study

1. To study the role of knee joint in postural adjustment when the postural control was disturbed.
2. To study and compare pattern of muscle activity around knee joint between individuals with knee hyperextension and normal knee alignment during quiet stance.
3. To compare knee joint position sense of individuals with knee hyperextension and those who had normal knee alignment in weight bearing position.

1.6 Research questions

1. How did knee joint involved in postural adjustment during somatosensory and visual disturbance?
2. Did individuals with knee hyperextension demonstrate different neuromuscular control compare to normal knee alignment individuals in terms of level and pattern of muscle activity?
3. Did individuals with knee hyperextension demonstrate poorer knee joint position sense compare to normal knee alignment individuals?

1.7 Hypotheses of the study

1. Individuals with knee hyperextension would demonstrate different knee joint postural adjustment compare to normal knee alignment group.
2. Individuals with knee hyperextension would demonstrate different knee muscle activity pattern compare to those with normal knee alignment.

3. Individuals with knee hyperextension would show different muscle activity around the knee joint when postural control was more challenged compare to normal knee alignment individuals.
4. Individuals with knee hyperextension would demonstrate different capacity in detecting knee joint position sense compare to normal knee alignment individuals.

1.8 Brief methodology

Participants were recruited if they had sagittal knee angle more than zero degrees in flexion or hyperextended more than 10 degrees. The surface electromyography and electrogoniometer were used to extract the neuromuscular activity, muscle activity and knee joint angle, of the participants. All of them were asked to stand under four conditions randomly; (1) Firm surface with eyes open, (2) Firm surface with eyes closed, (3) Foam surface with eyes open, and (4) Foam surface with eyes closed. Afterward, the knee joint position sense was tested in weight bearing position.

1.9 Advantages of the study

1. The results might provide an understanding of how muscles around knee joint contribute to control stance stability.
2. The results might provide the information of how knee joint involved in postural control during quiet stance.
3. Treatment plan or specific intervention program might be made precisely to improve knee joint stability in people with knee hyperextension.

CHAPTER 2
REVIEW LITERATURE

Human stance control can be achieved through the complex interaction between nervous system and musculoskeletal system. Brain receives sensory information mainly from visual, vestibular and somatosensory systems to perceive and adjust body position in space. During quiet stance, it was suggested that both center of mass (CoM) and its velocity should be of concerned when determining stance stability (Shumway-Cook, 2007).

Quiet stance is described by small amount of spontaneous postural sway (Shumway-Cook, 2007). There are three main factors that contribute to the control of quiet stance; (1) body alignment, (2) postural tone, and (3) muscle tone. Body alignment could affect how our body reacts to the gravitational force. The postural tone refers to muscle activity that is generated by the postural muscles during upright position, while the muscle tone refers to muscle activity that increase due to the muscle is being elongated (Shumway-Cook, 2007). Since this study tends to determine how healthy individuals with knee hyperextension control their knee position during quiet stance, thus, all attention is put on the body alignment. Other two sensory systems are controlled and assumed to be normal in this study. Normally, line of gravity passes through mastoid process, a point just in front of shoulder joint, the hip joint, a point just in front of the center of knee joint, and a point just in front of the ankle joint in standing position. This position allows us to maintain in equilibrium and requires only small amount of muscular effort (Shumway-Cook, 2007).

Once the alignment of the joint is deformed or aligned in different positions, postural control changed, for example, individuals who have osteoarthritis with increasing knee abduction angle tend to shift their weight in mediolateral direction more than normal knee alignment (Knoop et al., 2011). However, this may not directly reflect the influence of knee joint position on postural control since articular surface is also destructed in the degenerative process. Unlike knee hyperextension, this condition can generally be found in society and without certain consequences perceived by that individual. Some evidences point out that individuals with joint hypermobility are likely to develop degenerative joint disease. The structures within and around hyperextend knee joint may still be in a perfect condition or may be elongated without destruction of proprioceptors (Stillman, 2002). Even though the mechanism and long term consequences from knee hyperextension injury have been reported (Loudon et al., 1998), none of those studies report the neuromuscular control of this condition. Further, the structures and functions of knee joint will be discussed.

2.1 The anatomy of knee joint

The knee joint consists of two separate joints; tibiofemoral joint and patellofemoral joint. The roles of knee joint are mainly to allow stability, accommodate for different terrains, transmit and absorb forces caused during activities of daily life. The maximal stability of the knee joint is gained at full knee extension (Masouros, Bull, and Amis, 2010).

The knee joint can be defined as modified hinge joint since its movements occur mostly in sagittal plane couple with small movement in horizontal and frontal plane (Masouros et al., 2010). The tibiofemoral joint can move through 160 degrees of flexion, combine with other two planes of movements; small angle of rotation in horizontal plane and gliding in mediolateral plane. The tibiofemoral joint, the biggest joint in the body, is made up between a ball-like femoral condyles put on top of meniscal sockets over the tibial plateaus. Generally, the lateral and medial femoral condyle appearances are different from each other. The medial femoral condyle has larger surface and more curvature than the lateral one. Its articular surface extends anteroposteriorly. The lateral femoral condyle is smaller in size and contributes to the vagus and anteroposterior alignment of the knee. The tibial plateaus are concave medially and circular, convex laterally. Taking all the shapes of femoral condyles and tibial plateaus into account, the tibiofemoral joint can move through three axes, having the medial side of the joint move over the lateral one (Goldblatt and Richmond, 2003; Lovejoy, 2007).

Considering the geometry of the knee joint, it is unstable as it moves through a wide range of motion, requiring tension from soft tissues, muscles, and tendons around the knee joint to improve joint stability. Stability of knee joint composes of (1) static stability, (2) active stability, and (3) passive stability. The static stability is caused by the geometry and articular surface of knee joint. The active stability is caused by muscle contraction. Finally, the passive stability is caused by ligaments and tendons across the joint (Masouros et al., 2010).

As the line of gravity passes just in front of the center of knee joint. With knee at full extension, weight support and stability are at the maximum. If the knee is in flexion, line of gravity would fall behind the knee joint causes the quadriceps muscle to increase muscle work to maintain body upright against gravitational force. On the other hand, if the knee is hyperextended, the knee would become stable due to passive tension from joint capsule and ligaments around it (Masouros et al., 2010).

The main knee joint ligaments that restrain joint displacement consist of; (1) anterior cruciate ligament (ACL); (2) posterior cruciate ligament (PCL); (3) medial collateral ligament (MCL); (4) lateral collateral ligament (LCL); (5) meniscus-meniscal ligament construct; (6) patellar retinacula and medial patellofemoral ligament (Masouros et al., 2010).

Anterior cruciate ligament is the primary restraint to anterior tibial translation, aid in preventing knee hyperextension. The posterior cruciate ligament is the primary restraint to posterior tibial translation. Taken together, both ACL and PCL control the anterior-posterior rolling and sliding of the tibiofemoral joint during flexion and extension. The medial collateral ligament is the primary restraint to valgus angulation and tibia internal rotation. The lateral collateral ligament acts mainly to restrain varus angulation. The meniscus-meniscal ligament complex is mainly restrained to tibial external rotation. Finally, the patellar retinacula and the medial patellofemoral ligament act as the primary passive restraint to lateral patellar displacement and assist in controlling patellar motion (Masouros et al., 2010).

2.2 Knee hyperextension

Knee hyperextension is a common entity found in clinics that may lead to destruction of knee joint structures and is more likely to develop degenerative joint disease (Loudon et al., 1998; Tanamas et al., 2009). Individuals with knee hyperextension may have impaired proprioception of the knee joint during end range of flexion to extension (Loudon et al., 1998). However, this cannot be concluded since the findings are still controversial (Loudon, 2000; Stillman et al., 2002). Stillman and co-workers compared ipsilateral, non-weight bearing joint re-position ability between young adults who had more mobile knee (average knee extension was -10.3° ± 3.7°) and less mobile knee (average knee extension was -1.0° ± 3.2°). The results found that individuals with more mobile knee did not demonstrate impaired knee joint position. Besides, they demonstrated more accuracy in matching knee joint angle than less mobile knee individuals (Stillman et al., 2002).

Recently, Siqueira and colleagues found that knee hyperextension had influence upon postural control as shown by higher CoP velocity during quiet stance (Siqueira et al., 2011). The higher CoP velocity reflected poorer motor control ability. Nevertheless, Kawahara and colleagues found no significant difference in other gait parameters including joint angle, joint moment, and ground reaction force during over ground walking in participants with knee hyperextension. On the other hand, the presence of ACL deficiency did alter gait parameters (Kawahara et al., 2012). According to these two studies, individuals with knee hyperextension might have a poorer control, however they were able to walk normally. This also suggested that knee hyperextension was postural condition highly dependent on postural control that can be accommodated by individuals (Siqueira et al., 2011).

The researchers found the common knee structures that were usually injured in individuals with knee hyperextension. Mostly, the structures on posterolateral corner of knee joint usually affected as well as ligament within the knee joint (Fornalski et al., 2008; Loudon et al., 1998; Tanamas et al., 2009). A study in fresh-frozen cadaveric knees had suggested that the more knee hyperextension increase, the more soft tissue failure within and at posterolateral corner of the knee joint found (Fornalski et al., 2008). Researchers tested the cadaveric knee on the custom jig that could produce anterior-posterior tibiofemoral joint displacement. They found the ACL, LCL, tendon of popliteus muscle and soft tissue at the posterolateral corner of the knee were the most involving structures that injured in isolated knee hyperextension injury. Loudon and colleagues suggested that the lateral head of gastrocnemius muscle, as one of the arcuate complex, was also stressed in knee hyperextension (Loudon et al., 1998).

Ligaments within knee joint are not only mechanical structures that restrain excessive movement of the adjoining bones, but also yield neurological functions aiding in joint stability (Ageberg, 2002; Solomonow, 2006). Researchers reported that all 4 types of mechanoreceptors (Pacinian-like, Ruffini-like, Golgi tendon-like organ, and free nerve ending) can be found in ligaments of major joints of the body (Solomonow, 2006). The injured ligament can cause many consequences on human neuromuscular control, such as changes in the natural inhibition of muscle, muscular atrophy, deficient kinesthetic perception and gait deviations (Ageberg, 2002; Di Fabio et al., 1992; Solomonow, 2006). The ACL, as a primary restraint to anterior tibial translation of the knee also displays a neurological function. The hamstrings reflex response elicited after the ACL is stretched beyond its usual length aiding in preventing excessive anterior tibial translation. The injured ACL not only loses it mechanical properties (increase anterior knee joint laxity), but also loses its neurological properties known as the ligamento-muscular reflex (Solomonow, 2006).

The example of ligament laxity that influenced postural response had shown by Di Fabio and colleagues. They tested the individuals with ACL insufficiency on the anterior translation platform during bilateral and single stance. They found an additional hamstring response to posterior sway which suggested that motor preprogramming was modulated to compensate for ligament laxity (Di Fabio et al., 1992).

The study by Shultz and colleagues showed that female athletes who have anterior knee joint laxity might be less sensitive to joint displacement (Shultz et al., 2004). The participants were disturbed anteriorly during single leg stance with knee joint at 30 degrees flexion. They found that biceps femoris muscle in anterior knee laxity group demonstrated an increase in reflex response time (16 ms delay) as well as increase activation amplitude of the electromyographic recording (Shultz et al., 2004). The mechanoreceptors within the ACL might be disturbed in knee hyperextension. These mechanoreceptors are part of proprioceptive system that aid in postural control. It might be suspected that proprioceptive response might also be disturbed.

Another study by Shultz and colleagues investigated the relationship between lower limb alignment and anterior knee joint laxity, they found that greater knee hyperextension, greater foot pronation, lower anterior pelvic tilt and lower tibiofemoral angle were associated with anterior knee joint laxity in female. For male, lower anterior pelvic tilt, greater hip anteversion were associated with anterior knee joint laxity. The strongest predictors for anterior knee joint laxity were greater knee hyperextension and foot pronation for both male and female (Shultz et al., 2009). As the results reported, position of knee joint, hip joint and ankle joint are correlated. Individuals who have knee misalignment may also influence overall lower limb alignment.

The findings of knee hyperextension indicated the risk to develop osteoarthritic change of knee joint, inconclusive joint position detection capability, altered muscular responses to external perturbation in anterior and posterior directions, changed of motor preprogramming, and relationship with other lower limb joint alignment. Finally, these physiological changes might have influences upon postural control.

2.3 Knee joint and postural control

Researchers suggest that human stance can be viewed as a single inverted pendulum (Winter, 1995). This model predominates the roles of muscles and passive stiffness around ankle joint in controlling quiet stance. The double inverted pendulum predominates the roles of hip and ankle joint during stance. However, with an advanced technology, it has proved that single inverted pendulum is an oversimplified model to explain human stance control (Gunther et al., 2009; Gunther et al., 2011; Hsu et al., 2007).

Sequeira and colleagues had conducted the study to investigate whether knee hyperextension affect human stance stability. Their results showed that when postural control was more challenged, most of participants tend to bend their knees. Also, the researchers had measured CoP velocity and the differences were found between normal knee alignment and knee hyperextension group. During standing on firm surface with eyes open, the knee hyperextension group showed higher CoP velocity in the antero-posterior direction. In the most challenging condition, standing on foam surface with eyes closed, the knee hyperextension group showed the lowest CoP velocity. The mean velocity has been linked to the amount of regulatory activity associated with the level of stability. According to this assumption, Sequeira and colleagues concluded that knee hyperextension affects human stance stability (Siqueira et al., 2011). The results of Sequeira and colleagues may be explained by concept of postural control of quiet stance that body alignment affects postural control.

The study of Nyland and colleagues demonstrated that the frontal plane knee alignment (increase knee abduction or adduction angle more than 5 degrees) affects postural control of the individuals during single leg stance with 20 degrees of knee flexion. Mean anteroposterior CoP pressure location was more directed to the rarefoot than neutral knee alignment group. They explained that the more rarefoot location of CoP pressure used by the more frontal knee angle individuals aid in modulation of midtarsal joint inversion-eversion on more mobile foot lever to maintain postural equilibrium (Nyland et al., 2002).

From Sequeira’s study, even with the same biomechanical response (increase knee flexion angle) between the normal knee alignment and the knee hyperextension groups, neuromuscular control over the knee is not known. If we can understand how neuromuscular control over the knee is different between two groups, then it may be concluded that neuromuscular and postural control are affected by knee alignment.

As previously stated, anterior knee joint laxity is correlated with knee hyperextension. Joint mechanoreceptors of knee hyperextension might be disturbed as well. Assessing knee proprioception might allow researchers to gather more conclusive information about proprioceptive and postural control in knee hyperextension individuals.

2.4 Proprioception

Proprioception is the capability of the individuals to perceive body positions and movements in space, and is based on sensory signals provided to the brain via muscle spindle, joint mechanoreceptors, and cutaneous receptors without the use of vision (Gilman, 2002; Goble, 2010; Kiran et al., 2010; Proske and Gandevia, 2009; Stillman, 2002). Proprioception composes of two different sensations which are the joint position sense and the movement sense (kinesthesia) (Gilman, 2002; Proske and Gandevia, 2009).

Stillman wrote an article about ‘sense’ and ‘perception’ to identify their difference. Sense literally means recognizing a single specific type of stimulus. Perception, on the other hand, is the potential of the brain to clarify the origin of a stimulus. He quoted that proprioception was an example of perception (Stillman, 2002).

Human brain receives and processes sensory inputs from peripheral receptors. The processed information allows human to detect the position of joints and allows individuals to perceive how the joints are moving. The peripheral receptors that provide proprioceptive information are primarily from muscle spindles accompany with joint mechanoreceptors and cutaneous receptors (Gilman, 2002; Proske and Gandevia, 2009; Stillman, 2002). Recently, some researchers suggest that motor commands (the signal outflows from the brain that are targeting at the muscle) may contribute in detecting joint position sense (Gandevia et al., 2006; Walsh et al., 2009).

2.4.1 Muscle spindle and proprioception

Muscle spindles are small encapsulated, fusiform shape sensory receptors found within the fleshy part of the muscle. Theirs main function is to signal changes of length of muscle which they are located (Pearson and Gordon, 2000). Each muscle spindle is composed of three parts; (1) intrafusal muscle fiber, (2) large-diameter myelinated sensory ending which originated from the central region of the intrafusal fibers, and (3) small-diameter myelinated motor ending that innervated the polar region of the intrafusal fibers (Pearson and Gordon, 2000).

Because muscle spindles are arranged in parallel with the extrafusal fibers, the length of intrafusal fibers change as the length of extrafusal fibers change. When muscle spindles are stretched, their firing rate increase, and vice versa. The changes of firing rate are useful for the CNS to interpret the position of the body (Pearson and Gordon, 2000).

The extrafusal fibers receive innervation from *alpha motor neurons*, while the intrafusal fibers receive innervation from *gamma motor neurons*. Motor command that derives from motor cortex has influences on alpha motor neurons and causes the extrafusal fibers to contract. If the extrafusal fibers contract, the intrafusal fibers will become slack and their firing rate decrease. To prevent the loss of muscle signals to the CNS, gamma motor neurons become activated, consequently, the polar regions of the intrafusal fibers contract and stretch the central region which leads to an increase firing rate. This phenomenon is called *alpha-gamma motor neuron co-activation or fusimotor co-activation.* Thus, the gamma motor neuron is important for adjusting the sensitivity of the muscle spindle (Pearson and Gordon, 2000).

Many evidences have revealed the role of muscle spindles in detecting joint position and movement sense (Kito et al., 2006; Proske, 2006; Walsh et al., 2009). The first experimental study by Goodwin and colleagues had shown that muscle spindle signals provided proprioceptive information to the CNS (Goodwin, McCloskey, and Matthews, 1972). The effect of vibration altered muscle spindle firing rate and caused the brain to perceive movement in the opposite direction to the muscle whose tendon was vibrated (Walsh et al., 2009). The physiological effect of vibration caused muscle spindle to fire at the higher rate, so the brain interprets as that muscle is lengthened (Proske, 2006).

There are many factors affecting muscle spindles in detecting joint position sense or movement sense (Proske, 2006; Proske, Wise, and Gregory, 2000; Weiler and Awiszus, 2000). Since muscle spindle mainly responses to muscle length change and rate of length change, thus any factors that would alter the length of muscle or rate of muscle length change would therefore alter muscle spindle activity. The term “hysteresis” refers to a state in which muscle spindle activity is higher during the muscle is elongated than it is shortened while the limb is being moved through a cycle of movement (Weiler and Awiszus, 2000).

Another property of muscle spindles that might affect the interpretation of proprioception is called muscle thixotropy, a passive property of muscle which is dependent on the previous contraction history and length changes (Proske, 2006). As a muscle contracts, stable cross-bridges are formed between actin and myosin, after muscle relaxes these stable cross-bridges are still remained for some period of time in unperturbed or passively moved muscle. If the antagonistic muscle is actively contract, these bridges are then detached and give rise of the neuromuscular burst at the point of detachment. As a result of muscle thixotropy, it alters resting discharge rate of the muscle spindle and causes an inaccuracy of joint position perception (Proske, 2006).

2.4.2 Joint mechanoreceptors and proprioception

Joint mechanoreceptors are pervaded within structures of the knee. There are four different types of receptors that respond to different stimuli and present with different functions; (1) Pacinian-like, (2) Ruffini-like, (3) Golgi tendon-like organ (GTO), and (4) free nerve ending (Newton, 1982). These four receptors are presented in different structures and are function distinctly. These joint mechanoreceptors can be classified into rapid and slow adaptive receptors. The slow adaptive receptors are mainly function for joint position sense, this is why individuals can sense the position of their joint even though they have been motionless for some period of time. The fast adaptive receptors are function for movement sense (Newton, 1982; Stillman, 2002). The details of mechanoreceptors are presented in Table 2.1.

Table 2.1 Summary of joint mechanoreceptor characteristics (from Newton, 1982)

Type	Location	Appearance	Sensory unit	Physiologic function
Type I	- Stratum fibrosum of capsule; ligaments - Higher density in proximal joints	- Laminated Ruffini-like corpuscle - 300 μm wide - 300 - 800 μm long	- Myelinated parent and 2 - 6 corpuscles	- Active at rest and during movement - Low threshold for activation - Slowly adapting
Type II	- Junction of synovial joint and fibrosum of capsule; intra-articular and extra-articular fat pads - Higher density in distal joint	- Laminated pacinian-like, cornically shaped corpuscle - 150 - 250 μm long - 20 - 40 μm wide	- Myelinated parent axon and 1 - 5 corpuscles	- Active at onset and termination of movement - Low threshold for activation - Rapidly adapting
Type III	- Collateral ligaments but not found in ligaments of cervical region	- GTO-like corpuscle - 800 μm long - 100 μm wide	- Myelinated parent axon and 1 corpuscle	- Active at end of joint range - High threshold for activation - Slowly adapting
Type IV	- Ligaments, capsules, and articular fat pads - Absent in synovial tissue	- Free nerve endings or lattice type ending	- Thinly myelinated parent axon and terminal ending	- Active only to extreme mechanical and chemical irritation - High threshold for activation - Slowly adapting

However, the study of Clark and colleagues had demonstrated that anesthetizing joint mechanoreceptors only had minimal effect on the ability to perceive knee joint movement and joint matching capacity. According to their results, they concluded that knee joint mechanoreceptors were less important for knee joint position sense during static condition (Clark et al., 1979). Some evidences from people who underwent a total knee replacement surgery did not lose knee proprioception may also confirm this idea (Ishii et al., 1997).

2.4.3 Cutaneous receptors and proprioception

The evidences that support the role of cutaneous receptors in providing proprioceptive input to the central nervous system have begun in human hand, especially finger joints. Later, the studies of cutaneous input at other joints yielded the same results. The researchers concluded that cutaneous receptors also contribute to proprioception (Clark et al., 1979; Collins et al., 2005; Edin, 2001).

According to the study of Clark and co-workers, they tried to determine the importance of cutaneous inputs on the ability to detect knee joint position in young healthy adults. They anesthetized cutaneous receptors within 15-centimeter band around the knee being tested. Participants were asked to respond whether two legs were matched the same position or not, if not, then the participants had to tell the researcher to re-correct the position of the tested knee to match the other. Their results did not find a significant different on the ability to correct knee joint position even though the cutaneous receptors were almost completely anesthetized. They concluded that cutaneous receptors were not important and had only minor effect on knee joint position sense (Clark et al., 1979).

However, the effect of anesthetizing skin within only 15-centimeter band over knee joint might not be sufficient to eliminate all the cutaneous inputs from skin over anterior aspect of thigh. Edin underwent microneurographic recording from the lateral cutaneous nerve of thigh when skin was stimulated by using von Frey hair (Edin, 2001). The results demonstrated a large skin area that was innervated by lateral cutaneous nerve of thigh, from 5 - 10 centimeters below inguinal ligament down to below and lateral to the knee joint (Edin, 2001). Thus, participants might use cutaneous inputs from those cutaneous receptors that were not anesthetized to interpret the position of knee joint.

It was the study of Collins and co-workers which demonstrated that cutaneous receptors did involve in the perception of limb movement but not joint position sense other than interphalangeal joint, including the knee joint (Collins et al., 2005). Simulated skin stretch to the proximal and distal interphalangeal joint, elbow joint and knee joint can induced the perception of joint movement in many participants. At the knee joint, 3 out of 10 participants whose skin over the anterior aspect of thigh was stretched felt that their knee became flexed (Collins et al., 2005).

2.5. Neural pathway of proprioception

The proprioceptive information from muscle spindles, joint mechanoreceptors, and cutaneous receptors reach the brain through the posterior column-dorsal leminiscal pathway (Gilman, 2002). The afferent fibers mediating joint position sense and movement sense course through peripheral nerves into the medial aspect of the dorsal root and then enter the dorsal horn of spinal cord. Many of these fibers form synaptic connection with second order neurons in the dorsal horn, and these second order neurons ascend through the ipsilateral dorsolateral funiculus of the spinal cord. The secondary neurons then form the connections with lateral cervical nucleus, which is located in the two upper cervical segments of the spinal cord. Postsynaptic neurons from the lateral cervical nucleus project across the midline of the spinal cord, ascend to enter the medulla, and join the medial lemniscus. Currently, it appears that the dorsolateral funiculus is the principal ascending pathway for proprioception. Some afferents mediating joint position sense and movement sense project directly to the ipsilateral dorsal columns and ascend the spinal cord, terminating in the dorsal column nuclei. Fibers ascending the dorsal column develop a topographical arrangement. Afferent fibers join the lateral aspect of the dorsal columns in succession, caudal to rostral, at each spinal cord segment. This causes a laminated pattern, with fibers from the more caudal segments positioned medially and fibers from the rostral segments positioned more laterally (Gilman, 2002).

In the upper spinal cord, fibers from sacral, lumbar, and lower thoracic spinal segments form the gracile (medial) fascicle and those from the upper thoracic and cervical segments form the cuneate (lateral) fascicle. Thus, the proprioception from head, neck, upper limbs, and upper trunk ascend through the cuneate fascicle, and the proprioception from lower trunk and lower limbs ascend through the gracile fascicle. Mechanosensory information from face and scalp is transmitted to the principal trigeminal nucleus (Gilman, 2002).

The axons from cuneate and gracile nuclei then pass through brain stem and cross to contralateral brain at medial lemniscus of medulla to the ventral posterior lateral nucleus of thalamus. As the medial lemniscus fibers cross midline, the body map reversed; the sacral segments are located most laterally and the cervical segments located most medially. The sensory signals then project to cerebral hemisphere for proprioceptive perception (Gilman, 2002).

2.6. Sensorimotor areas which are active during movement illusion

In particular, the primary somatosensory area (S1) is the main cortical area that serves for perception and interpretation of sensory information. Recently, study by Naito and colleagues had shown that not only the S1 but also the primary motor cortex (M1) of human respond to movement sense (Naito, Roland, and Ehrsson, 2002; Naito et al., 2005). By vibrating the tendon of left or right extensor carpi ulnaris muscle, participants felt that their vibrated wrist immediately flexed and the contralateral M1 and S1 was activated. Moreover, the right supplementary motor area, right premotor cortex, right area 8, and right S1 were activated no matter the right or left extensor carpi ulnaris tendon was vibrated (Naito et al., 2002). In the other case, the two hands were in contact with each other while the tendon was vibrated. All participants perceived as both hands were moved to the opposite direction of the vibrated wrist, researchers called this as transfer of illusion (Naito et al., 2002).

2.7 The roles of proprioception

As the above mention about proprioceptors and neural pathways, many receptors take part in signaling neural information to the central nervous system. These signals synapse many level within the central nervous system and are integrated to create the perception of appropriate position of the limbs and trunk and execution of accurate motions. Moreover, the proprioceptive information also plays an important role in cognitive programming and motor learning (Jerosch and Prymka, 1996). Roles of proprioception can be classified into two categories; (1) role in postural control and (2) functional joint stability (Jerosch and Prymka, 1996; Riemann and Lephart, 2002).

2.7.1 Proprioception and postural control

The accuracy of proprioceptive input is important for individuals to have a good postural control. The sensory information concerning both internal and external cues helps individuals to adapt motor performance to match with the task and environment. The roles of proprioception in motor control can be classified into 2 categories. The first category involves the role of proprioception with the external environment. The example of this situation is when individuals use the proprioceptive information to adjust body from perturbation during walking on uneven surface. Individuals can adjust their ankle position while they are walking on uneven surface before visual information and provide the fastest response and more accurate than the visual information did (Riemann and Lephart, 2002). Considering the neural pathway of the proprioceptive system, neural input from proprioceptors travel along the spinal cord and synapse many levels within the nervous system. These inputs can be processed and modulated to suit with the environment (Shumway-Cook, 2007).

The second role of proprioception is to plan and modify motor outputs to achieve a smooth and coordinated movement (Riemann and Lephart, 2002). Proprioceptive signals project to areas of the cerebral hemisphere, these areas include primary somatosensory area (area 2 and 3a), primary motor cortex, premotor cortex, supplementary motor cortex, cingulate motor area and cerebellum (Naito et al., 2002; Naito et al., 2005). The supplementary motor area is responsible for the initiation and controlling internally generated movements, while the premotor area is responsible for controlling the movements that are activated by external stimuli. The cerebellum is known as a movement comparator which receives and compares signals from primary motor cortex as well as proprioceptors from the moving joint (Shumway-Cook, 2007). These cortical motor areas work together to plan and initiate movements and can be adjusted to achieve a smooth and coordinate movement with helps of the cerebellum.

2.7.2 Proprioception and functional joint stability

How can human achieve stability throughout all movements? As earlier mentioned about knee joint stability, all three types of stability are gained by the mechanical properties of muscle, ligament, tendon and joint capsule. The joint and muscle stiffness together with viscoelastic property of ligament allow individuals to safely and accurately move their joints through range of movement. The attachments of the ligaments guide the movement of the adjoining bones (Riemann and Lephart, 2002; Solomonow, 2006).

Both muscle and ligament also have neural properties that accomplishing each other in stabilizing joint from an unexpected perturbation via the ligamento-muscular reflex (Riemann and Lephart, 2002; Solomonow, 2006). The neural signals from the stretched ligaments trigger muscular responses relative to functions of that ligament, such as the stretched ACL can activate hamstrings response reflex to prevent further anterior tibial translation (Jerosch and Prymka, 1996).

2.8 Proprioceptive assessment

Literally, proprioception can be assessed differentially between joint position sense and movement sense. Clinicians or researchers can assess joint position sense through passive or active limb re-positioning. However, it cannot be assessed the integrity of the system. Considering testing procedure, proprioceptive system is being assessed from the periphery receptors to the central processing center. Stillman (2002) proposed that passive limb re-positioning may not provide the proprioceptive characteristics in motor control, even though the passive limb re-positioning involves proprioceptive pathway from the periphery to the cerebral cortex. The active limb re-positioning provides more information, however, it provides only limited evidence of proprioceptive system’s motor control function. The superiority of the active test is that it receives corollary discharge of the upper motor neurons that project to a specific proprioceptive region of the brain (Stillman, 2002). The limb re-positioning can be tested on ipsilateral or contralateral limb (Boerboom et al., 2008; Friden et al., 2001; Goble, 2010).

On the other hand, specialized equipment is needed to assess the movement sense. The term called "threshold to detect passive motion" reported as degree change from the starting position to the response angle of the participants. This method is totally passive movement (Boerboom et al., 2008). The detail of proprioceptive evaluation will be further discussed, joint position sense is more concerned in this review.

2.8.1 Test for joint position sense

The principle of the test is to ask participants to match the position of the joint being tested with the reference position previously established (Stillman, 2002). As mentioned above, reference position establishment can be done actively or passively which are called active limb re-position and passive limb re-position test respectively (Goble, 2010; Stillman, 2002). There is some disagreement among researchers whether which position should be used to assess knee joint position sense since the knee joint is mainly function during weight bearing position. The following texts provide the information that could affect knee joint position sense assessment.

(1) Reference position establishment can be done actively or passively. For the active limb re-position, the participant actively moves the limb to the test angle and holds that position for a few seconds before returning the limb to the starting position. Then the participant will be asked to move the limb to match with previous limb position. The procedure of passive limb re-position test is almost identical with that of active test, except that the reference position is established by clinician or researcher (Goble, 2010; Stillman, 2002). With active limb reposition, participants are more efficiently re-position of the knee joint than the passive limb re-position due to more proprioceptive information from efferent copy of motor commands. The efferent copy will be sent to the cerebellum and used as comparative information for the brain to compare the joint position being tested with the reference position.

(2) The second factor affecting joint position test is the limb that is used to establish reference position. Clinicians may use the contralateral limb or uninjured limb to establish reference position but some may use ipsilateral limb (Goble, 2010;

Stillman, 2002; Stillman and McMeeken, 2001). When the test is performed on ipsilateral limb, the judgment is depended on their memory. If the test is performed on contralateral limb, then participant will need more interhemispheric connection in addition to memory (Goble, 2010). Goble and colleagues had compared the result from joint position testing between ipsilateral and contralateral elbow joint re-position expressed as relative and absolute error. Their results showed greater relative and absolute error for contralateral elbow joint re-position (Goble, 2010).

(3) Assessing knee joint position sense can be done either in weight bearing or non-weight bearing positions (Stillman and McMeeken, 2001). However, controversy still remained whether weight bearing or non-weight bearing position is more appropriate, since weight bearing position is more functional and more related to activities of everyday life (Stillman and McMeeken, 2001). All proprioceptive inputs from cutaneous, joint mechanoreceptors, and muscle spindles which aid in joint angle detection are projected to the CNS, including the proprioceptive inputs from other joints. Thus, weight bearing position may not be able to specifically identify proprioceptive sources within and around knee joint (Stillman and McMeeken, 2001).

On the other hand, the non-weight bearing position provides less proprioceptive inputs from adjacent joints, but this position can be more specifically tested the knee joint proprioception. Knee joints are less compressed during non-weight bearing position, thereby, the joint mechanoreceptors in connective tissues are less activated. Thus, non-weight bearing knee joint position sense assessment may be more reliable, but less accurate than weight bearing assessment (Stillman and McMeeken, 2001).

(4) Testing knee joint position sense at different angles yield different results. Ghiasi and Akbari had compared contralateral passive limb re-position ability of healthy participants between weight bearing (standing) and non-weight bearing (prone lying) at three different angles (45°, 60°,90°). The results showed significant lower absolute error for weight bearing position compared to non-weight bearing position at 60° and 90° (Ghiasi and Akbari, 2007). Besides from the position used to joint position sense, the capacity to detect joint position also depends on the angle of knee joint.

(5) The age of participants also has an influence on the ability to detect knee joint angle. Studies found that postural control declines with age. Age-related changes in older adults may alter proprioceptive function. Peripherally, the degeneration of proprioceptors within muscles, ligaments, and articular surface may lead to less proprioceptive inputs. The muscle spindle changes involved in ageing process are 1) increase capsular thickness, 2) decreased spindle diameter, 3) decreased sensitivity, 4) a fewer total number of intrafusal fiber, and 5) axonal swelling. The cutaneous receptors and joint mechanoreceptors are also decrease in number (Goble, 2010). Centrally, inadequate proprioceptive information processing has been suggested to be the main factor of proprioceptive depletion. The working memory capacity also declines with age. Since the joint position testing require the participants to remember the joint position. It is likely that their working memories are also important factor affecting joint position test (Goble, 2010; Goble, Mousigian, and Brown, 2012). Comparing between the high and low working memory older adults, indicated by the length of the backward digit span test more or less than 5 digits respectively, the high working memory group showed lower angle matching error than the other (Goble et al., 2012). According to the above mentioned, researchers demonstrated that the older adults showed greater magnitude of joint matching error than younger participants. The study of Ribeiro and Oliveira compared joint position sense between healthy young adults and older adults, their results indicated more joint matching error in the older adult group (Ribeiro and Oliveira, 2010).

(6) Comparing between sedentary individuals and athletes, the proprioceptive ability of athletes were superior to that found in sedentary individuals. Besides, exercise can also attenuate physically declination in elderly (Ribeiro and Oliveira, 2010). Exercise induces many changes within central and peripheral level. At peripheral level exercise induces morphological adaptations in the muscle spindle. There are adaptations on a micro level, the intrafusal muscle fibers could show some metabolic changes, and on a more macro level, the latency of the stretch reflex response decrease and the amplitude of stretch reflex response increase (Hutton and Atwater, 1992). At central level, exercise can modify proprioception through the modulation of the muscle spindle gain and the induction of plastic modifications in the central nervous system.

(7) Applying cryotherapy over the knee joint has a deteriorative effect on knee joint position sense. Uchio and colleagues investigated the effects of cryotherapy on knee joint position sense. Their study pointed out some interesting results. Joint position sense inaccuracy increase 1.7 degrees after 15 minutes of knee joint cooling (Uchio et al., 2003). The systematic review by Costello and Donnelly (2010) found that 3 studies from 7 studies have reported an increase in joint position matching error after application of cryotherapy. Schmid and co-workers found that muscle activity decrease after the application of the ice bag for 20 minutes. This reduced muscle activity may explain the decrease ability to replicate knee joint angle. The decreased muscle activity might lower the muscle spindle sensitivity, thus reduced muscular feedback to the brain (Schmid, Moffat, and Gutierrez, 2010).

(8) Authors have suggested that fatigue has adversely influences upon ability to detect joint position (Ju, Wang, and Cheng, 2010; Miura et al., 2004). A study conducted by Miura and colleagues compared the effects of local and general fatiguing protocol on knee joint position sense. They found that local fatigues did not alter knee joint position sense. On the other hand, general fatigue did alter knee joint position sense (Miura et al., 2004). However, Ju and colleagues had demonstrated that fatiguing muscle around the knee joint reduced and delayed muscle activation of quadriceps and hamstring muscles when they were de-stabilized (Ju et al., 2010).

(9) The presence of pain does affect joint position detection of individuals (Baker et al., 2002). Baker compared knee joint position sense in patellofemoral pain individuals and found that the presence of pain deteriorated knee joint position sense compare to normal participants.

(10) In an attempt to prove that motor commands have influences upon joint position detection, Gandevia and colleagues had carried out a study in 2006 to find out the answer. Six participants had undergone anesthesia of their right arm with pressure cuff to abolish all sensory signals from cutaneous and muscle receptors. After 40 minutes of ischemic paralysis of the forearm and hand, the EMG of extensor carpi radialis and flexor carpi radialis were completely abolished. After complete anesthesia and paralyzed below the elbow, participants were asked to exert the

force at 30% of maximum voluntary contraction toward wrist flexion or extension. All participants perceived that their wrist joint position was altered during they were attempting to move their wrist. The perceived wrist position was on the same direction of an attempted action. Gandevia and colleagues concluded that motor commands influence the perception of joint position (Gandevia et al., 2006).

2.8.2 The tools used to evaluate knee joint position sense

Many researchers had evaluated knee joint position sense with different measuring tools, for example filming the picture or video, electrogoniometer, and isokinetic machine (Smith et al., 2012). Despite different tools being used to evaluate knee joint position sense, the methods used for recording knee joint angle were quite familiar. Among these tools, filming the picture or video and the use of electrogoniometer can be done in both weight bearing and non-weight bearing position, while the isokinetic machine can be done only in sitting position. As mentioned earlier, different testing position have influence upon the test result. Hence, the researchers need to choose a tool that is appropriate with the test position.

2.8.3 Test for movement sense

The kinesthetic sense or the movement sense is acceptably tested by the process called “threshold to detect passive motion” (TTDPM) (Boerboom et al., 2008; Friden et al., 2001). To test kinesthetic sense, specific designed equipment was used to obtain accurate information. The participants were positioned in side lying position while the knee was passively moved through flexion or extension. Participants have to respond as soon as they perceive movement at the joint being tested. The angular velocity between 0.5 to 2.5 degrees/second was used and believed to maximally stimulate joint mechanoreceptors while minimally stimulate muscle spindle (Friden et al., 2001).

2.9 Conceptual framework

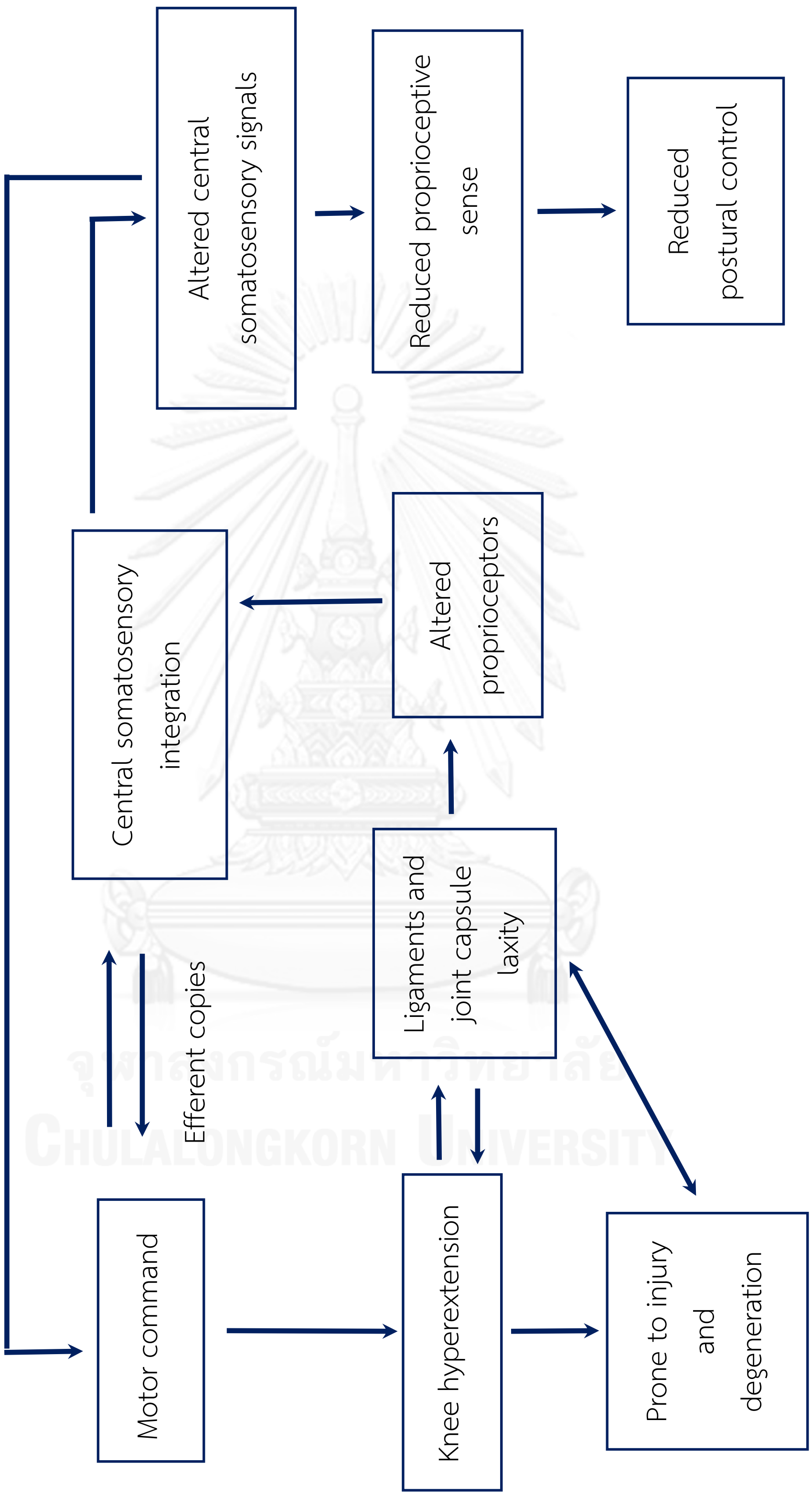

Figure 2.1 The conceptual framework shows the consequences of knee hyperextension

CHAPTER 3
MATERIALS AND METHODS

This study was an experimental study aimed to study the postural control via neuromuscular control and ability to detect knee joint position between normal knee and knee hyperextension participants. The criteria for selecting participants, materials used and data collection were reported in the following sections.

3.1. Participants

Healthy female participants who were eligible for the study protocol were recruited. All of them were the undergraduate and post-graduate students from the universities in Thailand. All participants were informed about testing procedure prior to the study, the criteria for participant recruitment were as the following.

3.1.1 Inclusion criteria

1. Female participants aged between 18 and 30 years old.
2. Body mass index less than or equal to 23.5 kg/m^2.
3. Normal knee alignment group demonstrated bilateral knee angle during standing more than zero degree.
4. Knee hyperextension group demonstrated bilateral sagittal knee angle during standing 10 degrees beyond anatomical position.
5. No history of knee joint injury or surgery during the past 12 months.
6. No other injury related to any joints of lower extremities during the past 12 months.
7. No systematic diseases that may disturb muscular functions and proprioceptive system.
8. No regularly participating in any sport or creational activity more than three times a week.

3.1.2 Exclusion criteria

1. BMI exceeded 23.5 kg/m^2
2. Any existing pain in lower back or lower extremities.
3. Injuries of lower back or lower limb during the past 12 months.
4. Demonstrated or complained signs of vertigo.
5. Visual problems except that could be corrected with eye glasses or contact lens.
6. Demonstrated or complained signs of sensory disturbance.
7. Participants who had been taking any medication with sedative effect or known medications that would affect postural control ability within 24 hours prior to testing.
8. Participants who consumed alcohol within 24 hours prior to testing.
9. Unable to stand either on foam surface or eyes closed condition without assistance for at least 30 seconds.

3.2 Screening test

Participants who met all inclusion criteria and free from exclusion criteria were then screened to eliminate any possibility to have knee ligament injury or other factors that could confound research results. If participants met only one positive results of the screening test they would not be able to participate in this study. The participants were informed the testing procedures prior to establish each screening test. The screening tests were as follow:

3.2.1 Lachman's test

The Lachman's test was used to test the integrity of the ACL. First, knee joint was held in 30° of knee flexion. The upper hand of examiner placed on the lateral aspect of thigh above knee joint, the other hand placed on the medial surface of the tibia bone with thumb near joint line. Participants were asked to relax, and then researcher gently lifted the lower leg upward as trying to separate the joint in the anterior direction.

3.2.2 Reverse Lachman's test

The Reverse Lachman's test was used to test the integrity of the PCL. To test, knee joint was held in 30° of knee flexion. The upper hand of examiner placed on the lateral aspect of thigh above knee joint, the other hand placed on the medial surface of the tibia bone with thumb near joint line. Asking the participants to relax, then researcher gently pushed the lower leg downward as trying to separate the joint in the posterior direction.

3.2.3 Valgus stress test

The valgus stress test was used to test the integrity of the medial collateral ligament. With knee joint in full extension, researcher placed one hand at the lateral surface of the knee joint with the other hand at the distal tibia. Then, the abduction force was applied attempting to move the knee into abduction.

3.2.4 Varus stress test

The varus stress test was used to test the integrity of the lateral collateral ligament. With the knee joint in full extension, researcher placed one hand at the medial surface of the knee joint with the other hand at the distal tibia. Then, the adduction force was applied attempting to move the knee into adduction.

3.2.5 Leg length discrepancy

The leg length was measured using a measuring tape from the anterior superior iliac spine (ASIS) to the medial malleolus, the difference between left and right leg was then determined. If the difference exceeded 2 centimeters, that participant could not participate in this study.

3.3 The study variables

3.3.1 The primary variable: knee hyperextension angle

Knee hyperextension angle was measured in standing position. This angle is formed between femur and tibia in sagittal plane. To measure the knee hyperextension angle, participants were asked to stand quietly and look straight ahead while the researcher was performing the measurement. First, the following anatomical landmarks were localized and marked with a marker pen: (1) greater trochanter of femur, (2) lateral epicondyle of femur, and (3) the most prominent part of the lateral malleolus. The standard goniometer was used to measure this angle. Using the lateral epicondyle of femur as a fulcrum, the stationary arm was fixed in a line connecting between the greater trochanter and the fulcrum, and the movable arm was then adjusted to the line connecting between the lateral malleolus and the fulcrum. This sagittal knee angle data was used to discriminate participants into normal knee alignment or knee hyperextension group.

3.3.2 Associative factors

The following measurements was taken to determine the dominant limb and identify the associative factors that could potentially affect neuromuscular activity of the lower limb which include lower limb alignment and muscle strength of the non-dominant limb. The lower limb characteristics were concerned since it may affect postural control ability of each individual.

3.3.2.1 Dominant lower limb

The dominant lower limb was determined as the lower limb that was used to perform at least 2 out of 3 of the following tasks: kicking a ball, picking up a small object from floor with their toes, and tracing shape on the floor. These three tasks were chosen because they had been proved to be moderate to high reliable in determining dominant lower limb (Schneiders et al., 2010).

3.3.2.2 Femoral anteversion angle

Participants were positioned in prone lying with the knee flexed to 90 degrees, the examiner passively rotated hip joint until greater trochanter was palpated to be at the most lateral position. The femoral anteversion was then measured between the imaginary line in vertical plane and the shaft of the tibia with a standard goniometer.

3.3.2.3 Anterior pelvic tilt angle

The anterior pelvic tilt was measured while participants were in standing position. The angle was formed between an imaginary line in horizontal plane and a line from anterior superior iliac spine to posterior superior iliac spine. This angle was measured with an inclinometer.

3.3.2.4 Tibiofemoral angle

With participants in supine lying position, tibiofemoral angle was measured with standard goniometer. This angle was formed between two imaginary lines. The first line began at midway between anterior superior iliac spine and greater trochanter to the center of knee joint, the other line was drawn from the center of knee joint to the center of ankle joint.

3.3.2.5 Navicular drop

Navicular drop was the difference of navicular height during non-weight bearing and weight bearing position, which was measured with a straight edge ruler in standing position. The navicular height was first measured during participants were sitting and later while they were in a standing position.

3.3.2.6 Muscle strength

The muscle strength of knee extensor, knee flexor, ankle dorsiflexor and ankle plantar flexor muscles were measured with hand held dynamometer (Lafayette® Manual Muscle Test System) within 15 degrees of passive knee extension. Each muscle was tested under isometric contraction which lasted for 5 seconds, repeated 3 times with 60 seconds rest between each contraction. The 60 seconds rest interval was enough for strength recovery in young adults (Parcell et al., 2002). The muscle strength might be one predictor among the predictors of how individual controlled their knee position. The starting positions used in the study may not be the recommended position in the standard manual muscle test, however, the researcher attempted to control the length of the hip muscles.

Knee extensor and ankle dorsiflexor strength were measured in supine lying position. After the knee joint was set to the desired position, the hand held dynamometer was placed over anterior aspect of the ankle joint and participants were asked to maximally extend their knees to measure knee extensor strength. Afterward, the hand held dynamometer was placed over the dorsal aspect of the foot to measure the ankle dorsiflexor strength in the same manner.

Knee flexor and ankle plantar flexor strength were measured in prone lying position. After the knee joint was set to the desired position, the hand held dynamometer was placed over posterior aspect of the ankle joint and asked participants to bend their knees against the hand held dynamometer to measure knee flexor strength. The ankle plantar flexor was then measured by asking participants to maximally push their balls of foot against the hand held dynamometer.

The position of hip and knee joints may influence upon the length of quadriceps and hamstrings muscle. Hence, the supine and prone lying positions were chosen to control the hip and knee joints position.

3.4 Instrumentation

Muscle activities were recorded with surface EMG system (TeleMyo 2400T G2, Noraxon, Scotsdale, AZ), with unit specification as follow: input impedance of 100 mega ohm, common mode rejection ratio 100 dB, baseline noise less than 1 μV RMS, signal gain of 500. All channels had sampling frequency set to 1000 Hz. The signal displayed via 16 bit resolution A/D convertor. Self-adhesive Ag-AgCl disc surface electrodes (Ambu® Blue Sensor P Model, ref: P-00-S/50) with the diameter of 1 centimeter were used to collect EMG signal.

The electrogoniometer (SG 150, Biometrics Ltd. Blackwood, Gwent, UK) was used to record and report the knee joint angle throughout the testing session. The accuracy of ± 2 degrees over the range of 90 degrees was reported in the manual guideline and the repeatability was better than ± 1 degree. The electrogoniometer used in the study was light-weight and easy operated.

The cushions used in the study were T-foam™ cushion with medium density (AlimedInc., High Street, Dedham, Massachusetts, United State). Ten sheets of 1 centimeter thick T-foam™ were packed in a pliable fabric case to be able to perturb balance. The strips painted with a permanent marker pen were on top of the pliable fabric case to indicate the feet position for the participants.

During postural adjustment data collection, the digital video camera (Cannon s90, Japan) with recording frame rate of 30 frames per second was also used to capture all events that might help the researcher to identify the strategies used by the participants.

Hand held dynamometer (The Lafayette® Manual Muscle Test System, Sagamore Parkway North, USA) was used to measure muscle strength. This device can measure muscle strength range between 0 and 136.1 kg. Testing duration can be adjusted from 1 to 10 seconds with 1 second increments. The accuracy of this dynamometer ranges between ± 1% over full scale.

3.5 Electrodes placement for EMG recording

Seven muscles were chosen to study lower limb muscle activation pattern; (1) tibialis anterior, (2) medial gastrocnemius, (3) vastus lateralis, (4) rectus femoris, (5) vastus medialis, (6) medial hamstrings, and (7) lateral hamstrings. Before applying the electrodes, the skin was rubbed with alcohol for skin preparation. The ground electrode was placed over tibial tubercle. Two recording electrodes were placed with center-to-center 2 centimeters apart over musculotendinous junction. The orientation of electrode was aligned with the muscle fiber arrangement to maximize signal recording (Figure 3.1). All electrode placements were confirmed with manual muscle testing and checked for crosstalk.

3.6 Electrogoniometer placement

To collect the knee joint angle, zero setting was performed before the application of the electrogoniometer to the participants. This allowed researcher to compare the actual knee joint position among participants. The sampling frequency was set to 1,000 Hz along with the frequency of the electromyography since the electrogoniometer and the surface EMG system were needed to be synchronized. The electrogoniometer was placed over the lateral aspect of the non-dominant knee joint. The fixed end-block was placed over the imaginary line between the greater trochanter and the lateral condyle of the femur. The telescopic block was placed over the imaginary line between the head of fibula and the most prominent part of the lateral malleolus. The two-sided adhesive tape was used to secure the electrogoniometer in place. The positive values represented knee flexion while the negative values represented knee extension.

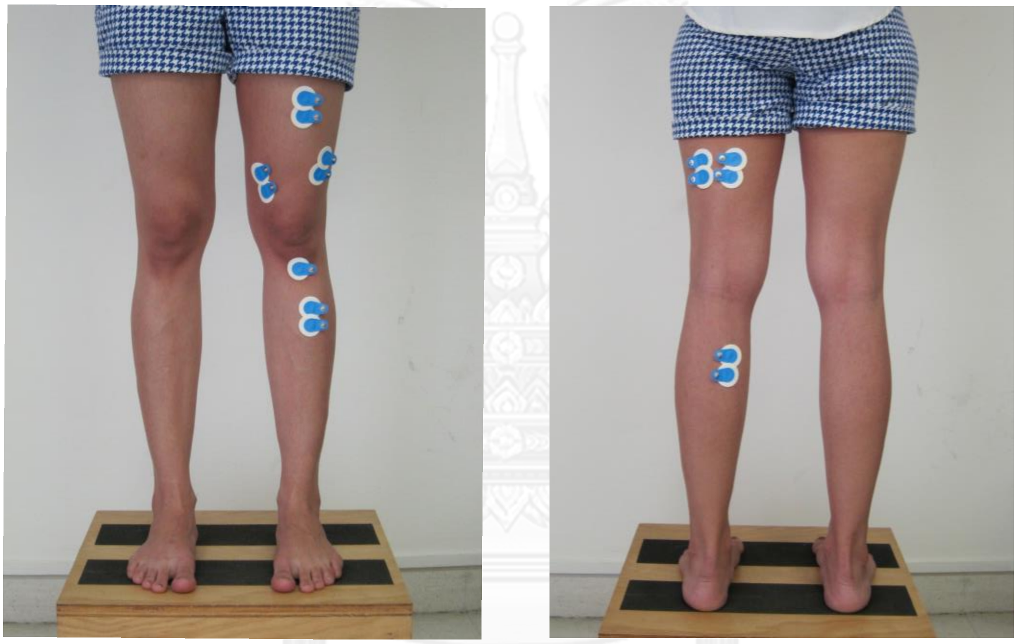

Figure 3.1 Electrode placement; (left) anterior aspect, (right) posterior aspect.

3.7 Testing procedures

3.7.1 Postural adjustment and muscle activation pattern

Lower limb muscle activities and postural adjustment were recorded with electromyography, electrogoniometer and video camera under 4 test conditions;

- Condition 1: Firm surface with eyes open (Firm-EO)
- Condition 2: Firm surface with eyes closed (Firm-EC)
- Condition 3: Foam surface with eyes open (Foam-EO)
- Condition 4: Foam surface with eyes closed (Foam-EC)

The first condition served as a reference condition. Another three conditions then were randomly selected during data collection to avoid effect of training with 2 minutes rest between each condition. For both eyes open conditions, participants were asked to look straight ahead at a fixed point on the wall two meters away to stabilize their gaze and head movements. During all tests, participants stood with feet on marked points with the distance ranged between 20 and 26 centimeters to ensure the same foot placement among testing conditions (Figure 3.2).

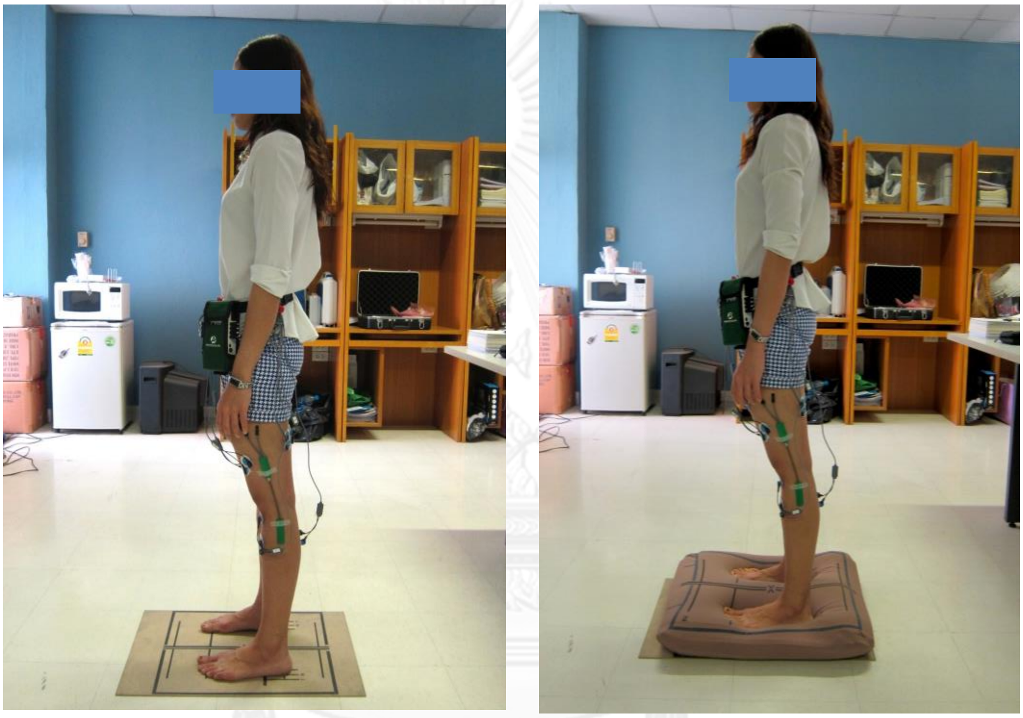

Figure 3.2 EMG and knee joint angle data recording during standing on firm (left) and foam (right) surfaces.

To collect the data on foam surface conditions, participants were asked to stand next to the foam and the data collection was then started for a few seconds before the researcher asked them to step on the foam. This procedure allowed the researcher to observe pattern of muscle activity during changing supporting surface from stable to unstable surface. The software markers were used to indicate the time point when participants' feet were on the foam or when they were told to close their eyes. Each condition was recorded for 30 seconds and repeated twice. During data collection, video camera was also used to capture all events. The position of the camera was set perpendicularly at the same level of participant's knee joint with the distance of 2 meters. The muscle activity and knee joint angle were recorded synchronously.

3.7.2 Knee joint position sense testing

For the knee joint position sense testing, the researcher chose the ipsilateral, active limb reposition matching task in weight bearing position. The reference angle was set to 15 degrees from the knee extension angle measured during the screening session of each participant. The participants were asked to stand on their non-dominant legs while their hands touched on the backrest of a chair and slowly bent their knees to the reference angle. After the knee reference angle was reached, the participants held that position for 4 seconds. Verbal command was used to encourage participants to remember the position of their knee joint and without mentioned another joint position. Once the participants returned to the starting position, they were allowed to rest for at least 10 seconds before starting the next test. All testing were performed with the eyes closed. Three successive trials were needed to accomplish the testing session.

3.8 Outcome measurements

The outcome measurements of this study included lower limb muscle activities and muscle activation patterns during quiet stance from 4 conditions using surface electromyography. The muscle activities of (1) tibialis anterior, (2) medial gastrocnemius, (3) vastus lateralis, (4) rectus femoris, (5) vastus medialis, (6) medial hamstrings, and (7) lateral hamstrings were of interest. In addition, postural adjustment determined as knee joint angle in sagittal plane was also reported using the data from the NoraxonTeleMyo 2400T G2 software and video files from the recording camera. The average knee joint angles during 30 seconds of recorded data were reported, showing average trend toward flexion or extension.

The ability to match knee joint position in standing position or joint position sense were reported as (1) absolute error, (2) relative error, and (3) variable error. The absolute error represented the signless arithmetic difference between reference angle and re-position angle. The relative error represented the arithmetic difference between reference angle and re-position angle. The negative value indicated an underestimate response and positive value indicated an overestimate value of the re-position angle. The variable error represented joint position sense reliability, this value was calculated from the standard deviation from the mean of each set of three relative errors (Stillman and McMeeken, 2001).

3.9 Data processing

The raw EMG signals from seven muscles were filtered between 20 and 500 Hz, full-wave rectified, and smoothed with a time constant of 50 ms. The data were then stored in the personal computer for offline analysis. For this study, the maximum voluntary contraction (MVC) was not used to normalize the muscle activity because the EMG amplitude obtained from the MVC would be too high to compare with small EMG amplitude during quiet stance. The EMG amplitude data from two trials of each muscle and each condition were averaged and then normalized with the mean amplitude of reference condition. Then the results were reported as percentage increase or decrease from the Firm Eyes-open condition. The pattern of muscle activity of each condition was displayed and reported as a column graph to compare muscle activity pattern between the normal and knee hyperextension groups. This report might provide just an over-view of muscle activity whether there was a difference control strategy between the two groups.

3.10 Statistical analysis

The statistical analysis was performed with SPSS version 17.0 for Windows. The Shapiro-Wilk test was used to test normality of all variables. A normal distribution of the data was found, the independent sample t-test was then used to compare participant's characteristics and the errors from knee joint position sense testing. The two way mixed analysis of variance (two-way mixed ANOVA) was used to determine whether there was any difference between groups for muscle activity and knee joint postural adjustment. Significant level of 0.05 was considered to be a real difference between groups.

3.11 Ethical consideration

The study protocol was approved by the Ethnic Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University with the certificate of approval number 113/2012 (see APPENDIX A - B). All participants who agreed to participate in this study gave the informed consent form prior to the data collection. The study results were presented in terms of qualitative descriptions and quantitative values. All participants' information was kept confidentially.

CHAPTER 4
RESULTS

4.1 Participant's characteristics

Thirty-six female participants were recruited in this study (18 normal knee participants and 18 hyperextended knee participants). Statistical analysis revealed no significant differences between the two groups in all variables. Most of the participants were right leg dominance, only one participant from the knee hyperextension groups was left leg dominant. The participant's characteristics data were reported in Table 4.1.

Table 4.1 Participant's characteristics

Characteristics	Normal (n=18)	Hyperextended (n=18)	p value
Age (year)	21.56 ± 2.57	22.00 ± 2.97	0.634
Weight (kg)	50.16 ± 4.61	50.67 ± 4.85	0.750
Height (cm)	162.94 ± 0.06	161.50 ± 0.05	0.418
Body mass index (BMI) (kg/m^2)	18.87 ± 1.24	19.44 ± 1.85	0.293
Non-dominant limb			
Right	0	1	-
Left	18	17	

Note: Data were reported in mean ± standard deviation

4.2 Knee joint angle and postural adjustment

4.2.1 Comparison of the knee joint angle between groups

The data of knee joint angle in each standing condition demonstrated similar kinematics responses when the postural control system was more challenged. The participants in both groups tended to flex their knees. However, the knee hyperextension group had their knees further extended in the Firm-EC condition. The average knee joint angles of 30 seconds data recording were reported in Table 4.2.

Table 4.2 Knee joint angle (degree) in each standing condition of normal and hyperextended knee groups

Conditions	Normal	Hyperextended
Firm-EO	2.20 ± 2.20	-14.80 ± 2.93
Firm-EC	2.52 ± 2.55	-15.29 ± 3.86
Foam-EO	2.59 ± 2.45	-14.55 ± 3.69
Foam-EC	3.19 ± 2.70	-13.83 ± 3.84

**The minus values represent the position of the knee in extension position.

**The positive values represent the position of the knee in flexion position.

4.2.2 Comparison of the knee joint angle within group

Within-group analysis showed that knee flexion angle tended to increase with sensory disturbance in both groups except for the Firm-EC condition in hyperextended knee group. Knee angle did not significantly vary in the normal knee group, whereas the hyperextended knee group showed significantly lower knee angles in the Foam-EC condition than in the Firm-EC condition ($p = 0.003$) as shown in Table 4.3.

Table 4.3 Within-group comparison of the knee joint angles during four standing conditions of the hyperextended knee group

Conditions		p value
Firm-EC	Firm-EO	1.000
	Foam-EO	0.065
	Foam-EC	0.003**

** Significant difference at the level of $p < 0.05$

4.3 Muscle activity of the lower limb

4.3.1 Level of muscle activity

Seven lower limb muscles were chosen for EMG recording as they affected movement of the knee joint. Two-way mixed ANOVA revealed that all muscle activities were changed. However, there was no significantly difference in muscle activities between groups in all standing conditions except for the medial hamstrings muscle in the Firm-EC condition. During the Firm-EC condition, the hyperextended knee had greater medial hamstring activity than the normal knee group ($p < 0.05$).

The two-way mixed ANOVA revealed that there was no group x condition effect and group main effect for all muscle activity. There was condition main effect for tibialis anterior muscle ($F_{(3, 102)} = 26.678$, $p < 0.01$), medial gastrocnemius muscle ($F_{(3, 102)} = 15.652$, $p < 0.01$), vastus medialis oblique muscle ($F_{(3, 93)} = 15.133$, $p < 0.01$), rectus femoris muscle ($F_{(3, 99)} = 17.902$, $p < 0.01$), vastus lateralis muscle ($F_{(3, 87)} = 21.211$, $p < 0.01$), medial hamstrings muscle ($F_{(3, 102)} = 24.196$, $p < 0.01$), and lateral hamstrings muscle ($F_{(3, 99)} = 15.503$, $p < 0.01$). Post hoc analysis was then performed to find out which conditions caused these muscle activity differences.

Post hoc analysis showed that the following muscle activities were significantly different between the Firm-EO and Foam-EO conditions; tibialis anterior ($p < 0.01$), medial gastrocnemius ($p < 0.05$), vastus medialis oblique ($p < 0.05$), rectus femoris ($p < 0.01$), vastus lateralis ($p < 0.01$), and lateral hamstrings ($p < 0.05$).

Comparing between the Firm-EO and Foam-EC conditions, post hoc analysis revealed the difference of the following muscle activity; tibialis anterior ($p < 0.01$), medial gastrocnemius ($p < 0.05$), vastus medialis oblique ($p < 0.01$), rectus femoris ($p < 0.01$), vastus lateralis ($p < 0.01$), medial hamstrings ($p < 0.01$), and lateral hamstrings ($p < 0.01$).

Comparing the muscle activity between the Firm-EC and the Foam-EO conditions, post hoc showed that the muscle activity of the tibialis anterior ($p < 0.01$), rectus femoris ($p = 0.01$), and vastus lateralis ($p < 0.05$) were significantly different between standing conditions.

During the Firm-EC and the Foam-EC conditions, post hoc analysis showed that the following muscle activities were significantly different; tibialis anterior ($p < 0.01$), medial gastrocnemius ($p < 0.01$), vastus medialis oblique ($p < 0.01$), rectus femoris ($p < 0.01$), vastus lateralis ($p < 0.01$), medial hamstrings ($p < 0.01$), and lateral hamstrings ($p < 0.01$).

Lastly, post hoc analysis showed that the following muscle activities were significantly different between the Foam-EO and the Foam-EC conditions; tibialis anterior ($p < 0.01$) and medial hamstrings ($p < 0.01$).

Table 4.4 Comparison of mean ± SD of percentage of lower limb muscle activity during each standing condition between groups

Muscles	Percentage of muscle activity (% Firm Eyes-open)					
	Firm Eyes-closed		Foam Eyes-open		Foam Eyes-closed	
	Normal	Hyperextension	Normal	Hyperextension	Normal	Hyperextension
Tibialis anterior	104.09 ± 26.78	112.32 ± 47.35	348.27 ± 344.79	315.22 ± 285.16	476.97 ± 432.10	545.07 ± 419.18
Medial gastrocnemius	102.07 ± 21.41	146.89 ±121.03	178.79 ± 104.64	235.29 ± 273.80	254.19 ± 153.98	325.31 ± 345.13
Vastus medialis oblique	116.38 ± 53.01	111.82 ± 41.23	258.51 ± 250.55	260.53 ± 213.51	297.49 ± 224.02	437.07 ± 479.43
Rectus femoris	129.37 ± 93.20	109.64 ± 48.08	323.32 ± 376.23	297.68 ± 237.10	391.94 ± 340.19	402.54 ± 394.00
Vastus lateralis	132.80 ± 81.63	112.03 ± 80.24	340.51 ± 314.60	250.75 ± 223.80	434.09 ± 324.16	373.57 ± 284.53
Medial hamstrings	114.42 ± 36.26	192.14 ± 156.18*	229.76 ± 177.63	199.88 ± 134.11	404.17 ± 315.19	626.82 ± 549.60
Lateral hamstrings	130.56 ± 88.89	145.50 ± 120.06	216.30 ± 171.81	200.06 ± 86.43	261.85 ± 165.45	363.75 ± 323.75

* Significant difference between normal and hyperextended knee groups at the level of $p < 0.05$

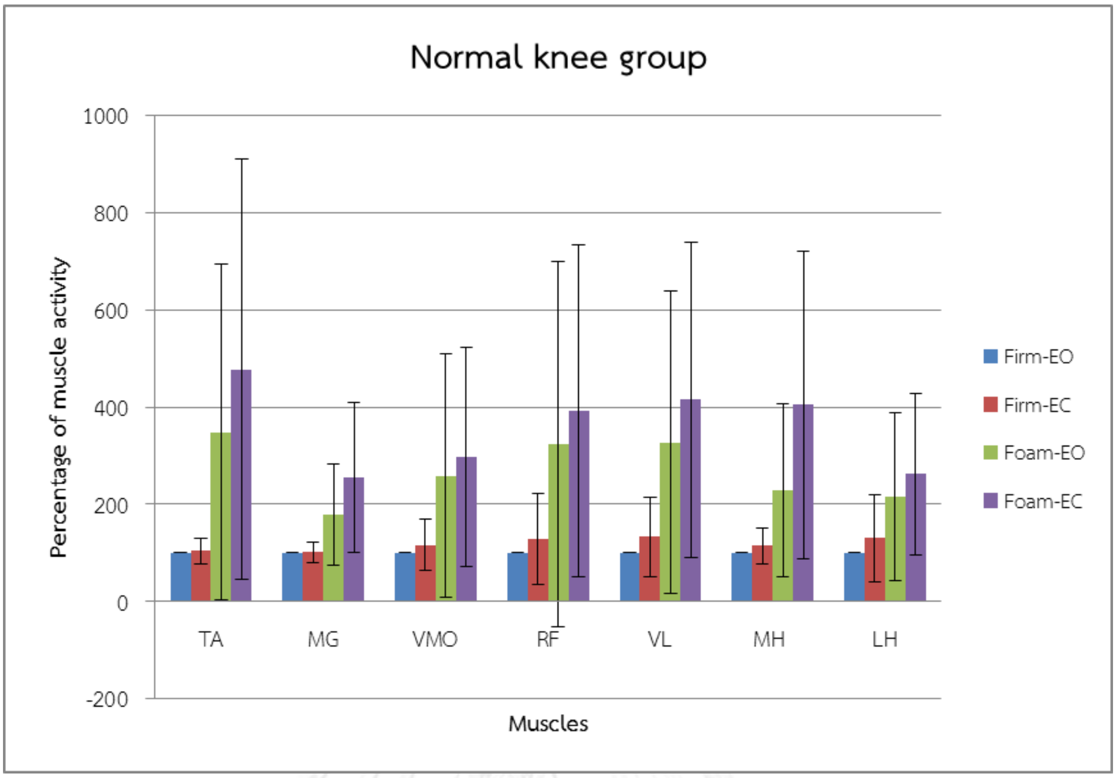

Figure 4.1 Percentage of muscle activity of normal knee participants during quiet stance in four conditions.

The Firm-EO condition served as a reference condition, thus all data were set to 100%. For another three conditions, the data reported an increase or decrease muscle activity due to change in postural perturbation.

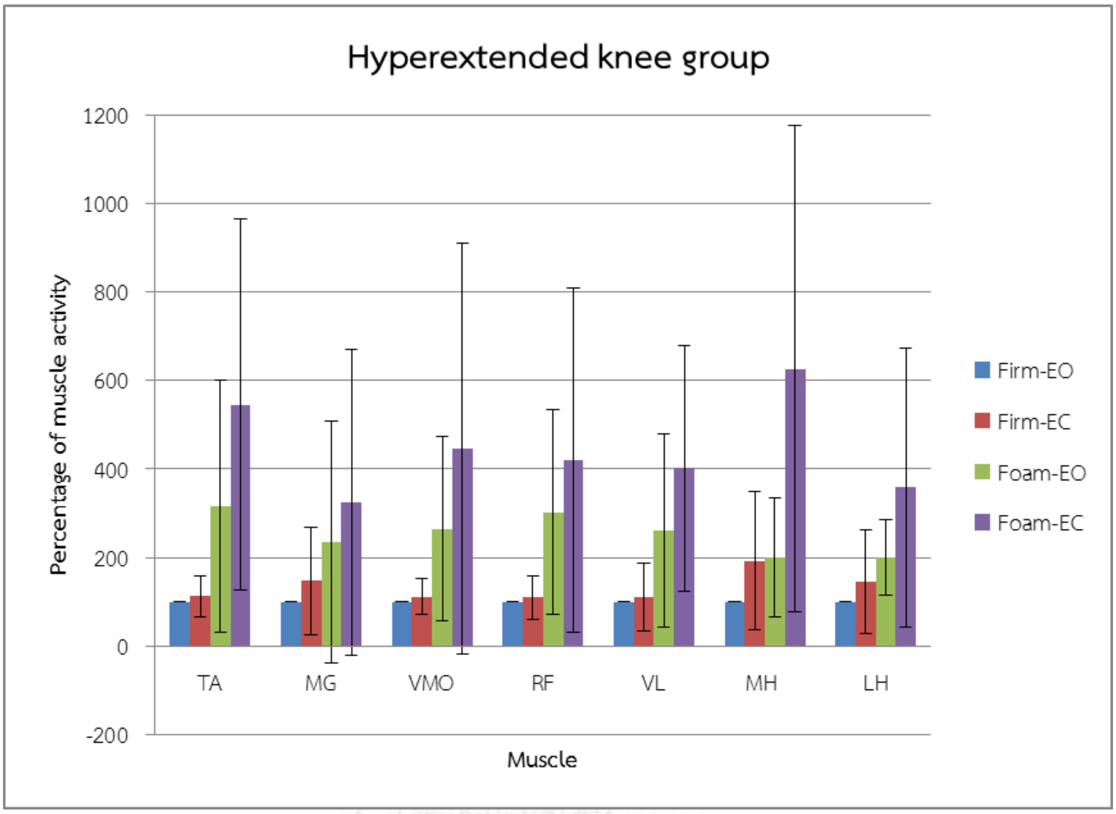

Figure 4.2 Percentage of muscle activity of hyperextended knee participants during quiet stance in four conditions.

The Firm-EO condition served as a reference condition, thus all data were set to 100%. For another three conditions, the data reported an increase or decrease muscle activity due to change in postural perturbation.

4.3.2 Comparison of muscle activities within group

Table 4.5 – 4.6 presented the data comparing mean ± SD of percentage of muscle activities within normal and hyperextended knee groups, respectively.

Table 4.5 Within-group comparison of mean ± SD of percentage of muscle activity of the normal knee group in each standing condition

Muscles	Percentage of muscle activity (% Firm Eyes-open)		
	Firm Eyes-closed	Foam Eyes-open	Foam Eyes-closed
Tibialis anterior	104.09 ± 26.78[‖]	348.27 ± 344.79[‡]	476.97 ± 432.10[§]
Medial gastrocnemius	102.07 ± 21.41[‖]	178.79 ± 104.64[¶]	254.19 ± 153.98
Vastus medialis oblique	116.38 ± 53.01	258.51 ± 250.55[‡]	297.49 ± 224.02
Rectus femoris	129.37 ± 93.20[‖]	323.32 ± 376.23	391.94 ± 340.19[§]
Vastus lateralis	132.80 ± 81.63[‖]	340.51 ± 314.60[‡]	434.09 ± 324.16[§]
Medial hamstrings	114.42 ± 36.26[‖]	229.76 ± 177.63[‡]	404.17 ± 315.19[§]
Lateral hamstrings	130.56 ± 88.89	216.30 ± 171.81[‡]	261.85 ± 165.45

‡ Significant difference between the Firm-EO and Foam-EO conditions the level of $p < 0.05$

§ Significant difference between the Firm-EO and Foam-EC conditions at the level of $p < 0.05$

‖ Significant difference between the Firm-EC and Foam-EC conditions at the level of $p < 0.05$

¶ Significant difference between the Foam-EO and Foam-EC conditions at the level of $p < 0.05$

Table 4.6 Within-group comparison of mean ± SD of percentage of muscle activity of the hyperextended knee group in each standing condition

Muscles	Percentage of muscle activity (% Firm Eyes-open)		
	Firm Eyes-closed	Foam Eyes-open	Foam Eyes-closed
Tibialis anterior	112.32 ± 47.35‖	315.22 ± 285.16‡,¶	545.07 ± 419.18§
Medial gastrocnemius	146.89 ±121.03‖	235.29 ± 273.80¶	325.31 ± 345.13§
Vastus medialis oblique	111.82 ± 41.23‖	260.53 ± 213.51¶	437.07 ± 479.43§
Rectus femoris	109.64 ± 48.08‖	297.68 ± 237.10‡	402.54 ± 394.00§
Vastus lateralis	112.03 ± 80.24‖	250.75 ± 223.80	373.57 ± 284.53§
Medial hamstrings	192.14 ± 156.18†, ‖	199.88 ± 134.11¶	626.82 ± 549.60§
Lateral hamstrings	145.50 ± 120.06‖	200.06 ± 86.43‡	363.75 ± 323.75§

† Significant difference between the Firm-EO and Firm-EC conditions at the level of $p < 0.05$

‡ Significant difference between the Firm-EO and Foam-EO conditions the level of $p < 0.05$

§Significant difference between the Firm-EO and Foam-EC conditions at the level of $p < 0.05$

||Significant difference between the Firm-EC and Foam-EC conditions at the level of $p < 0.05$

¶ Significant difference between the Foam-EO and Foam-EC conditions at the level of $p < 0.05$

4.3.3 Pattern of lower limb muscle activity

The following figures illustrated the patterns of muscle activity of two groups of the participants.

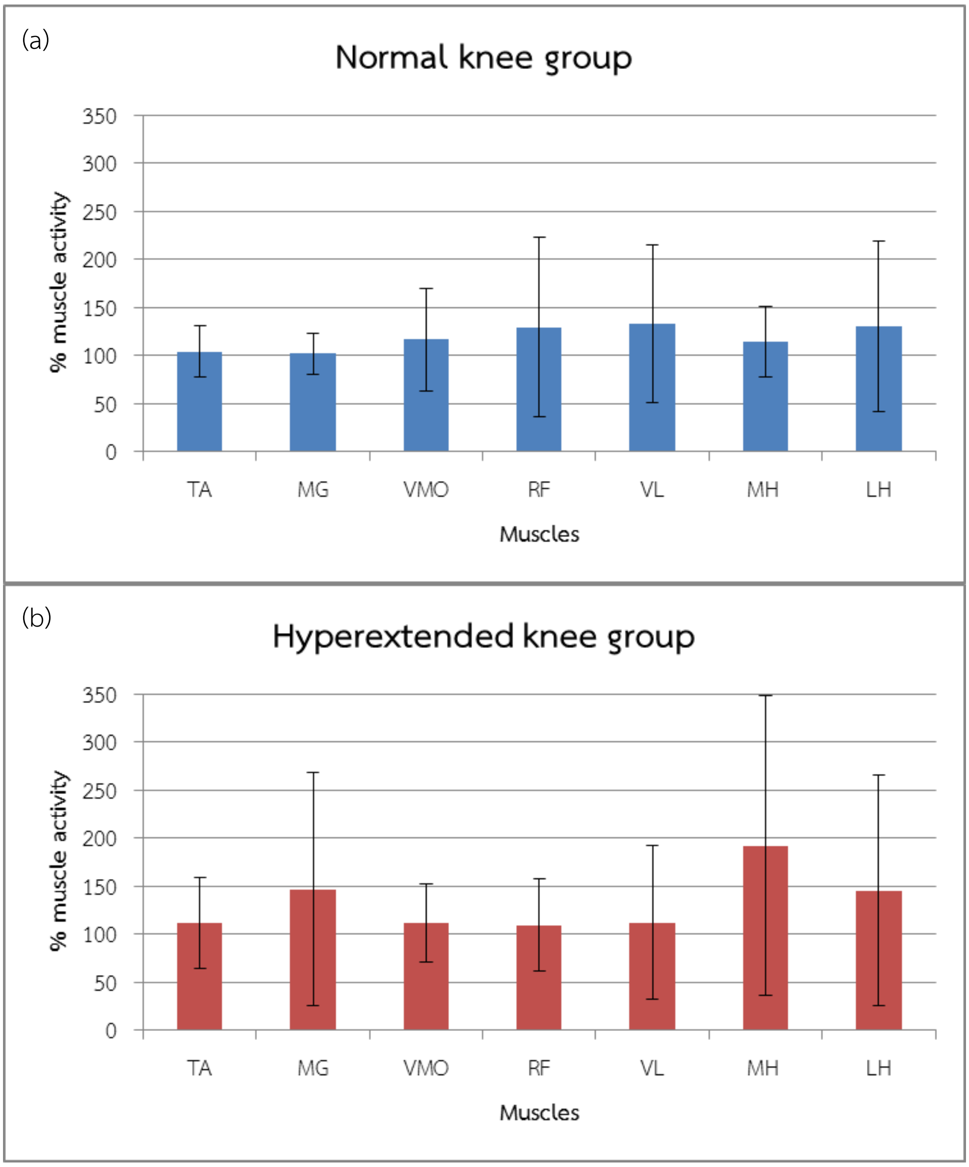

Figure 4.3 (a,b) The patterns of lower limb muscle activity of the normal (4.3a) and the hyperextened knee group (4.3b) in the Firm-EC condition.

The medial hamstrings muscle and medial gastrocnemius muscle of the hyperextended knee group were activated with higher percentage than the normal knee group, while the activity of quadricep muscles of the normal knee group were activated more than the hyperextended knee group, though no significant difference was found.

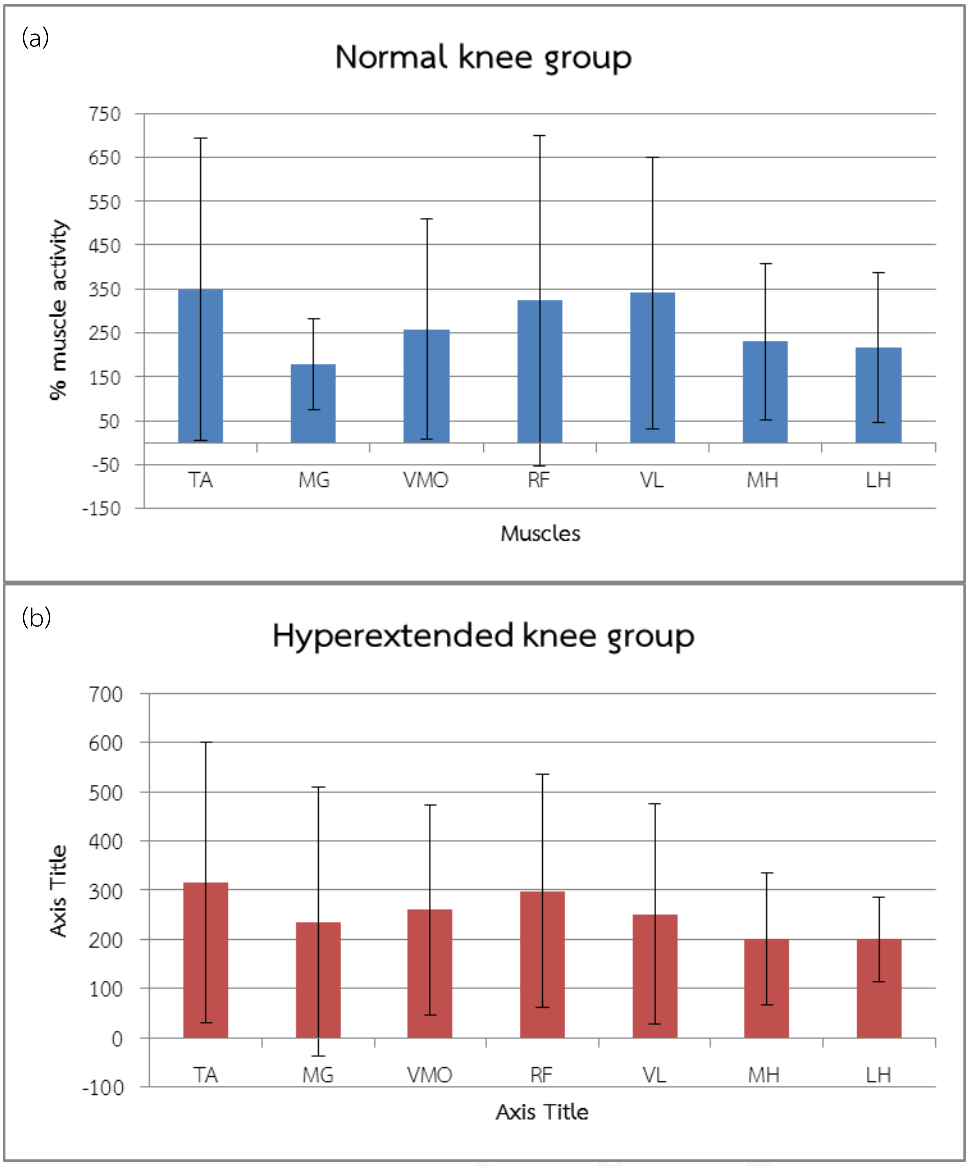

Figure 4.4 (a,b) The patterns of lower limb muscle activity of the normal (4.4a) and the hyperextened knee group (4.4b) in the Foam-EO condition.

The muscle activaties of both groups were activated with the same pattern. The tibialis anterior muscle was activated with the highest percentage compared to the activity of the same muscle from the Firm Eyes-open condition. The quadriceps muscles group were on the second rank.

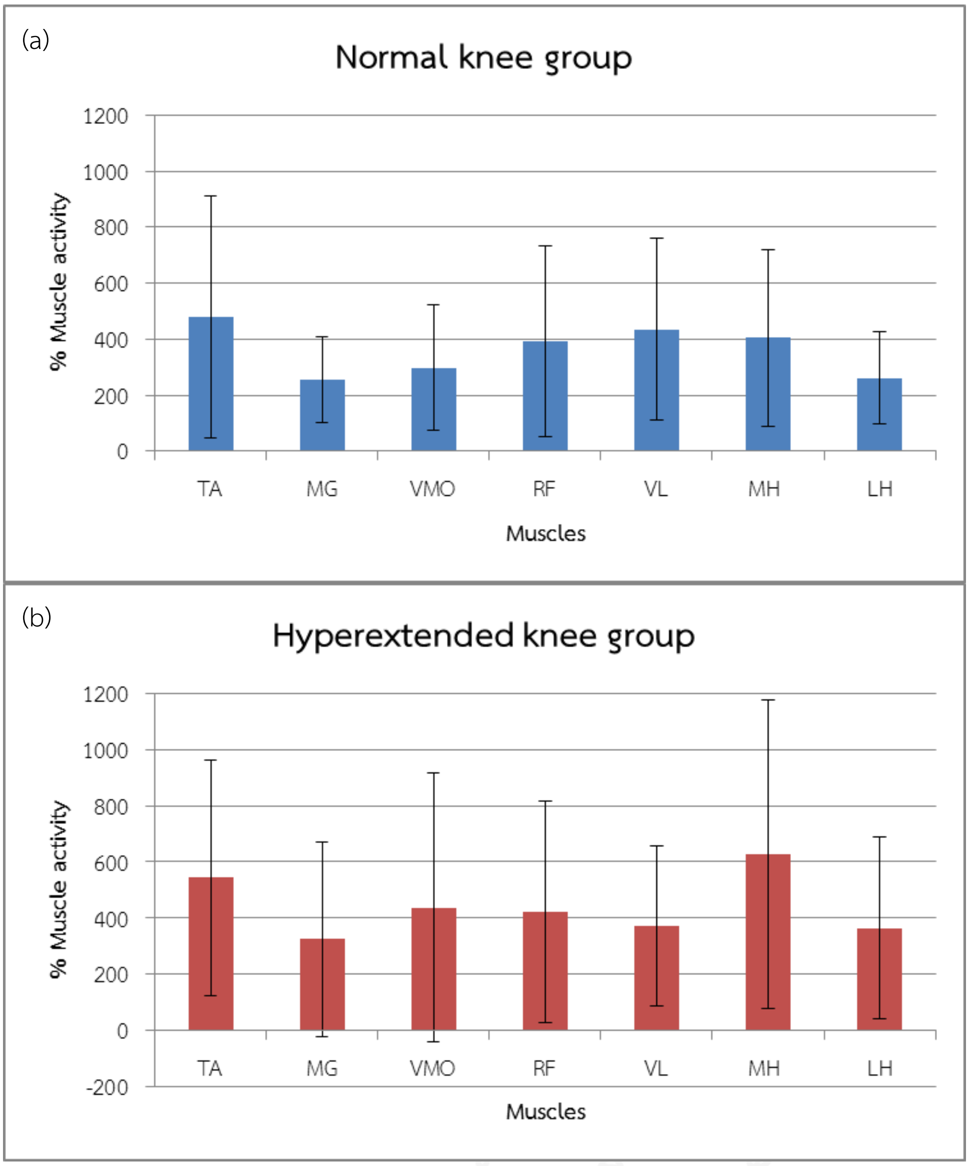

Figure 4.5 (a,b) The patterns of lower limb muscle activity of the normal (4.5a) and the hyperextened knee group (4.5b) in the Foam-EC condition.

The pattern of lower limb muscle activation of the normal knee group was similar to those pattern in the Foam Eyes-open condition of their own group but with higher percentage of activation. For the hyperextended knee group, the activation pattern changed. The medial hamstrings muscle activity was activated with the highest amplitude among the seven muscle studied, followed by the tibialis anterior muscle.

4.4 The knee joint position sense testing

Considering the relative error, participants were likely to over-estimate the reference position as the results were presented with positive values. The independent sample t-test revealed significant difference for the variable error between groups (p = 0.017). The results of all outcomes for the active limb reposition test were reported in table 4.5.

Table 4.7 Comparison of Joint position sense errors

Types of error	Normal	Hyperextension	p value
Absolute error	2.90 ± 1.84	3.93 ± 2.86	0.210
Relative error	2.01 ± 2.67	1.26 ± 4.75	0.564
Variable error	3.04 ± 0.51	4.95 ± 0.68	0.017**

** Significant difference at the level of $p < 0.05$

CHAPTER 5
DISCUSSION

This study aimed to explore the effect of body alignment, specifically the knee hyperextension, on the postural control of quiet stance. The role of the knee joint in maintaining the stance stability and the different capability between female with and without knee hyperextension were studied. The ability to detect knee joint position sense was also investigated.

Participants in this study were recruited from the universities in Thailand. The participants' characteristics were similar between groups. These results ensured us that the factors related to postural control ability were similar in both groups. Besides, the decision had been made that the age of the participants should not exceed thirtieth in order to avoid the potential of having degenerative changes of the knee structures. In this chapter, the results were discussed; (1) the knee joint involved in the postural control, (2) the neuromuscular control about the knee joint, and (3) the ability to detect knee joint position sense. Furthermore, the relationship between the knee joint position sense and the ability to control stance stability was also discussed.

5.1 Knee joint and postural adjustment

Our results indicated that the postural adjustment did present at the knee joint as it had been reported in other studies (Fransson et al., 2007; Gage et al., 2004; Gunther et al., 2009; Hsu et al., 2007). The earlier studies of quiet stance mostly relied on the inverted pendulum model (Horak, Nashner, and Diener, 1990; Winter, 1995). The researchers believed that the control about the ankle joint and its passive musculoskeletal component were essential and sufficient for the control of quiet stance (Winter, 1995). In accordance with those studies, the video that was recorded during the data collection showed that the pattern of postural response resembled the shape of an inverted pendulum, and movement strategy prominently observed at the ankle joint. However, two postural strategies about the knee joint were observed, flexing or extending the knee joint.

The authors hypothesized that the participants in the hyperextended knee group would demonstrate different postural adjustment of the knee joint from the normal knee group. However, the postural responses observed in the hyperextended knee group were similar to those of the normal knee group. Some of the participants had their knees flexed as the postural challenge was increased while the other participants had their knees further extended. Seven participants from the normal and ten participants from the hyperextended knee groups further extended their knees in the Firm-EC condition. During the Foam-EC condition, only three normal knee participants and five knee hyperextension participants had their knees extended compared to the knee joint angle in the Firm-EO condition (see APPENDIX I and APPENDIX J). The results demonstrated that the postural responses varied among participants, even within the same group. Isableu and Vuillerme also reported that the relationship between kinesthetic relationships and postural control of 140 participants varied from one participant to another (Isableu and Vuillerme, 2006).

The postural control system allows individual to choose degrees of freedom that appropriate to the sway direction. It also depends on the environmental constraint and the task being performed (Shumway-Cook, 2007). Thus, for the knee joint, there are two movement directions to be chosen from, flexion or extension, which might depend on ones' experience and their choice of stability (Horak, Diener, and Nashner, 1989).

The adopted knee flexion strategy lowered the body CoM and increased the stance stability. Pereira and colleagues demonstrated a better stability when slightly knee flexion was permitted while measuring stability on the Biodex Stability System (Pereira et al., 2008). An increasing number of the participants who had their knees flexed in the Foam-EC condition supported this idea and might reflect a more advantage strategy when coping with postural challenge. Despite increased knee flexion angle was found, it was not known whether the CoM could be lowered as suggested in the literature because the changes in knee flexion were small. Moreover, the knee joint angle of the knee hyperextension group remained hyperextended. It was suggested that the movements of the knee joint drastically cooperated with the mechanical dynamics of quiet stance (Gunther et al., 2009) and might keep the control system to track the body CoM more consistently (Gage et al., 2004). The control system might be benefited from this slightly knee flexion as the selection of movement directions could be chosen more promptly to counteract with the sway. Even though the knee flexion strategy might allow a better stability, an alternative knee extension response might provide another choice of stability to the control system.

The reason that individuals chose knee extension response during sensory perturbation might be explained by the speculation of close packing mechanism (Di Giulio et al., 2013) which put the knee in the most stable position. Moreover, Burke and colleagues as well as Nade and colleagues showed that the proprioceptive afferent output from capsular, ligamentous, and muscular mechanoreceptors increased exponentially as these structures were lengthened especially when the joint was moved near the end of physiological range (Burke, Gandevia, and Macefield, 1988; Nade, Newbold, and Straface, 1987). An increased proprioceptive input might be helpful for the CNS to track the body motions easier. The study by Lackner indicated that the perceptual representation of the shape of the body was highly modifiable (Lackner, 1988). Thus, participants who had their knees further extended might sought for an increase proprioceptive input as to create a new exact reference body position and to keep the internal representation updated. An alternative hypothesis would be that the sensory perturbations were not strong enough to cause the postural strategy to change.

The authors found a significant difference between the knee joint angle in the Firm-EC and the Foam-EC conditions for the hyperextended knee group ($p = 0.003$). This result might indirectly suggest that individuals with knee hyperextension more likely relied on the visual inputs more than normal knee participants. Once the vision was eliminated in the Firm-EC condition, the sensory reweighing mainly toward the somatosensory system was likely to occur (Creath et al., 2002) since the capability of the vestibular system would not contribute much to the control process of quiet stance during standing on the firm surface. The number of the participants who chose knee extension responses was most evidenced in the Firm-EC condition for both groups. The somatosensory input provided the most useful and reliable information and was the primary contribution of the control of quiet stance (Riemann and Lephart, 2002). Hence, an increase of the knee extension response as to raise the sensory input might be the choice of stability which the control system chose. Hsu and colleagues reported that the joint configuration variance increased when the vision was eliminated. The joint configuration variations might increase the sensory inputs, adding more information to the control system (Hsu et al., 2007; Krishnamoorthy, Yang, and Scholz, 2005). The more information the control system had, the easier to track the body CoM.

However, during the Foam-EC condition, when the somatosensory information was unreliable and the visual information were absent, the torque about the ankle joint was unable to effectively correct the position of the body. The vestibular system became the only reliable source of sensory information left. Accurate sensory information from the vestibular system allowed the participants to perceive the verticality and head movement, hence the participants could detect and estimate the body sway direction (Shumway-Cook, 2007). In this situation, the normal knee group gained advantaged over the hyperextended knee group since the capability in detecting the knee joint position sense was better. The hyperextended knee group might have less accurate sensory information and needed more muscular control over the knee joint.

The knee joint postural responses were clearly elicited when participants stood on the foam surface than the firm surface. Fransson and colleagues reported that when standing on the foam surface, the multi-segment movement pattern was more obviously evidenced than when standing on the firm surface. They also found that movements of the knee joint were significantly higher than those of the hip joint (Fransson et al., 2007). The results of the current study indicated that the mean change of knee joint angle was trended toward flexion response which was in accordance with the study of Siqueira and colleagues (Siqueira et al., 2011). Even though the current study was mainly concerned about the knee joint postural response, the postural response of other joints were not known and were needed to be taken into account to fully understood the whole biomechanical aspect of quiet stance. The study by Gunther and colleagues found coupling movements of the ankle and knee joints, also their torques (Gunther et al., 2009), suggesting that controlling the quiet stance by adjusting the movement of the lower limb was essential. Once the alignment of the knee joint changed, the coupling movement as well as the torque coupling might be interrupted, leading to poor stance stability.

The knee joint postural adjustment observed when the sensory information was limited in the normal and hyperextended knee groups were comparable. However, the neuromuscular control revealed the difference in the medial hamstrings muscle as discussed below. Note that the patterns of knee joint postural responses were different from the well-known ankle and hip strategies. Hence, the patterns of knee muscle activation were different as well.

5.2 The neuromuscular control of the knee joint

In this study the authors used the muscle activity from the Firm-EO condition as a reference value to normalize the muscle activity from other standing conditions. In this case, we could not compare the pattern of muscle activity in normal standing condition between groups. All results only suggested the ability to recruit or de-recruit motor units when the postural demand was challenged. Our results revealed that healthy females with knee hyperextension were able to modulate muscle activities according to the postural demand similar to the normal knee participants when the visual information was presented. On the other hand, when the somatosensory and visual information were perturbed, the hyperextended knee participants elicited different muscle activation patterns.

5.2.1 Medial hamstrings muscle and the movement control of knee joint

Seven muscles around the knee joint were chosen as they had influence on the movements of the knee joint. All muscle activities were found increased when the level of postural challenge was increased in both normal and hyperextended knee groups. Only the medial hamstrings muscle activities were found significant difference between the two groups in the Firm-EC condition. An increasing medial hamstrings muscle activity might reflect an increased postural demand and joint protective mechanism. As the knee joint was further extended, the ligament or joint proprioceptors firing rate was increased (Nade et al., 1987) and might activate the hamstrings muscle response (Solomonow, 2006). The capsular-hamstrings reflex response was the synergistic activity that aimed to prevent excessive anterior tibial translation, hence prevented joint capsule and ligament damaged (Solomonow, 2006). Previously, Greenwood and co-workers compared the muscle activity of the hypermobility syndrome individuals during bipedal and single leg stance, with or without vision. They found that the semitendinosus muscle activity, as well as the erector spinae muscle activity, were significantly higher than normal participants in all standing conditions. Greenwood and colleagues suggested that an increases semitendinosus muscle activity was to compensate for joint instability (Greenwood et al., 2011). However, the participants in this study were not diagnosed as having a benign joint hypermobility syndrome. As a consequence, the muscles other than the knee joint might not be affected.

Flaxman and co-worker identified the semitendinosus muscle to be a moment actuator of the knee joint. The moment actuator means a muscle with relatively high specificity and an asymmetrical activation pattern about its reported moment arm orientation. Furthermore, the specific function of the semitendinosus muscle was found when the leg was attempted to move in the posterior direction with the foot restricted (Flaxman, Speirs, and Benoit, 2012). Considering the medial hamstrings as a moment actuator of the knee joint and its specific direction of function, its role would be to internally rotate the tibia or preventing it from excessive external rotation and anterior displacement. It was possible that an increased medial hamstrings muscle activity during the Firm-EC condition would be to respond to the screw-home mechanism, the tibia was externally rotated while the femur internally rotated, in order to prevent excessive external rotation and increase the knee joint stability (Masouros et al., 2010). In the other conditions, the knee joints were moved into a more flex position, hence the tibia was not as externally rotated as it was in the Firm-EC condition and the medial hamstrings muscle did not necessarily be activated that much. However, the 3-dimensional study is needed to prove that the external rotation movement of the tibia is correlated with an increased medial hamstrings activity.

Di Fabio and colleagues found that the medial hamstrings muscle activation was selectively activated during backward body sway in lax knee caused by the ACL injury. Their results suggested that the motor command could be modified and restructured by the presence of altered joint mechanoreceptors (Di Fabio et al., 1992). As the hyperextended knee participants were less capable of perceiving the exact knee joint position, the knee joint might not be as stable as when the vision was presented. Selective recruitment of the medial hamstrings muscle into play might be a consequence of knee hyperextension that caused the motor command to change. This might provide an additional joint stabilization strategy preventing knee joint injury.

5.2.2 Patterns of muscle activation

Muscle co-activations of the limbs and trunk which are identified during the control of quiet stance are called muscle synergy. A set or sets of muscle synergies can be activated in response to the specific directional postural perturbation, muscle activation pattern can then be defined as a consequence (Ting and McKay, 2007). For example, during forward body sway, the ankle strategy usually evokes muscle contraction on the posterior aspect of the trunk, while the backward body sway evokes muscle contraction on the anterior aspect of the body (Creath et al., 2005; Runge et al., 1999). However, the postural sway direction that is caused by the absent of vision or an inaccurate somatosensation can hardly be predicted since the movement direction of the body CoM quite varies. Furthermore, the diversity of contracting muscles and timing of muscle contraction cause an equivalent displacement of the body CoM. Thus, the pattern of muscle activation may vary according to the CoM trajectories and may vary among people (Ting, 2007). However, Horak and colleagues suggests that the complex pattern of muscle activity remains unchanged but rather increases in magnitude of response when the stability is perturbed in healthy participants (Horak et al., 1989). This notion is well suited with the normal knee participants in the current study but not with the hyperextended knee group. Considering the results of the normal knee group, the muscle activation patterns were quite the same among conditions, only increased in the level of muscle activity.

The current study demonstrated that the presence of knee hyperextension caused the muscle activation pattern to differ from those of the normal knee group. As the results from the study of Di Fabio and co-workers, the motor command could be re-constructed and led to the modification of the muscle activation pattern (Di Fabio et al., 1992). The muscle activation of the hyperextended knee group changed with the present or absent of the vision. During the Firm-EC condition, vision caused no significant difference on the muscle activity level of the normal knee group, while there were some effects on the medial hamstring muscle of the hyperextended knee group. On the other hand, when vision was eliminated in the Foam-EC condition, the level of muscle activity was obviously affected. These results suggested that the normal knee participants relied on the sensory information that arose from the somatosensory system more than the visual system and vice versa.

The alignment of the knee hyperextension was not only shifted in posterior direction but concurrently occurred in the lateral direction as seen with the lower tibiofemoral angle (see APPENDIX G). The lateral head of gastrocnemius muscle was reported to be more stressful in the hyperextended knee (Fornalski et al., 2008; Loudon et al., 1998; Tanamas et al., 2009). MacLeod reported that the lateral head of the gastrocnemius muscle and semitendinosus muscles were activated with high percentage of MVIC when the participants were trying to move their legs in backward movement direction with their feet were restricted with the ski boot attached to the floor. These two muscles may be synergistic in internal rotation the tibia and unlocking it (MacLeod et al., 2013). However, due to the limitation of the instrument, the authors could not collect the muscle activity from the lateral gastrocnemius muscle. The role of the lateral gastrocnemius is required to further investigated.

5.3 Knee joint position sense was less reliable in hyperextended knees

The memory-based, ipsilateral active joint re-position matching task was used to examine the ability to detect the knee joint position in weight bearing position. While the variable error was found significantly different between groups, the absolute error and relative error were not. The variable error, represented the reliability of the individual in replicating the test angle (Stillman et al., 2002), reflected that the individuals with knee hyperextension were less reliable when performing joint position matching task. These results indicated that the capability in detecting knee joint position of individuals with knee hyperextension was at least comparable to but less reliable than those of the normal knee participants.

The earlier studies that aimed to compare the joint position sense in knee hyperextension yielded conflict results (Loudon, 2000; Stillman et al., 2002). Loudon reported that the women who habitually stood with their knees hyperextended, more than 5 degrees, had a poorer ability in detecting knee joint position sense at 10 degrees of knee flexion (Loudon, 2000). On the other hand, Stillman and colleagues found greater proprioceptive accuracy and reliability in the participants who exhibited knee extension more than 6 degrees beyond straight. However, the position used to test the knee joint position sense could potentially affect the study results (Stillman and McMeeken, 2001). Neither study tested knee joint position in standing position. Loudon tested the joint position sense in supine position with 30% of body weight transmitted through the lower limbs, while Stillman tested in sitting position. The difference of the test position might respond for the inconclusive results. Besides, the test positions used were not relevant to the control of the knee joint during quiet stance.

Our recent study was based on the notion that individuals with knee hyperextension would have a deficient proprioception of the knee joint due to the elongated ligaments and soft tissues of the knee (Loudon et al., 1998). For this reason, the authors chose the test angle at 15 degrees from standing knee angle of each participants that was measured during the screening session, assuming an equal tension of the ligaments in the tested knee. However, the finding did not fully support the idea. The peripheral receptors were range-specific activated, this was known as "place code". Furthermore, the changes of frequency of the firing rate were coded as changes of joint position (Burgess et al., 1982). The actual length of the lax ligament might be changed according to the stretched position of the knee joint and caused the change of the place code as well as the frequency of the firing rate to differ from its original length. The altered place and frequency code in the hyperextended knee might be responsible for the difference of the variable error between the two groups.

The explanation above would be well fitted to the main idea of the study if the muscle spindle could not function properly. Stillman and colleagues proposed that there was no proprioceptive deficiency in the hyperextended knee or the deficient proprioception from the ligament was compensated by another proprioceptive source like muscle spindles (Stillman et al., 2002). Moreover, the joint or ligament proprioceptors were reported to have a small effect on joint position perception (Burgess et al., 1982; Clark et al., 1979). On the other hand, muscle spindle was known and accepted for its contribution in proprioceptive function (Burgess et al., 1982; Proske, 2006). The proof that revealed an outstanding role of the muscle spindle was done by vibrating the relevant muscle tendon. Vibration applied to the tendon of a muscle created movement illusion in the direction opposite to function of that vibrated muscle (Walsh et al., 2009). The changes of the muscle spindle activity might generate more meaningful proprioceptive signal which was more useful for the CNS to process and interpret the knee joint position.

Generally, the stretched or contracting muscle caused the firing rate of the muscle spindle to increase. The changing of muscle spindle firing rate was perceived by the CNS as the changing of the joint position (Burgess et al., 1982). During active muscle contraction, the alpha-gamma motor neuron co-activation took place and hence increased the proprioceptive information. Additionally, an active muscle contraction generated the "efferent copy" as a feedback signal to the CNS, making more proprioceptive information available for the comparison (Proske, 2006). Some studies demonstrated a benefit from an increasing spindle discharge (Allen, Ansems, and Proske, 2008; Ghiasi and Akbari, 2007; Stillman and McMeeken, 2001). Allen and colleagues found that adding weight (10% or 25% of MVC) to the pre-conditioned muscles could reduce the error from position matching task (Allen et al., 2008). The studies that tested the knee joint positions sense in weight bearing position reported smaller absolute error than non-weight bearing position (Ghiasi and Akbari, 2007; Stillman and McMeeken, 2001).

Another reason that we did not found the difference of the absolute and relative errors might be because we tested joint position sense on the non-dominant limb which most of the participants were left side. Some studies pointed out that the non-dominant lower limb were likely to be more specific for stability tasks (Clifford and Holder-Powell, 2010; Schneiders et al., 2010). The brain imaging study also revealed that the right hemisphere was dominant for processing and detecting limb movements (Naito et al., 2005). These data emphasized the idea of lateralization which meant that one might prefer to use one limb over the other when performing a motor task. The superior ability of the right cerebral hemisphere to process the proprioceptive information might reduce the error from the assumed-damage proprioceptors in the hyperextended knee joint. As we tested the joint position sense on the non-dominant leg, it might be under the influence of this lateralization and caused non-significant difference of the absolute and relative errors between groups.

To study the proprioceptive capability of the individuals with knee hyperextension, we might need to consider both the peripheral and central components of the proprioceptive system. The ability of the CNS to process and differentiate the signals from various proprioceptive sources may be higher in the right hemisphere. However, the methodology of the current study could not answer this question.

5.4 The contribution of proprioception to knee joint postural adjustment

The sensory reweighting as the main process used by the CNS in order to maintain a steady quiet stance position when task requirements and environmental constraints change required sensory input from various sources (Isableu and Vuillerme, 2006). The proprioceptive inputs, as the main contribution in postural control, are used and interpreted by the CNS to coordinate movements of the body and are useful for movement sequences (Cordo et al., 1994). How each individual processes and responses to the proprioceptive information can be different among one another (Isableu and Vuillerme, 2006). According to the results, ability to detect knee joint position in individuals with knee hyperextension was comparable to the normal participants. This might serve the hyperextended knee participants in adjusting their knee joint postures not differ from the normal knee participants. However, the present of the hyperextended knee position resulting in lower reliability in detection of the knee joint position.

Considering the knee joint position sense as proprioceptive cues for adjusting the movements of the body, the lower knee joint reliability might partly explained the poorer postural control during quiet stance reported by Siqueira (Siqueira et al., 2011). Moreover, the sequence of movement at other joints might also have been changed according to the lower reliability of the knee joint position sense. Nonetheless, the movements at other joints were not known and needed to be further investigated.

5.5 Conclusion

The postural control, in term of knee joint postural adjustment of individuals with knee hyperextension was similar to normal participants. Both groups demonstrated knee flexion response with sensory disturbance except the participants in the knee hyperextension group during the Firm-EC condition. The knee flexion responses found in the study might be a strategy chosen by the CNS in order to lower the body CoM hence increased the stance stability, or the control system prepared to counteract with the sway. Moreover, the slightly knee flexion position increased degree of freedom which allowed more flexibility to respond to the sway. On the other hand, the knee extension responses might help the individuals to gain more somatosensory input and update the CNS with the exact position of the knee joint. Though the knee flexion responses were observed, the patterns of muscle activity were difference between two groups when the visual information was eliminated. Furthermore, the joint position sense acuity of knee hyperextension group was less reliable than the normal knee group. The cause of the difference was unknown.

5.6 Clinical implication

The individuals with knee hyperextension should be informed about their knee posture and the adverse consequences of the hyperextended position. Even though the range of motion cannot be restored, they should be encouraged to aware and to keep a proper position of their knee joints. In spite of less reliable in detecting the knee joint position sense, these individuals were capable of detecting the knee joint position. Hence, proprioceptive training along with muscle control training should be cooperated into physical therapy program in order to regain knee joint position sense acuity and to prevent the individuals with knee hyperextension from knee injuries.

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APPENDIX

APPENDIX A
THE FIRST CERTIFICATE OF ETHICAL APPROVAL

The first ethical approval granted by the Ethical Review Committee for Research Involving Human Subjects and/or Use of Animal in Research, Health Science Group of Faculties and Institutes, Chulalongkorn University, Thailand.

AF 02-12

The Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University
Institute Building 2, 4 Floor, Soi Chulalongkorn 62, Phyat hai Rd., Bangkok 10330, Thailand,
Tel: 0-2218-8147 Fax: 0-2218-8147 E-mail: eccu@chula.ac.th

COA No. 113/2012

Certificate of Approval

Study Title No.077.2/55 : **NEUROMUSCULAR CONTROL OF KNEE JOINT IN INDIVIDUALS WITH KNEE HYPEREXTENSION DURING QUIET STANCE: RESULTS FROM ELECTROMYOGRAPHIC AND JOINT POSITION SENSE STUDY**

Principal Investigator : MR.PAWAN CHAIPARINYA

Place of Proposed Study/Institution : Faculty of Allied Health Sciences, Chulalongkorn University

The Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Thailand, has approved constituted in accordance with the International Conference on Harmonization – Good Clinical Practice (ICH-GCP) and/or Code of Conduct in Animal Use of NRCT version 2000.

Signature:	Signature: ....
(Associate Professor Prida Tasanapradit, M.D.)	(Assistant Professor Dr. Nuntaree Chaichanawongsaroj)
Chairman	Secretary

Date of Approval : 31 July 2012 Approval Expire date : 30 July 2013

The approval documents including

1) Research proposal
2) Patient/Participant Information Sheet and Informed Consent Form
3) Researcher
4) Questionnaire
5) Advertising Brochure

Protocol No. 077.2/55
Date of Approval 31 JUL 2012
Approval Expire Date 30 JUL 2013

The approved investigator must comply with the following conditions:

1. *The research/project activities must end on the approval expired date of the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University (ECCU). In case the research/project is unable to complete within that date, the project extension can be applied one month prior to the ECCU approval expired date.*
2. *Strictly conduct the research/project activities as written in the proposal.*
3. *Using only the documents that bearing the ECCU's seal of approval with the subjects/volunteers (including subject information sheet, consent form, invitation letter for project/research participation (if available).*
4. *Report to the ECCU for any serious adverse events within 5 working days*
5. *Report to the ECCU for any change of the research/project activities prior to conduct the activities.*
6. *Final report (AF 03-12) and abstract is required for a one year (or less) research/project and report within 30 days after the completion of the research/project. For thesis, abstract is required and report within 30 days after the completion of the research/project.*
7. *Annual progress report is needed for a two- year (or more) research/project and submit the progress report before the expire date of certificate. After the completion of the research/project processes as No. 6.*

APPENDIX B

THE SECOND CERTIFICATE OF ETHICAL APPROVAL

The second ethical approval granted by the Ethical Review Committee for Research Involving Human Subjects and/or Use of Animal in Research, Health Science Group of Faculties and Institutes, Chulalongkorn University, Thailand.

AF 02-12

The Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University
Institute Building 2, 4 Floor, Soi Chulalongkorn 62, Phyat hai Rd., Bangkok 10330, Thailand,
Tel: 0-2218-8147 Fax: 0-2218-8147 E-mail: eccu@chula.ac.th

COA No. 118/2013

Certificate of Approval

Study Title No.077.2/55 : **NEUROMUSCULAR CONTROL OF KNEE JOINT IN INDIVIDUALS WITH KNEE HYPEREXTENSION DURING QUIET STANCE: RESULTS FROM ELECTROMYOGRAPHIC AND JOINT POSITION SENSE STUDY**

Principal Investigator : MR.PAWAN CHAIPARINYA

Place of Proposed Study/Institution : Faculty of Allied Health Sciences, Chulalongkorn University

The Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Thailand, has approved constituted in accordance with the International Conference on Harmonization – Good Clinical Practice (ICH-GCP) and/or Code of Conduct in Animal Use of NRCT version 2000.

Signature: .... Signature: ....
(Associate Professor Prida Tasanapradit, M.D.) (Assistant Professor Dr. Nuntaree Chaichanawongsaroj)
Chairman Secretary

Date of Approval : 31 July 2013 Approval Expire date : 30 July 2014

The approval documents including

1) Research proposal
2) Patient/Participant Information Sheet and Informed Consent Form
3) Researcher
4) Questionnaire
5) Advertising Brochure

Protocol No. 077.2/55
Date of Approval 31 JUL 2013
Approval Expire Date 30 JUL 2014

The approved investigator must comply with the following conditions:

1. *The research/project activities must end on the approval expired date of the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University (ECCU). In case the research/project is unable to complete within that date, the project extension can be applied one month prior to the ECCU approval expired date.*
2. *Strictly conduct the research/project activities as written in the proposal.*
3. *Using only the documents that bearing the ECCU's seal of approval with the subjects/volunteers (including subject information sheet, consent form, invitation letter for project/research participation (if available).*
4. *Report to the ECCU for any serious adverse events within 5 working days*
5. *Report to the ECCU for any change of the research/project activities prior to conduct the activities.*
6. *Final report (AF 03-12) and abstract is required for a one year (or less) research/project and report within 30 days after the completion of the research/project. For thesis, abstract is required and report within 30 days after the completion of the research/project.*
7. *Annual progress report is needed for a two- year (or more) research/project and submit the progress report before the expire date of certificate. After the completion of the research/project processes as No. 6.*

APPENDIX C
SCREENING QUESTIONNAIRE

<u>แบบสอบถามเพื่อคัดกรองอาสาสมัครเข้าร่วมงานวิจัย</u>

กรุณาตอบคำถามโดยใส่เครื่องหมาย ✓ ในช่องสี่เหลี่ยมตามความเป็นจริง

1. ท่านมีอาการปวดเมื่อยบริเวณหลังส่วนล่างหรือส่วนหนึ่งส่วนใดของรยางค์ขาหรือไม่

☐มี ☐ไม่มี

2. ท่านเคยประสบอุบัติเหตุบริเวณหลังส่วนล่างหรือส่วนหนึ่งส่วนใดของรยางค์ขาในระยะ 12 เดือนที่ผ่านมาหรือไม่

☐ใช่ ☐ไม่ใช่

3. ท่านเคยได้รับการผ่าตัดบริเวณหลังส่วนล่างหรือส่วนหนึ่งส่วนใดของรยางค์ขาหรือไม่

☐เคย ☐ไม่เคย

4. ท่านมีอาการเวียนศีรษะบ้านหมุนหรือไม่

☐มี ☐ไม่มี

5. ท่านมีปัญหาทางสายตาที่อาจส่งผลต่อการมองเห็นซึ่งไม่สามารถแก้ไขได้ด้วยการใส่แว่นสายตาหรือเลนส์สัมผัสหรือไม่

☐มี ☐ไม่มี

6. ท่านดื่มเครื่องดื่มที่มีแอลกอฮอล์ในช่วง 24 ชั่งโมงที่ผ่านมาหรือไม่

☐ดื่ม ☐ไม่ดื่ม

7. ท่านได้รับยาที่อาจทำให้มีอาการง่วงซึม (เช่นยาแก้หวัดยาแก้ปวดที่มีส่วนผสมที่ออกฤทธิ์ทำให้ง่วงนอนเป็นต้น) ในช่วง 24 ชั่วโมงที่ผ่านมาหรือไม่

☐ทาน ☐ไม่ได้ทาน

8. ท่านออกกำลังกายกี่ชั่วโมงต่อสัปดาห์ .... ชั่วโมง/สัปดาห์

9. ท่านได้ออกกำลังกายมากกว่าปกติในช่วง 1 สัปดาห์ที่ผ่านมาหรือไม่

☐ใช่ ☐ไม่ใช่

10. ท่านเคยได้รับการวินิจฉัยทางการแพทย์ว่ามีปัญหาเกี่ยวข้องทางระบบกระดูกและกล้ามเนื้อหรือไม่

☐ใช่ระบุ.................................... ☐ไม่ใช่

11. ท่านเคยได้รับการวินิจฉัยทางการแพทย์ว่ามีปัญหาเกี่ยวข้องทางระบบประสาทหรือไม่

☐ใช่ระบุ................................... ☐ไม่ใช่

APPENDIX D
DATA RECORDING SHEET

แบบบันทึกข้อมูลและตรวจร่างกายเพื่อคัดกรองอาสาสมัครเข้าร่วมงานวิจัย

ลำดับที่ของอาสาสมัคร.................................... อายุ ....ปี

น้ำหนัก.............................กิโลกรัมส่วนสูง............................. เซนติเมตร

BMI .... kg/m^2

อาชีพ ....

การตรวจร่างกาย	หน่วย	ผลการตรวจร่างกาย		หมายเหตุ
		ขวา	ซ้าย	
Dominance leg	left-right			
Leg length	cm			
Lachman's test	+ve / -ve			
Reverse Lachman's test	+ve / -ve			
Valgus stress test	+ve / -ve			
Varus stress test	+ve / -ve			
Femoral anteversion	Degree			
Anterior pelvic tilt	Degree			
Knee hyperextension	Degree			
Quadriceps angle	Degree			
Tibiofemoral angle	Degree			

การตรวจร่างกาย	หน่วย	ผลการตรวจร่างกาย		หมายเหตุ
		ขวา	ซ้าย	
Navicular drop	mm			
Knee extensor strength	kg			
Knee flexor strength	kg			
Ankle dorsiflexor strength	kg			
Ankle plantar flexor strength	kg			

APPENDIX E

PARTICIPANTS' INFORMATION SHEET

ข้อมูลสำหรับกลุ่มประชากรหรือผู้มีส่วนร่วมในการวิจัย

ชื่อโครงการวิจัย การทำงานของระบบประสาทและกล้ามเนื้อในการควบคุมการเคลื่อนไหวของข้อเข่าขณะยืนนิ่งในประชากรที่มีข้อเข่าแอ่น: การศึกษาจากคลื่นไฟฟ้ากล้ามเนื้อและความสามารถในการรับรู้ตำแหน่งของข้อต่อ

ชื่อผู้วิจัย นายปวัน ชัยปริญญา นิสิต ปริญญาโท

สถานที่ติดต่อผู้วิจัย

(ที่ทำงาน) ภาควิชากายภาพบำบัด คณะสหเวชศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย 154 ถนนพระราม 1 แขวงวังใหม่ เขตปทุมวัน กรุงเทพมหานคร 10330

(ที่บ้าน) 583/25 ซอยประชาราษฎร์บำเพ็ญ 15 แยกเกษมสุข 12 แขวงห้วยขวาง เขตห้วยขวางกรุงเทพมหานคร 10310

โทรศัพท์ (บ้าน) 02-690-2955 โทรสาร: 02-2183766

โทรศัพท์มือถือ 08-7504-4954 E-mail: pawan_cu@hotmail.com

สถานที่ดำเนินงานวิจัย

หน่วยปฏิบัติการบริการวิทยาศาสตร์สุขภาพ คลินิกกายภาพบำบัด ชั้น 3 อาคารบรมราชชนนีศรีศตพรรษ คณะสหเวชศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ขอเรียนเชิญอาสาสมัครเข้าร่วมในงานวิจัย ก่อนที่อาสาสมัครจะตัดสินใจเข้าร่วมในการวิจัย มีความจำเป็นที่อาสาสมัครควรทำความเข้าใจว่างานวิจัยนี้ทำเพราะเหตุใด และเกี่ยวข้องกับอะไร กรุณาใช้เวลาในการอ่านข้อมูลต่อไปนี้อย่างละเอียดรอบคอบ และสอบถามข้อมูลเพิ่มเติมหรือข้อมูลที่ไม่ชัดเจนได้ตลอดเวลา

งานวิจัยนี้เป็นงานวิจัยเชิงการทดลองที่ต้องการศึกษาถึงความสามารถในการควบคุมตำแหน่งและการเคลื่อนไหวของข้อเข่าในขณะยืนนิ่ง โดยเปรียบเทียบระหว่างประชากรสองกลุ่มคือ กลุ่มที่มีมุมของข้อเข่าเป็นปกติ (ช่วงการเคลื่อนไหวปกติของข้อเข่าคือ 0 องศาถึง 160 องศา) และกลุ่มที่มีข้อเข่าแอ่นมากกว่า 10 องศา เมื่อเปรียบเทียบกับช่วงการเคลื่อนไหวปกติ ข้อมูลที่นำมาใช้ในการเปรียบเทียบประกอบด้วยคลื่นไฟฟ้ากล้ามเนื้อและความสามารถในการรับรู้ตำแหน่งของข้อเข่า

วัตถุประสงค์ของการวิจัย

งานวิจัยนี้ได้จัดทำขึ้นโดยมีวัตถุประสงค์ 3 ข้อได้แก่

1. เพื่อศึกษาและเปรียบเทียบการทำงานของกล้ามเนื้อรอบข้อเข่าในขณะยืนนิ่ง โดยจะมีการรบกวนการทำงานของระบบรับความรู้สึกที่ทำหน้าที่ในการทรงท่า ได้แก่การยืนหลับตา ยืนบนพื้นโฟมที่มีความนุ่ม และการยืนหลับตาบนพื้นโฟม ทั้งนี้จะทำการเปรียบเทียบคลื่นไฟฟ้ากล้ามเนื้อและการเปลี่ยนแปลงตำแหน่งของข้อเข่าของการยืนแต่ละลักษณะ

2. เพื่อเปรียบเทียบความสามารถในการรับรู้ตำแหน่งของข้อเข่าในขณะยืน

3. เพื่อศึกษาการทำงานของข้อเข่าในการปรับการทรงท่าในขณะยืน

รายละเอียดของกลุ่มประชากรหรือผู้มีส่วนร่วมในการวิจัย

ลักษณะของกลุ่มประชากรหรือผู้มีส่วนร่วมในการวิจัยเป็นเพศหญิงที่มีอายุระหว่าง 18 – 30 ปี จำนวน 44 คน แบ่งเป็นสองกลุ่มคือ (1) กลุ่มที่มีมุมของข้อเข่าเป็นปกติและ (2) กลุ่มที่มีข้อเข่าแอ่นมากกว่า 10 องศา กลุ่มละ 22 คนโดยมีเกณฑ์การคัดเข้า และเกณฑ์การคัดออกดังต่อไปนี้

- **เกณฑ์การคัดเข้า**
  - มีค่าดัชนีมวลกายน้อยกว่า หรือเท่ากับ 23.5 กิโลกรัมต่อตารางเมตร
  - กลุ่มประชากรที่มีมุมของข้อเข่าปกติจะต้องมีช่วงการเคลื่อนไหวของข้อเข่าทั้งสองข้างอยู่ในเกณฑ์ปกติ หรือกลุ่มประชากรที่มีภาวะข้อเข่าแอ่นต้องมีข้อเข่าแอ่นมากกว่า 10 องศาเมื่อเปรียบเทียบกับเกณฑ์ปกติ
  - ต้องเป็นผู้ที่ไม่เคยได้รับการผ่าตัดหรือมีการบาดเจ็บของข้อเข่าในช่วง 12 เดือนที่ผ่านมา
  - ต้องไม่เคยได้รับการบาดเจ็บในส่วนหนึ่งส่วนใดของรยางค์ขาในช่วง 12 เดือนที่ผ่านมา
  - ต้องไม่มีโรคร้ายแรงใดๆที่อาจส่งผลต่อการทำงานของกล้ามเนื้อและการทำงานของระบบการรับความรู้สึก
  - เป็นผู้ที่ออกกำลังกายน้อยกว่า 3 ครั้งต่อสัปดาห์

- **เกณฑ์การคัดออก**
  - มีค่าดัชนีมวลกายมากกว่า 23.5 กิโลกรัมต่อตารางเมตร
  - มีอาการปวดที่บริเวณหลังส่วนล่างและรยางค์ขา
  - มีความยาวขาทั้งสองข้างต่างกันมากกว่า 2 เซนติเมตร

- เคยได้รับบาดเจ็บหรือมีความผิดปกติบริเวณหลังส่วนล่างในช่วง 12 เดือนที่ผ่านมา
- มีอาการบ้านหมุนหรือตรวจพบว่ามีอาการบ้านหมุน
- มีความผิดปกติของการรับความรู้สึก เช่น มีอาการชาหรือรับความรู้สึกได้น้อยกว่าปกติที่บริเวณใดบริเวณหนึ่งของขา
- มีปัญหาทางสายตานอกเหนือจากภาวะสายตาสั้น สายตายาว หรือสายตาเอียง ซึ่งไม่สามารถแก้ไขได้ด้วยการใช้แว่นสายตาหรือเลนส์สัมผัส
- ได้รับยาที่อาจส่งผลทำให้มีอาการง่วงซึม เช่นยาแก้หวัด หรือยาแก้ปวดบางชนิด ในช่วง 24 ชั่วโมงก่อนทำการเก็บข้อมูล
- ดื่มเครื่องดื่มที่มีแอลกอฮอล์ในช่วง 24 ชั่วโมงที่ผ่านมา
- ไม่สามารถยืนหลับตาหรือยืนบนพื้นโฟมได้เอง ต้องได้รับความช่วยเหลือในการทรงตัว

อาสาสมัครของงานวิจัยนี้จะใช้วิธีการสุ่มตัวอย่างตามสะดวก (Convenience sampling) จากกลุ่มประชากรในจุฬาลงกรณ์มหาวิทยาลัยโดยผู้วิจัยได้ติดประกาศเพื่อเชิญชวนผู้ที่มีความสนใจเข้าร่วมในงานวิจัยนี้ตามบอร์ดประชาสัมพันธ์ของคณะต่างๆและของมหาวิทยาลัย นอกจากนี้อาสาสมัครยังสามารถแนะนำผู้ที่สนใจซึ่งอาจเป็นเพื่อนหรือคนรู้จักของตนเองเพื่อเข้าร่วมงานวิจัยนี้ได้เช่นกัน

วิธีการดำเนินงานวิจัย

ผู้วิจัยจะอธิบายข้อมูลภาพรวมและขั้นตอนของงานวิจัยแก่อาสาสมัคร และหากอาสาสมัครยินดีเข้าร่วมในงานวิจัย ผู้วิจัยจะขอให้อาสาสมัครลงนามในหนังสือแสดงความยินยอมเข้าร่วมในงานวิจัยก่อนเริ่มทำการเก็บข้อมูล

ขั้นตอนการตรวจคัดกรองอาสาสมัคร

1. อาสาสมัครตอบแบบสอบถามเพื่อคัดกรองอาสาสมัครเข้าร่วมงานวิจัยจำนวน10 ข้อ ซึ่งใช้เวลาราว 1 – 2 นาที
2. เมื่ออาสาสมัครผ่านเกณฑ์การคัดเข้าเบื้องต้นแล้ว ผู้วิจัยจะทำการตรวจประเมินความแข็งแรงของเส้นเอ็นบริเวณข้อเข่าทั้งสองข้างเพื่อช่วยยืนยันความมั่นคงของข้อเข่าและทำการตรวจประเมินความยาวขาทั้งสองข้าง หากการตรวจร่างกายพบว่า อาสาสมัครมีความผิดปกติของเส้นเอ็น หรือมีความยาวขาทั้งสองข้างแตกต่างกันมากกว่า 2 เซนติเมตร อาสาสมัครจะไม่สามารถเข้าร่วมงานวิจัยนี้ได้ ผู้วิจัยจะให้การรักษาเบื้องต้น

แก่อาสาสมัครที่ตรวจพบความผิดปกติในขั้นตอนการตรวจประเมิน รวมถึงให้คำแนะนำในการปฏิบัติตนเพื่อป้องกันผลเสียที่อาจเกิดขึ้นจากการมีความผิดปกติของเส้นเอ็นและการมีความยาวขาที่ต่างกันมากกว่าปกติในการตรวจประเมินนี้จะใช้เวลาประมาณ 2-3 นาที

ในขณะที่ทำการตรวจประเมินและการเก็บข้อมูลงานวิจัยนั้น ผู้วิจัยมีความจำเป็นต้องขอให้อาสาสมัครใส่กางเกงขาสั้น (ความยาวของขากางเกงระดับกึ่งกลางต้นขา) ทั้งนี้เพื่อให้สามารถสังเกตการเคลื่อนไหวที่ข้อเข่าได้ชัดเจน

ขั้นตอนการวิจัย

1. ผู้วิจัยทำการตรวจประเมินเพื่อระบุขาข้างที่ถนัดของอาสาสมัคร จากนั้นจะทำการวัดการวางตัวของกระดูกขาข้างที่ไม่ถนัดซึ่งจะเป็นข้างที่ใช้เก็บข้อมูลคลื่นไฟฟ้ากล้ามเนื้อ การปรับการทรงท่าของข้อเข่า ความสามารถในการรับรู้ตำแหน่งของข้อเข่า และความแข็งแรงของกล้ามเนื้อ
2. เมื่อทำการเก็บข้อมูลดังกล่าวข้างต้นแล้ว ผู้วิจัยจะทำการติดขั้วบันทึกสัญญาณไฟฟ้ากล้ามเนื้อและอุปกรณ์สำหรับติดตามการเคลื่อนไหวของข้อเข่าให้แก่อาสาสมัครโดยอุปกรณ์ทั้งสองจะเชื่อมต่อกับกล่องรับข้อมูลที่ถูกติดไว้ที่บริเวณเอวของอาสาสมัคร
    a. ผู้วิจัยจะเช็ดผิวหนังบริเวณที่ต้องติดขั้วบันทึกด้วยแอลกอฮอล์ จากนั้นจะติดขั้วบันทึกสัญญาณไฟฟ้ากล้ามเนื้อซึ่งมีลักษณะเป็นแผ่นวงกลมเส้นผ่าศูนย์กลางราว 3.3 เซนติเมตร จำนวน 15 ชิ้นลงบนผิวหนังเหนือกล้ามเนื้อขาที่ต้องการศึกษา (ด้านหน้าต้นขา 6 ชิ้น ด้านหลังต้นขา 4 ชิ้น บริเวณหน้าแข้ง 3 ชิ้น และบริเวณน่อง 2 ชิ้น) โดยการบันทึกสัญญาณไฟฟ้ากล้ามเนื้อนี้ไม่ทำให้เกิดความเจ็บปวดแต่อย่างใด
    b. สำหรับอุปกรณ์สำหรับติดตามการเคลื่อนไหวของข้อเข่ามีลักษณะเป็นแท่งพลาสติก 2 แท่งเชื่อมติดกันด้วยแกนลวด จะถูกติดไว้ทางด้านข้างของข้อเข่า โดยยึดติดกับขาด้วยเทปกาวสองหน้า
3. การเก็บข้อมูลในส่วนที่ 1 เป็นข้อมูลเกี่ยวข้องกับการทำงานของกล้ามเนื้อรอบข้อเข่าในการปรับการทรงท่า ผู้วิจัยจะขอให้อาสาสมัครยืนนิ่ง กางขาเท่ากับความกว้างของช่วงไหล่ ตามองตรงไปด้านหน้าเพื่อกำหนดตำแหน่งของเท้าด้วยเทปกาว เมื่อระบุตำแหน่งเท้าเรียบร้อยแล้ว อาสาสมัครนั่งพักราว 1 นาทีก่อนเริ่มทำการเก็บข้อมูล การเก็บข้อมูลในส่วนที่หนึ่งนี้อาสาสมัครจะยืนบนพื้นห้องตามปกติในขณะที่ลืมตาและในขณะที่หลับตา และยืนบนแผ่นโฟมที่สามารถรบกวนการทรงท่าได้ทั้งในขณะที่ลืมตาและหลับตาเช่นเดียวกัน โดยในการยืนแต่ละลักษณะผู้วิจัยจะขอให้อาสาสมัครทำซ้ำ 2 ครั้ง ครั้งละ 30 วินาที มีช่วงพัก 1-2 นาทีระหว่างการเก็บข้อมูลแต่ละครั้งในขณะทำการเก็บข้อมูล ผู้ช่วยผู้วิจัยจะยืนอยู่ในระยะที่สามารถประคอง

อาสาสมัครได้และมีเก้าอี้ตั้งอยู่ในระยะที่สามารถเอื้อมมือมาจับได้เพื่อป้องกันการล้ม

4. ในส่วนที่ 2 การเก็บข้อมูลด้านความสามารถในการรับรู้ตำแหน่งของข้อเข่านั้น จะทำการเก็บข้อมูลในขณะที่อาสาสมัครยืนบนขาข้างที่ไม่ถนัดข้างเดียวและหลับตา โดยผู้วิจัยจะขอให้อาสาสมัครจับขอบโต๊ะหรือเก้าอี้ไว้เพื่อป้องกันการล้มแล้วย่อเข่าลงมาที่ตำแหน่งที่ต้องการ จากนั้นให้หยุดค้างไว้ 4 วินาที ระหว่างนี้ขอให้อาสาสมัครจำตำแหน่งของข้อเข่าไว้แล้วกลับมายืนตรงเพื่อพักการใช้งานของกล้ามเนื้อขา จากนั้นจะขอให้อาสาสมัครพยายามย่อเข่าลงไปยังตำแหน่งเดิมโดยในการทดสอบผู้วิจัยจะไม่บอกให้อาสาสมัครรู้ว่าถึงตำแหน่งที่ต้องการแล้วหรือยัง แต่อาสาสมัครจำเป็นต้องพยายามย่อเข่าให้อยู่ในตำแหน่งเดิมด้วยตนเองค้างไว้ราว 4 วินาทีเช่นกัน การทดสอบจะทำทั้งสิ้น 3 ครั้ง โดยให้มีช่วงพักอย่างน้อย 10 วินาทีก่อนเริ่มเก็บข้อมูลครั้งต่อไป

*** ผู้วิจัยมีความจำเป็นต้องถ่ายภาพเคลื่อนไหวด้วยกล้องวิดีโอเพื่อดูการเคลื่อนไหวต่างๆที่อาจเกิดขึ้นในขณะทำการเก็บข้อมูลด้วยเพื่อศึกษาการเคลื่อนไหวในขณะที่มีการรบกวนการทรงท่า โดยภาพวิดีโอนี้จะนำไปใช้ในการศึกษาแต่จะ<u>ไม่มีการนำไปเผยแพร่โดยเด็ดขาด</u>ทั้งนี้ <u>**ผู้วิจัยขออนุญาตเก็บภาพวิดีโอ**</u>ไว้ เพื่อใช้ในการศึกษาต่อไปในอนาคตหากอาสาสมัครไม่ต้องการให้เก็บภาพวิดีโอไว้ผู้วิจัยจะทำลายภาพวิดีโอหลังสิ้นสุดงานวิจัยแล้ว

5. เมื่อทำการเก็บข้อมูลทั้งสองส่วนเรียบร้อยแล้ว ผู้วิจัยจะทำการวัดกำลังของกล้ามเนื้อที่ทำหน้าที่เหยียดและงอข้อเข่า กล้ามเนื้อที่ทำหน้าที่กระดกและถีบปลายเท้ารวมทั้งหมด 4 กลุ่ม สำหรับกล้ามเนื้อที่ทำหน้าที่เหยียดข้อเข่าและกระดกปลายเท้าจะทำการวัดในท่านอนหงาย ส่วนกล้ามเนื้อที่ทำหน้าที่งอข้อเข่าและถีบปลายเท้าจะทำการวัดในท่านอนคว่ำ ผู้วิจัยจะขอให้อาสาสมัครออกแรงกล้ามเนื้อมัดต่างๆต้านกับแรงของผู้วิจัยอย่างเต็มที่ กล้ามเนื้อแต่ละกลุ่มจะทำซ้ำกลุ่มละ 3 ครั้งโดยพัก 1 นาทีระหว่างครั้ง

ขั้นตอนในการดำเนินการเก็บข้อมูลของงานวิจัยทั้งหมดจะใช้เวลาราว 90 นาที และเป็นการเก็บข้อมูลเพียงครั้งเดียว ซึ่งจะไม่มีผลกระทบต่อการเรียนและการรักษาใดๆ

ประโยชน์ที่ท่านจะได้รับ

การเข้าร่วมงานวิจัยในครั้งนี้ อาสาสมัครอาจไม่ได้รับรับประโยชน์โดยตรงหลังจากเข้าร่วมในงานวิจัย และอาสาสมัครจะได้รับค่าตอบแทน300 บาท นอกจากนี้ อาสาสมัครจะได้รับทราบข้อมูลที่เกี่ยวข้องกับความแข็งแรงของเส้นเอ็นรอบข้อเข่า ความสามารถในการรับรู้ตำแหน่งของข้อเข่าและกำลังกล้ามเนื้อ และผลที่ได้จากงานวิจัยนี้จะทำให้ทราบถึงการควบคุมการตำแหน่งของข้อเข่าและ

บทบาทของข้อเข่าต่อการควบคุมการทรงท่าในขณะยืน รวมถึงเป็นแนวทางในการวางแผนการรักษาหรือออกแบบการออกกำลังกายเพื่อป้องกันผลเสียในกลุ่มประชากรที่มีข้อเข่าแอ่นได้

ความเสี่ยงหรืออันตรายที่อาจเกิดขึ้น

การตรวจประเมินร่างกายเพื่อคัดกรองอาสาสมัครซึ่งประกอบด้วยการตรวจความแข็งแรงของเส้นเอ็นบริเวณข้อเข่าและการวัดความยาวขานั้นจะไม่ก่อให้เกิดอันตรายหรือผลเสียใดๆต่ออาสาสมัครทั้งสิ้น ยกเว้นกรณีที่อาสาสมัครมีความผิดปกติของเส้นเอ็นแต่ไม่แสดงอาการ การตรวจความแข็งแรงของเส้นเอ็นจึงอาจกระตุ้นให้แสดงอาการออกมาได้ในระหว่างการตรวจ ซึ่งเป็นไปตามขั้นตอนการตรวจปกติ แต่อาการจะหายไปหลังหยุดทำการตรวจประเมิน หากเกิดความผิดปกติขึ้นผู้วิจัยจะหยุดการตรวจและให้คำแนะนำและการรักษาทางกายภาพบำบัดที่เหมาะสมทันที

ส่วนขั้นตอนการเก็บข้อมูลมีการรบกวนความสามารถในการทรงตัวของอาสาสมัคร ความเสี่ยงต่อการหกล้มอาจเกิดขึ้นได้ ทางผู้วิจัยจะจัดอุปกรณ์ที่ช่วยในการทรงตัวรวมถึงผู้วิจัยหรือผู้ช่วยผู้วิจัยจะอยู่ในระยะที่สามารถป้องกันไม่ให้อาสาสมัครล้มได้

ในช่วงท้ายของงานวิจัยซึ่งมีการเก็บข้อมูลเรื่องความแข็งแรงของ กล้ามเนื้อ อาสาสมัครจำเป็นต้องออกแรงเกร็งกล้ามเนื้อทั้ง 4 กลุ่มอย่างเต็มที่ ซึ่งอาจก่อให้เกิดการเมื่อยล้าหรือปวดกล้ามเนื้อเล็กน้อยได้ แต่อาการดังกล่าวจะหายไปภายใน 2-3 วัน และทางผู้วิจัยจะให้คำแนะนำการยืดกล้ามเนื้อทั้งก่อนและหลังจากทำการเก็บข้อมูลแล้ว เพื่อป้องกันและลดผลเสียที่อาจเกิดขึ้นได้แต่หากอาสาสมัครมีอาการเจ็บกล้ามเนื้อเกิดขึ้นในขณะที่ทำการตรวจ ผู้วิจัยจะหยุดทำการตรวจทันทีและประคบด้วยแผ่นเย็นราว 20 นาทีและจะให้การรักษาทางกายภาพบำบัดเพิ่มเติมตามความเหมาะสมต่อไป

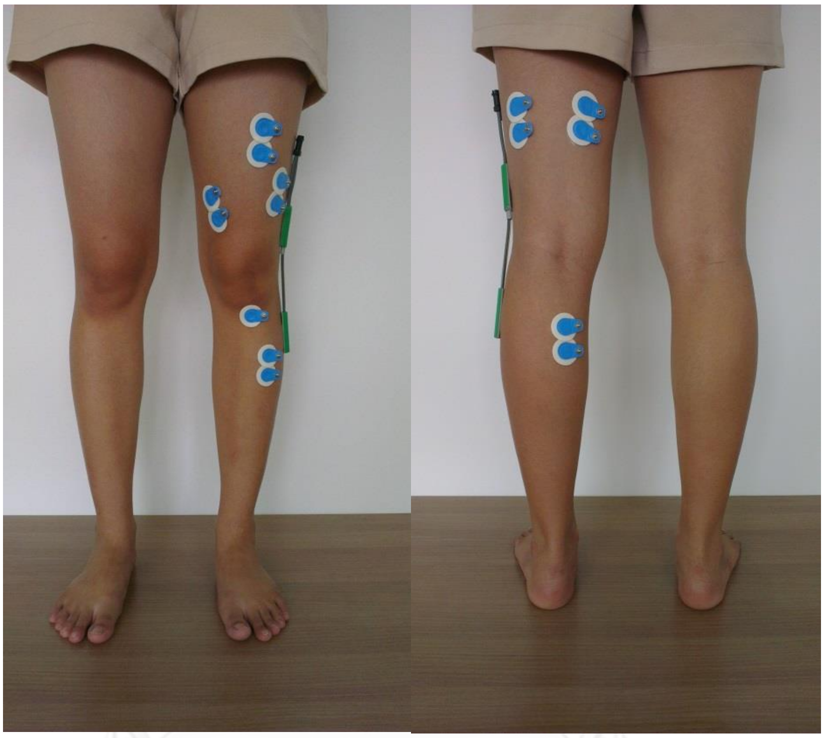
สิทธิของอาสาสมัคร

การเข้าร่วมในการวิจัยของอาสาสมัครเป็นไปโดยสมัครใจ และสามารถปฏิเสธที่จะเข้าร่วมหรือถอนตัวจากการวิจัยได้ทุกขณะโดยไม่ต้องให้เหตุผลและท่านจะไม่สูญเสียประโยชน์ที่พึงได้ ไม่มีผลต่อการเรียนและการรักษาใดๆของอาสาสมัคร

การเปิดเผยข้อมูลของอาสาสมัคร

ข้อมูลส่วนตัวและข้อมูลอื่นๆที่เกี่ยวข้องกับอาสาสมัครจะได้รับการปกปิดและถือเป็นความลับเฉพาะผู้วิจัยและอาจารย์ที่ปรึกษางานวิจัยเท่านั้น ข้อมูลใดที่สามารถระบุถึงตัวอาสาสมัครได้จะไม่ปรากฏในรายงานเว้นแต่จะได้รับการยินยอมจากอาสาสมัครในการเปิดเผยข้อมูล ข้อมูลทั้งหมดจะเปิดเผยในรูปแบบของข้อมูลงานวิจัยและผลสรุปของงานวิจัยเท่านั้น

หากอาสาสมัครไม่ได้รับการปฏิบัติตามข้อมูลดังกล่าวสามารถร้องเรียนได้ที่ คณะกรรมการพิจารณาจริยธรรมการวิจัยในคน กลุ่มสหสถาบัน ชุดที่ 1 จุฬาลงกรณ์มหาวิทยาลัย ชั้น 4 อาคารสถาบัน 2ซอยจุฬาลงกรณ์ 62 ถนนพญาไท เขตปทุมวัน กรุงเทพฯ 10330 โทรศัพท์ 0-2218-8147 หรือ 0-2218-8141 โทรสาร 0-2218-8147 E-mail:eccu@chula.ac.th



APPENDIX F

INFORMED CONSENT FORM

หนังสือแสดงความยินยอมเข้าร่วมการวิจัย

ทำที่..

วันที่..........เดือน........................พ.ศ..................

เลขที่ ประชากรตัวอย่างหรือผู้มีส่วนร่วมในการวิจัย..............................

ข้าพเจ้า ซึ่งได้ลงนามท้ายหนังสือนี้ขอแสดงความยินยอมเข้าร่วมโครงการวิจัย

ชื่อโครงการวิจัย“การทำงานของระบบประสาทและกล้ามเนื้อในการควบคุมการเคลื่อนไหวของข้อเข่าขณะยืนนิ่งในประชากรที่มีข้อเข่าแอ่น: การศึกษาจากคลื่นไฟฟ้ากล้ามเนื้อและความสามารถในการรับรู้ตำแหน่งของข้อต่อ”

ชื่อผู้วิจัยนายปวัน ชัยปริญญา

ที่อยู่ที่ติดต่อ583/25 ซอยประชาราษฎร์บำเพ็ญ 15 แยกเกษมสุข 12 เขตห้วยขวาง กรุงเทพมหานคร 10310

โทรศัพท์08-7504-4954

ข้าพเจ้า ได้รับทราบรายละเอียดเกี่ยวกับที่มาและวัตถุประสงค์ในการทำวิจัย รายละเอียดขั้นตอนต่างๆ ที่จะต้องปฏิบัติหรือได้รับการปฏิบัติ ความเสี่ยง/อันตราย และประโยชน์ซึ่งจะเกิดขึ้นจากการวิจัยเรื่องนี้ โดยได้อ่านรายละเอียดในเอกสารชี้แจงผู้เข้าร่วมการวิจัยโดยตลอด และได้รับคำอธิบายจากผู้วิจัย จนเข้าใจเป็นอย่างดีแล้ว

ข้าพเจ้าจึงสมัครใจเข้าร่วมในโครงการวิจัยนี้ ตามที่ระบุไว้ในเอกสารชี้แจงผู้เข้าร่วมการวิจัย โดยข้าพเจ้ายินยอมให้ความร่วมมือแก่ผู้วิจัยในการเก็บข้อมูลที่เกี่ยวข้องกับงานวิจัย ประกอบด้วยการตรวจคัดกรองอาสาสมัครด้วยแบบสอบถามและการตรวจร่างกาย 5 วิธีแบ่งเป็นการตรวจความแข็งแรงของเส้นเอ็นบริเวณข้อเข่าทั้งสองข้าง 4 วิธี และการตรวจความยาวขาอีก 1 วิธี เมื่อข้าพเจ้าผ่านเกณฑ์การคัดเข้าแล้ว ข้าพเจ้าจะได้รับการตรวจประเมินเพิ่มเติมเพื่อระบุขาข้างที่ถนัดและการจัดเรียงตัวของกระดูกของขาข้างที่ไม่ถนัด จากนั้นจึงทำการเก็บข้อมูลของงานวิจัยต่อไป ซึ่งประกอบด้วยการการตรวจประเมินความสามารถในการยืนทรงท่าในขณะที่มีการรบกวนการทำงานของระบบประสาทรับความรู้สึก การตรวจประเมินความสามารถในการรับรู้ตำแหน่งของข้อเข่า และการตรวจประเมินความแข็งแรงของกล้ามเนื้อรอบข้อเข่า

โดยข้าพเจ้าได้รับแจ้งจากผู้วิจัยว่าจะมีการบันทึกวิดีโอขณะทำการเก็บข้อมูลด้วย งานวิจัยนี้จะใช้เวลาราว 90 นาที หลังจากเสร็จสิ้นการวิจัยแล้ว อาสาสมัครไม่มีข้อผูกพันต่อไปในอนาคต และข้าพเจ้าได้อนุญาตให้ผู้วิจัยเก็บภาพวิดีโอเพื่อใช้ในการศึกษาต่อไปได้

ข้าพเจ้ารับทราบว่า ข้าพเจ้ามีสิทธิถอนตัวออกจากการวิจัยเมื่อใดก็ได้ตามความประสงค์ โดยไม่ต้องแจ้งเหตุผล ซึ่งการถอนตัวออกจากการวิจัยนั้น *จะไม่มีผลกระทบต่อการดูแลรักษาหรือต่อผลการเรียนการศึกษาใดๆ ของข้าพเจ้าทั้งสิ้น*

ข้าพเจ้าได้รับคำรับรองว่า ผู้วิจัยจะปฏิบัติต่อข้าพเจ้าตามข้อมูลที่ระบุไว้ในเอกสารชี้แจงผู้เข้าร่วมการวิจัย และข้อมูลใดๆ ที่เกี่ยวข้องกับข้าพเจ้า ผู้วิจัยจะเก็บรักษาเป็นความลับ โดยจะนำเสนอข้อมูลการวิจัยเป็นภาพรวมเท่านั้น ไม่มีข้อมูลใดในการรายงานที่สามารถนำไปสู่การระบุตัวข้าพเจ้า

หากข้าพเจ้าไม่ได้รับการปฏิบัติตรงตามที่ได้ระบุไว้ในเอกสารชี้แจงผู้เข้าร่วมการวิจัย ข้าพเจ้าสามารถร้องเรียนได้ที่คณะกรรมการพิจารณาจริยธรรมการวิจัยในคน กลุ่มสหสถาบัน ชุดที่ 1 จุฬาลงกรณ์มหาวิทยาลัย ชั้น 4 อาคารสถาบัน 2 ซอยจุฬาลงกรณ์ 62 ถนนพญาไท เขตปทุมวัน กรุงเทพฯ 10330
โทรศัพท์ 0-2218-8147, 0-2218-8141 โทรสาร 0-2218-8147 E-mail:**eccu@chula.ac.th**

ข้าพเจ้าได้ลงลายมือชื่อไว้เป็นสำคัญต่อหน้าพยาน ทั้งนี้ข้าพเจ้าได้รับสำเนาเอกสารชี้แจงผู้เข้าร่วมการวิจัย และสำเนาหนังสือแสดงความยินยอมไว้แล้ว

ลงชื่อ... ลงชื่อ..

(นายปวัน ชัยปริญญา) (..)

ผู้วิจัยหลัก ผู้มีส่วนร่วมในการวิจัย

ลงชื่อ..

(..)

พยาน

APPENDIX G
LOWER LIMB ALIGNMENT

The following lower limb alignment data were recorded according to the association found in anterior knee joint laxity individuals. These data served as associative factors that might help the researchers to understand the different muscle activity examined in this study.

According to the idea that body alignment contributes to postural control, the different alignment at each joint may affect the muscle activity in one way or another. The lower limb alignments that were measured in this study included anterior pelvic tilt angle, femoral anteversion, tibiofemoral angle, quadriceps angle, and narvicular drop. Only the tibiofemoral angle was found to be different between the two groups. The lower limb alignment data were reported in Table A1.

Table A.1 Lower limb alignments

Muscle groups	Groups		p value
	Normal (Mean ± SD)	Hyperextension (Mean ± SD)	
Anterior pelvic tilt (degree)	12.22 ± 5.08	12.78 ± 3.59	0.707
Femoral anteversion (degree)	10.41 ± 3.89	7.65 ± 4.36	0.060
Tibiofemoral angle (degree)	11.44 ± 2.89	8.89 ± 3.66	0.026**
Quadriceps angle (degree)	27.44 ± 4.41	25.22 ± 5.72	0.201
Navicular drop (mm)	4.22 ± 3.25	5.56 ± 4.15	0.201

** Significant difference at p value < 0.05

APPENDIX H
LOWER LIMB MUSCLE STRENGTH

Muscle strength is a component contributing the postural control. Four groups of muscles were tested with hand held dynamometer for their strength. These muscles groups included knee extensor muscles, knee flexor muscles, ankle dorsiflexor muscle, and ankle plantar flexor muscles. An independent sample t-test revealed significant difference of knee extensor strength between the two groups. The mean and standard deviation of muscle strength were reported in Table A2.

Table A.2 Lower limb muscle strength

Muscle groups	Groups		p value
	Normal (Mean ± SD)	Hyperextension (Mean ± SD)	
Knee extensors (kg)	14.81 ± 3.08	18.36 ± 2.66	0.001**
Knee flexors (kg)	20.30 ± 3.25	21.62 ± 3.29	0.242
Ankle dorsiflexors (kg)	13.90 ± 3.51	15.99 ± 2.68	0.052
Ankle plantar flexors (kg)	23.91 ± 2.85	25.65 ± 3.55	0.129

** Significant difference at p value < 0.05

APPENDIX I
RAW DATA OF KNEE JOINT ANGLE OF NORMAL PARTICIPANTS

Table A.3 The mean angle (degree) of the knee joint across 2 trials during data collection of normal knee participants

Conditions/ Participants	Firm - EO	Firm - EC	Foam - EO	Foam - EC
1	3.26	2.71	0.46	0.49
2	1.03	1.25	2.65	1.47
3	4.32	6.30	4.71	6.11
4	2.65	3.74	3.50	4.11
5	-0.08	-0.78	-0.47	-0.02
6	0.68	1.08	1.46	5.24
7	5.66	6.92	6.17	6.92
8	3.38	3.74	4.69	4.79
9	-1.41	-0.67	0.36	0.49
10	3.42	2.86	1.99	2.36
11	2.82	2.62	2.62	2.97
12	-0.89	-0.72	0.11	0.08
13	3.13	3.06	2.92	3.94
14	0.90	-0.42	-0.16	1.35
15	6.97	7.28	8.69	9.41
16	0.34	0.15	0.30	-0.23
17	1.12	2.58	2.39	3.69
18	2.28	3.66	4.22	4.28

APPENDIX J

RAW DATA OF KNEE JOINT ANGLE OF HYPEREXTENDED KNEE PARTICIPANTS

Table A.4 The mean angle (degree) of the knee joint across 2 trials during data collection of hyperextended knee participants

Conditions/ Participants	Firm - EO	Firm - EC	Foam - EO	Foam - EC
1	-19.40	-19.10	-17.40	-16.70
2	-11.05	-10.20	-8.72	-9.32
3	-10.65	-9.96	-9.40	-9.42
4	-12.75	-13.00	-9.47	-7.85
5	-14.20	-14.30	-14.90	-13.50
6	-17.50	-17.15	-17.40	-17.35
7	-13.55	-14.25	-14.95	-8.75
8	-13.75	-14.75	-13.55	-12.40
9	-15.50	-19.80	-16.90	-16.20
10	-20.30	-18.15	-16.50	-16.10
11	-16.30	-16.40	-16.30	-16.25
12	-15.75	-22.40	-21.50	-20.65
13	-14.60	-15.40	-13.40	-13.25
14	-13.50	-12.75	-12.65	-12.50
15	-19.90	-20.70	-20.60	-20.35
16	-12.75	-8.96	-10.40	-10.75
17	-13.35	-16.60	-15.95	-15.90
18	-11.55	-11.35	-12.00	-11.75

VITA

Mr. Pawan Chaiparinya was born on August 6, 1986 in Nakhon Ratchasima, Thailand. He graduated with a Bachelor's degree in Physical Therapy from the faculty of Allied Health Science, Chulalongkorn University, in 2007. After his graduation, he worked as a physical therapist at Bumrungrad International Hospital for two years. In June 2010, he enrolled in a Master degree in Neurological Physical Therapy at Department of Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University.