EFFECT OF FAST ECCENTRIC STRENGTH TRAINING ON HAMSTRING MUSCLE PERFORMANCE

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Thesis
entitled

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EFFECT OF FAST ECCENTRIC STRENGTH TRAINING ON HAMSTRING MUSCLE PERFORMANCE

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ABSTRACT

The purpose of this study was to investigate the effects of fast eccentric hamstring strength training on hamstring muscle performance in healthy male subjects aged between 18 and 25 years. Thirty males were randomized into two groups (15 subjects each) a control group and a fast eccentric hamstring strength training group. Both groups were similar in age, weight and height. The devices used in this study were Biodex system III (Biodex medical systems, Shirly, NY) for strength testing, Infrared timing device (Newtest Powertimer 300-series, Finland) for sprint testing and Myometer (Lafayette Manual Muscle Test) for eccentric hamstring testing (break test). The parameters investigated were quadriceps and hamstring peak torque, eccentric hamstring torque at end range of knee extension, percentage of h/q torque ratio and sprint velocity. The training group was trained at a frequency of 3 times/week for 4 weeks. Both groups were measured three times, at the 1^{st} week, 2^{nd} week and 4^{th} week.

The results showed no significant difference between both groups for all parameters. There were no significant differences in all parameters at 2^{nd} and 4^{th} week in the control group when compared to 1^{st} week. For the training group, the peak torque and sprint velocity significantly increased ($p<0.05$) whereas no significant difference was found in the percentage of h/q ratio.

In conclusion, this study indicated that the fast eccentric hamstring strength training which consisted of 4 sets per time, 3 times a week for 4 weeks was sufficient to increase strength both for hamstring and quadriceps muscles and improve sprint velocity. The training technique did not effect the stability of the knee joint.

KEYWORDS: HAMSTRING PERFORMANCE/ ECCENTRIC STRENGTH TRAINING/ HAMSTRING TRAINING/ HAMSTRING EXERCISE

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ผลการฝึกความแข็งแรงแบบยืดยาวออกอย่างเร็วต่อความสามารถของกล้ามเนื้อ hamstring
(EFFECT OF FAST ECCENTRIC STRENGTH TRAINING ON HAMSTRING MUSCLE PERFORMANCE)

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บทคัดย่อ

การศึกษานี้มีจุดมุ่งหมายเพื่อศึกษาผลการฝึกความแข็งแรงกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) แบบยืดยาวออกอย่างเร็วต่อความสามารถของกล้ามเนื้อ hamstringในชายไทยสุขภาพดี อายุระหว่าง 18-25 ปี จำนวน 30 คน ได้รับการสุ่มแบ่งออกเป็น 2 กลุ่ม ได้แก่ กลุ่มที่ได้รับการฝึก 15 คน และกลุ่มที่ไม่ได้รับการฝึก 15 คน โดยผู้เข้าร่วมการศึกษาทั้งสองกลุ่มมีอายุ น้ำหนักและ ส่วนสูงใกล้เคียงกัน เครื่องมือที่ใช้ในการศึกษาครั้งนี้ คือ Biodex system III (Biodex medical systems, Shirly, NY) ใช้สำหรับการทดสอบความแข็งแรงกล้ามเนื้อ Infrared timing device (Newtest Powertimer 300-series, Finland) ใช้สำหรับการทดสอบความเร็วในการวิ่ง และ Myometer (Lafayette Manual Muscle Test) ใช้สำหรับการทดสอบความแข็งแรงแบบยืดยาวออกของกล้ามเนื้อ hamstring (break test) ตัวแปรที่ใช้ในการทดสอบคือ peak torque ของกล้ามเนื้อ quadriceps และ hamstring, eccentric hamstring torque ณ ช่วงสุดท้ายของการเหยียดเข่า, percentage of h/q torque ratio และ sprint velocity กลุ่มฝึกจะได้รับการฝึกสัปดาห์ละ 3 วัน เป็นเวลา 4 สัปดาห์ โดยทั้ง 2 กลุ่มจะได้รับการทดสอบในสัปดาห์แรก สัปดาห์ที่ 2 และ สัปดาห์ที่ 4

ผลการศึกษาแสดงให้เห็นว่า ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติของทุกตัวแปรระหว่างกลุ่มควบคุมและกลุ่มฝึก สำหรับกลุ่มควบคุมไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติของทุกตัวแปรในสัปดาห์ที่ 2 และสัปดาห์ที่ 4 เมื่อเทียบกับสัปดาห์ที่ 1 สำหรับกลุ่มฝึกค่า peak torque และ sprint velocity มีการเพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติ ขณะที่ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติของค่าร้อยละของ h/q ratio

โดยสรุปการศึกษานี้แสดงให้เห็นว่าการฝึกความแข็งแรงกล้ามเนื้อ hamstring แบบยืดยาวออกอย่างเร็ว โดยโปรแกรมการฝึก 4 ชุด ต่อครั้ง 3 ครั้ง/สัปดาห์ เป็นเวลา 4 สัปดาห์สามารถเพิ่มความแข็งแรงของกล้ามเนื้อทั้งกล้ามเนื้อเหยียดและงอเข่าและสามารถพัฒนาความเร็วในการวิ่งให้ดีขึ้นได้ในขณะที่ไม่มีผลต่อความมั่นคงของข้อเข่า

135 หน้า.

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LIST OF ABBREVIATIONS

cm	=	centimeters (s)
Con	=	concentric
DOMS	=	delayed onset muscle soreness
Ecc	=	eccentric
EMG	=	electromyography
KE	=	knee extensor
KF	=	knee flexor
kg	=	kilogram (s)
h/q ratio	=	hamstring/quadriceps torque ratio
Ham/Quad Con	=	Hamstring concentric to quadriceps concentric ratio
min	=	minutes
MMT	=	manual muscle test
m/s	=	meters/second
Nm	=	Newton meter
PT	=	peak torque
°/sec	=	degrees/second
VAS	=	visual analog scale
yrs	=	years

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CHAPTER I
INTRODUCTION

Hamstring injuries are common problem in many sports which require rapid acceleration and maximum speed in running such as soccer (12% of all injuries) (1), basketball (6% of all injuries) (2), Australian Rules football (16% of all injuries) (3), cricket (11% of all injuries) (3, 4), hurling (5), rugby (6%-15% of all injuries) (6-10), and athletics especially in sprinters (8, 11). In addition, these injuries are leading to significant pain, disability, and time off sports participation. Persistent symptoms, slow healing, and a high rate of recurrence make hamstring injuries a frustrating occurrence for athletes, coaches, doctors and physiotherapists (12).

There are many factors influencing hamstring injury. Major factors of this injury include previous hamstring injuries (13), inadequate flexibility (14-16), improper warm-up (17), excessive fatigue (1, 9, 18, 19), hamstring and quadriceps muscles imbalance or hamstring weakness especially weakness of eccentric muscle strength (16, 20, 21).

The hamstring muscle is the biarticular muscle group which flexes the knee and extends the hip. Most sprinter have hamstring injuries in the later part of the swing phase and early stance (22). In running, hamstring function primarily is eccentric contraction to decelerate forward movement of the foot and the leg by decelerating knee extension in the later part of swing phase. The muscle develops tension while lengthening (23, 24).

When the velocity of muscle contraction is increased, the maximum eccentric force increases (25). The sprinting velocity is higher than running velocity. Therefore, sprinting has the shorten deceleration phase, requiring a higher eccentric activation of

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the hamstring to compensate for the forward momentum of the leg. This could be the cause of tearing in muscle-tendon unit (20). However, hamstring injury may occur during stance phase while the hamstring presumably shorten concentric contraction to assist extension of the hip joint. It means that the hamstring must change from functioning eccentric contraction to concentric contraction by becoming an active extensor of the hip joint which could induce a concentric contraction injury (1, 12). This indicates that during rapid change from eccentric to concentric contraction, the muscle is most vulnerable to injury (26).

The hamstring injury risk is potentially exacerbated by three other factors (14, 20, 27, 28). The first, the hamstring muscle is two joint muscles. It means that the hamstring lengthens over two points simultaneously in various stages of sprinting. Therefore, the hamstring has a greater change in length compare to muscles crossing only one joint and place in a position of increased passive tension. The increased passive tension may lead to an overstretch injury.

The second, hamstring muscles contract eccentrically. Functional activities in exercise require both concentric and eccentric contractions. Eccentric contractions are common in the deceleration phase of activity. Eccentric contraction is one factor in hamstring injuries because muscle forces can be higher during lengthening. This force is increased by the passive connective tissue element. The higher specific tensions produced in eccentric exercise lead to myofiber overload injury.

The third, the hamstring muscles have high proportion of “fast twitch” muscle fiber or Type II fibers (29, 30). These fast-twitch muscle fibers can create greater speed of contraction which involve in higher intensity and force production, and may predispose hamstring muscle action to injury. Most of the hamstring function involved with running and sprinting is eccentric, so the hamstring can generate high intrinsic force production (31). The high levels of intrinsic tension of the hamstring and extrinsic stretch involved in length changes over two joints may lead to injury during high intensity sprinting.

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Injury prevention is the best for hamstring injuries management and several techniques must be used such as increase flexibility, warm up before exercise (20) and increase hamstring endurance (32). The hamstring strength training is one way to prevent hamstring injury especially eccentric hamstring strength training. Askling in 2003 (29) investigated effects of strength training with eccentric overload. The results showed that there were significant increases in strength and speed in the training group. In addition, the training groups (3/15) had the occurrence of the hamstring strain injuries lower than in the control group (10/15).

There are several factors influencing muscle strength including length-tension relationship of the muscle at the time of contraction, recruitment of motor unit, cross section size of the muscle, speed of contraction, level of fitness and motivation and type of muscle contraction. Type of muscle contraction is the one of essential parameter influences to muscle strength because the magnitude of mechanical, metabolic and neural stimuli vary referring to the type of muscle contraction (33-36).

Muscle contraction can be defined as static and dynamic exercise. Static exercise is an isometric exercise, while dynamic exercise is an isotonic or isokinetic exercise that can be divided into concentric and eccentric exercise (33).

There are many differences between concentric and eccentric muscle contraction in terms of biomechanics and physiology, which lead to the differences in increasing muscle strength (37). From the literature review, eccentric exercise can improve eccentric strength more than concentric exercise (38, 39).

Garrett in 1990 (20) described benefits of eccentric training that muscle acts as energy absorbers in preventing injury to muscles and to associated bones and joints. Eccentric strength can improve a muscle’s ability to withstand force and strain without failing by absorbed energy from withstand force and strain (20).

Hamstring strength training has several ways to train both with and without equipment (28, 39). In general, athletes used a leg-curl machine (38) and isokinetic

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device (40) which these equipments are more expensive and large. Moreover, these special equipments could not train at actual movement velocity for sport specific tasks but muscles can adapt to training in a very specific manner. Similar limitations exist for eccentric muscle action as knee flexors can contract eccentrically at about 1,000 degrees/second during sprinting (41).

However, Nordic exercise is one choice in eccentric hamstring strength training but this exercise can not be performed near end range of knee extension at high velocity which hamstring injury mostly occurs. Moreover, this exercise is slow eccentric hamstring exercise.

From the literature, there are only few studies on the eccentric hamstring strength training especially near end range of knee extension and hip flexion which is similar to late swing phase in running (28, 38). There was only the study of Stanton and Purdam in 1989 which related to actual movement velocity (28). Their study indicated a valid method of preventing and rehabilitating the hamstring injury in terms of the positions at risk while sprinting. However, it was only a pilot study with one subject who was measured peak torque values by Photosonics high speed camera.

If hamstring strength training is essential factor for prevent hamstring injury, how to build eccentric hamstring strength effectively is the question. The athletes need to develop hamstring strength in functional way, comfortable and without special equipment. Therefore, the aim of the present study is to investigate the effectiveness of fast eccentric hamstring strength training which replicates position of late swing phase of sprinting on hamstring muscle performance.

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Purposes of the Study

General Objective

The aim of this study was to investigate the effects of fast eccentric hamstring strength training on hamstring muscle performance.

Specific Objectives

1. To compare peak torque both concentric and eccentric contraction of quadriceps and hamstring muscles among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.
2. To compare eccentric hamstring torque at end range of knee extension among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.
3. To compare hamstring to quadriceps ratio (con/con) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.
4. To compare hamstring to quadriceps ratio (ecc/ecc) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.
5. To compare hamstring to quadriceps ratio (ecc/con) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.
6. To compare sprint velocity between 1st and 4th week in fast eccentric hamstring strength training and control groups.

Parameters

1. Peak torque (Nm) of quadriceps and hamstring muscles
2. Eccentric hamstring torque at end range of knee extension (Nm)
3. Percentage of h/q torque ratio (%)
4. Sprint velocity (m/s)

Hypotheses of the Study

1. There were significant differences in peak torque both concentric and eccentric contraction of quadriceps and hamstring muscles among 1st, 2nd and 4th week in fast eccentric hamstring strength training group but not significant differences in control group.

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2. There were significant differences in eccentric hamstring torque at end range of knee extension among 1st, 2nd and 4th week in fast eccentric hamstring strength training group but not significant differences in control group.

3. There were no significant differences in hamstring to quadriceps ratio (con/con) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.

4. There were no significant differences in hamstring to quadriceps ratio (ecc/ecc) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.

5. There were no significant differences in hamstring to quadriceps ratio (ecc/con) among 1st, 2nd and 4th week in fast eccentric hamstring strength training and control groups.

6. There was significant difference in sprint velocity between 1st and 4th week in fast eccentric hamstring strength training group but not significant differences in control group.

Scope of the Study

This study focused on the effects of eccentric hamstring strength training in male subjects aged between 18 and 25 years. The peak torque of quadriceps and hamstring muscle, eccentric hamstring torque at end range of knee extension, and hamstring to quadriceps ratio were measured at the 1st, 2nd and 4th week in training. Sprint velocity was also measured at the 1st and 4th week.

Advantages of the Study

The results of this study would be a guideline for planning the training program to improve hamstring muscle performance.

This training technique is a simple technique, without special equipment and it is similar to functional movement. Therefore, the training technique used in this study could be applied in clinic.

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CHAPTER II
LITERATURE REVIEW

2.1 Principles of Training

The principles of training have been developed mainly as a result of trial and error. In current's world of sports, it appears that running must be bolstered by scientific inquiry if one wishes to achieve top performance. There are several numbers of laws of training such as overload, reversibility, and specificity (42).

2.1.1 Overload

The training principle application called overload requires insight into how the physiological processes of adaptation proceed. Overload occurs when homeostasis is disturbed. The term 'overload' means that the stimulus requires greater physical effort than the body's momentary capacity for carrying a load (42). Overload training must be optimized by alternating a heavy training session with sufficient period of rest. Because the state of equilibrium has been disturbed, many kinds of recovery process are initiated. The time required for physiological processes to recover will determine when the next session stimulus can be applied. One understands how the ability to carry a load develops is important, so that the degree of physical exercise can be adapted accordingly. The training principle called 'reversibility' is also on important role (42-44).

2.1.2 Reversibility

The principle of training called reversibility mostly leads to a negative connotation because it is associated with injury. Reversibility of functional changes can improve performance. As a result, training will revert to their original level in the absence of training stimuli (42). However, the current theory of training, reversibility is applied with full awareness when setting up a training program. The modern training set-up, the situation is quite different. The program of training consists of a number of periods of 4-12 weeks, in each of which a certain basic motor property is

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emphasized. The factors that influence speed of reversibility which are the ages of the athlete, the type of basic motor property being trained and the length of the training period. The basic property of strength, when an increased level of strength is the result of a long period of training, it will only decline slowly when training is stopped. In the contrast, rapid decline mostly occurs in the strength from short-term power training (42, 45).

During an intense period of strength training, the capacity to perform declines temporarily. It is the result of accumulated fatigue and the time is needed to adapt to the strength stimuli applied. Moreover, losing the effects of training depends also on the type of basic motor property concerned. Anaerobic endurance diminishes rapidly, while velocity maximum strength and aerobic endurance decline less quickly. Aerobic endurance is prominent in the list of consistent training effect (42, 43, 45).

2.1.3 Specificity

The specificity of training is one factor which is important in the training. To be effective and to achieve a higher adaptation, training specificity should be developed at specificity of the type of strength, dominant in a given sport or event (45). All adaptations to training are specific to the 1) muscle actions involved, 2) speed of movement, 3) range of motion, 4) muscle groups trained, 5) energy systems involved, and 6) intensity and volume of training (44).

The adaptation occurs only in muscles that have been stressed. The degree of specificity is now made equal to the extent to which transfers of training take place. In other words how can a specific training exercise contribute to increasing an individual's level of performance? (42). However, there is some carryover of training effect, but the most effective resistance training programs are those that are designed to target specific training goal (44).

2.1.4 Factors Influencing Muscle Strength

2.1.4.1 The Cross Sectional Area

The large muscles are stronger than small muscles. Inactivity decreases muscle size (atrophy), whereas activity will increase muscle hypertrophy (46).

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In training, overload stimulates protein synthesis and slows degradation in the muscle that leads to increase cross sectional area of the muscle (47). There has been presented about the linear relation between the larger cross sectional area of a muscle and the greater the potential for production of muscle force (48, 49).

In the Clinic, muscle size is determined by circumference measurement. However, circumference measures lack specificity for muscle size because skin, fat, fluid, vasculature, bone and other tissues are included (46). More precise measures on muscle size are muscle biopsy, magnetic resonance imaging (MRI), and computerized tomography (CT scan). These images, muscle cross-sectional area (CSA) can be calculated. Muscle mass is the cross-sectional area of the muscle and shows number of muscle which is available to produce strength (46).

Some authors argued that only cross sectional area did not present muscular force. There are many factors effecting the muscular force such as number of muscle fibers engaged during maximal force output and fiber types composition (50).

2.1.4.2 Length-tension Relationship of the Muscle

Length of muscle is one factor influence force production of muscle. When muscle is elongated, the total tension is greater because the total tension composes of elastic tension and contractile. Most of 120% to 130% resting length can produce the greatest total tension. There is no contractile tension if length of the muscle is shorter than about 50% resting length (51).

Hill in 1953 (52) concluded that when length of muscle increased 3-4% from resting length, an increase of the force equaled to the maximal isometric value (cited in Cavagna, 1968). Gordon et al in 1966 (53) studied in isolated skeletal animal muscle and reported that if muscle was in a physiological length, it could present a greater force. It has been concluded that the contractile tension is maximum when the muscle is at its resting length. If the muscle length changes, either shorter or longer, force is reduced (54).

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In 1989, Worrell et al (55) examined the force production in hamstring muscle. When muscles were placed in the shortened length, 10º of hip extension; actin-myosin cross-bridging was not efficient to produce force. In contrast, the position of hip flexion changed more lengthen, 110º of hip flexion, the greater force production of hamstring was generated. They concluded that hamstring force production was associated to length-tension relationship. Moreover, many studies reported that differences in patient or subject exercise positions could produce a different force production because of length-tension curve (33).

2.1.4.3 Recruitment of Motor Units

Information of motor units in human muscle can be obtained by recording the electromyography (EMG) activity. Electromyography is a common method to assess neural adaptation. The changing motor unit activation happened in the muscle after training exercise (56-58).

When the force or load is applied to the muscle, the numbers of motor units are recruited according to the size principle. The size principle is explained that low threshold motor units are first recruited. If the load or force is still increased, the higher threshold motor units are activated (59). Smidt and Rogers in 1982 (60) founded that strength of muscle was controlled by three neural mechanism: 1) the numbers of motor units activated, 2) firing frequency of motor unit and 3) the firing pattern of the motor units.

The majority mechanism to activate motor unit to produce a maximum muscle force in the short period of time was synchronization. Moreover, enhanced electromyography activity during maximal contraction following resistance training resulted in recruitment of an increased number of motor units and an increased firing rate of each motor unit (61).

Cavagna et al in 1968 (52) studied in a single muscle fiber. They suggested that the force-generating capability was occurred in cross-bridge interacting and recovery as elastic energy.

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Moreover, Colliader and Tesch in 1990 (62) concluded that resistance training can increase the recruitment of motor units during maximal voluntary contraction.

2.1.4.4 Types of Muscle Contraction

The muscles can produce force in various patterns. Patterns of static, concentric and eccentric will occur depending on the relationship between load and total muscle tension (60, 63). When the muscular force and external force are unequal, the external force is either greater or less than muscular force. When the muscular force is greater than external force, muscle will perform a concentric contraction to resist the external force. In the contrast, if the muscular force is lower than external force, muscle will perform an eccentric contraction to resist the external force (63).

A concentric contraction and an eccentric contraction are different in several characteristic such as generating of force, force-velocity relationship, recruitment of motor unit (25).

Friden in 1983 (64) described that eccentric training may improve ability to store elastic energy and coordination as well as the reorganization of the contractile part of muscle fibers. Whereas Ellenbecker in 1988 (65) reported that generated greater eccentric strength was not only due to the contractile tissue but it increased stiffness in series elastic component and sacrolemma (66).

The differences in force velocity curve of concentric and eccentric are caused by differences in the binding and interaction of actin and myosin within the muscle sarcomere (33). Higher tensions are produced for the same amount of motor unit activity with quick eccentric contraction. The series elastic component (SEC) is placed under greater stress than with concentric contraction. Hence, eccentric contraction is more likely to produce pathological forces within the SEC.

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At the same velocity, an eccentric contraction produced a greater maximum force than concentric contraction (67, 68). It has two reasons that relate to greater eccentric force production. The first, the eccentric force production results mainly from the activation of elastic component whereas concentric force production results mainly from the activation of contractile component. Secondly, the mechanisms of eccentric and concentric contraction are different. Eccentric can make a continuous formation and breakage of the actin-myosin crossbridges before the ATP release (69). Moreover, In 1988, Moritani (70) concluded that although the eccentric force is greater than the concentric, the eccentric contraction recruits less motor units compared with concentric contraction because less contractile elements are activated during eccentric contraction.

In concentric contraction, EMG activity and torque decrease at faster contraction velocities, because the muscle does not have sufficient duration to develop peak force (33). The EMG activity reduces at slow concentric and at fast eccentric tests due to the central nervous system is not fully activated (69). It is a result of inhibition of feedback from joint receptors, free nerve endings in the muscle, cutaneous, pain receptors and Golgi tendon organs. Inhibition form feedback has been suggested to maintain muscle tension within “safe” limits (63, 71).

In 1997, Takarada and Hirano suggested that the prestretch induced improvement of an intrinsic force generating capability of the agonist muscle caused the enhancement of power output (72).

2.1.4.5 Speed of Contraction

When the velocity of muscle contraction is increased, the maximum eccentric force increases whereas concentric force decreases. On the other hand, if the velocity of muscle contraction is decreased, the maximum eccentric force decreases but concentric force increases (25).

In 1989, Colliander compared eccentric and concentric torque of quadriceps and hamstring muscles in females and males. They founded that, with

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increasing angular velocity, quadriceps concentric and hamstring concentric peak torque were reduced. In each angular velocity, eccentric peak torque ordinarily was higher than concentric peak torque and quadriceps peak torque was higher than hamstring peak torque (73).

Duncan in 1989 (37) studied mode and speed specificity of eccentric and concentric exercise training. Duncan concluded that eccentric force significantly increased at the higher speed because a majority of stretching occurred in elastic components rather than increasing electrical activity of contractile elements.

2.1.4.6 Age

It has been demonstrated that increasing age leads to a reduction in muscle strength (74, 75). The age-associated loss of muscle strength starts to occur around the fifth decade. There is a 20% reduction in strength from age 50 to 65 years, with further reductions with age. The reduction includes both static (isometric) and dynamic (isokinetic) testing (46).

The reduction of muscle mass is one explanation for age-associated loss of strength. Cross-sectional area of the muscle mass declines by approximately 40% from age 20 to 80 years (76-78). This decline is related to muscle atrophy (injury or disuse) or through neurological changes. The number of muscle fiber both types I and type II fibers declines. Type II fibers have lost more than type I, resulting in a greater proportion of type I to type II fibers (79). Moreover, there is a 26% reduction in the size of type II fibers (76), resulting in a decrease in muscle volume. Moreover, the speed of muscle contraction does not decrease unless significant muscle fiber is lost. The overall loss of muscle fibers results in less strength.

The consequence of a decrease in force generating capacity was an alteration in the neuromuscular systems; a loss of motor unit and a reduction in muscle mass (80). Highgenboten in 1988 (81) compared knee hamstring/quadriceps ratio for both concentric and eccentric contraction in males and females age between 15 and 34 years. The kinetic communicator was used to measure concentric and

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eccentric torque. The results revealed that younger subjects aged 15 to 24 years of both females and males produced a greater concentric force than older subjects aged between 25 and 34 years.

Frontera in 1991 (82) showed that maximum concentric strength inclined to peak between age 20 and 30 years and still high, as far as, 50 years of age in men and after that a rate of reduction would decrease 12-15% per decade.

Jubrias et al in 1997 (77) states that, with increasing age, change in the composition of the muscle increases. People 65 to 80 years old have almost twice as much intramuscular, noncontractile tissue (such as fat) as those aged 23 to 57. This accounts loss of strength approximately 20%. Furthermore, there is a decline in the capacity of muscle to generate strength per unit of muscle area. This loss has been estimated at 10% to 37% less in older adults than younger adults. Jubrias et al explained that the loss in the capacity of muscle to generate strength per unit of muscle area is due to recruitment different fiber, cellular properties of the muscle fibers, or something in the contractile mechanism that has not been determined.

2.1.4.7 Motivation

Motivation also influences on the force production. Verbal encouragement and visual feedback are the types of motivation that stimulate the subject to produce a maximum voluntary contraction during testing and training (83). Verbal encouragement also has a dramatic effect to stimulate subject to exert a maximum force during any kinds of strength performance (83).

Some studies demonstrated that visual feedback can improved the moment output of both knee flexors and extensors at slow angular velocities (84, 85), whereas there are conflicting results on the influence of visual feedback on moment output at fast angular velocities (84-86). In 1984, Figoni and Morris (85) found that there was no effect of visual feedback during performing the test at the 180º/sec and 300º/sec because of a short duration for central nervous system to integrate the visual information. However, Kellis and Baltzopoulos in 1996 (87)

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showed that visual feedback could motivate subject to generate maximum muscular moment during isokinetic eccentric contraction at the 30º/sec and 150º/sec. Several studies (84-86) reported that when subjects watched the visual display during isokinetic test at slow angular velocity, they produced greater level of peak torque of the quadriceps and/or hamstring muscles.

2.2 Technique of Eccentric Hamstring Training

Eccentric contraction is an activation or contraction of the muscle at the same time as muscle elongates. Eccentric exercise is carried out when a negative work is performed. Several studies investigated effect of eccentric hamstring training.

Stanton et al in 1989 (28) described the role of eccentric exercise in hamstring injuries in sprinting. The eccentric muscle action is capable of producing very high forces within the series elastic component (SEC) of the hamstring in late swing phase of sprinting. Theses high forces have been shown to be related to hamstring injury. The utilization of eccentric exercise training regimens can prevent this injury by strengthening the SEC, resulting in a musculotendinous structure theoretically capable of both generating and withstanding higher eccentric and concentric forces. Stanton et al indicated that this exercise was a valid method of preventing and rehabilitating the hamstring injury in terms of the positions at risk while sprinting. One male athlete was positioned prone over a couch such that the thigh was supported on the couch and the torso was supported by the arms on the floor. This gave a hip and knee angle of approximately 30º and 90º respectively (figure 2.1). Following a start signal, the athlete extends the knee and decelerates at approximately 20º-30º via an eccentric hamstring contraction, followed by a quick concentric contraction (figure 2.2). The athlete performs the exercise as described previously with no weight and with weights of 0.6 kg and 2.5 kg affixed to the lower leg just above the malleoli. The results gave peak torque values of between 225 and 300 Nm during late eccentric/early concentric knee flexion at angular velocities close to 1000º/sec.

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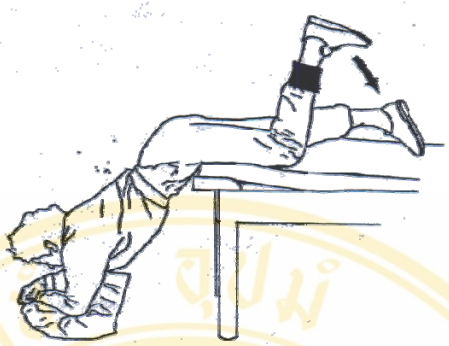

Figure 2.1 "Catch exercise".

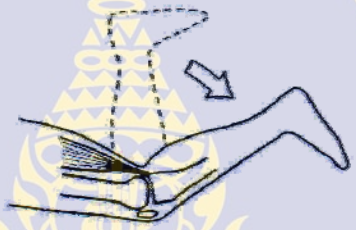

Figure 2.2 "Catch exercise".

Several studies suggested that the training at a specific velocity improved strength mainly at that velocity. As velocity deviates from the trained velocity, the less effective training will be (88-90). In the opposites, Ryan et al in 1991 (40) investigated velocity specific and mode specific effects of eccentric isokinetic training of the hamstring. The average force of three concentric and eccentric hamstring contractions was evaluated pre and post training at three increasing velocities: 60º/sec, 120º/sec, and 180º/sec. Training group was trained three times a week for six weeks with 15 maximal eccentric isokinetic contractions at 120º/sec. The results showed that the exercise group increased significantly ($p < 0.0083$) in eccentric force at all tested speeds and increased significantly ($p < 0.0083$) in concentric force at 120º/sec and 180º/sec. The eccentric isokinetic training of hamstring at 120º/sec was not speed specificity at 120ºsec $\pm$ 60º/sec and is not mode specific at 120º and 180º/sec.

However, isokinetic training and testing have limitation in velocity of testing and training. For example, MacDougall and colleagues (41) reviewed the

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characteristics of various isokinetic dynamometers. They reported that the concentric velocity for 80% of the machines was less than 450º/sec. Biodex system III in isokinetic eccentric testing mode had a velocity less than 300º/sec. Furthermore, there is lack of research relating training velocity to actual movement velocity for sport specific tasks.

Kaminski et al in 1998 (91) compared hamstring muscle strength gain between concentric and eccentric hamstring strength training. Subjects were randomly assigned to 1 of 3 treatment groups: eccentric training, concentric training, or control. They started by performing pretest 1 RM weight values on the Cybex isotonic prone hamstring curl for all subjects and used isokinetic for measure maximum of hamstring muscle in concentric and eccentric strength. Subjects in the training groups were trained 2 days per week for 6 weeks (12 sessions). In the concentric training group, subjects performed a weight equal to 80% of their 1RM value while subjects in the eccentric training group also performed a weight in concentric load at 40% of the 1RM value and eccentric load was placed at 100% of the 1RM value. After 6 weeks of training, all subjects returned for 1RM and isokinetic post testing. It was found that subjects in concentric group improved 19%, while the eccentric group improved 29%. The control group did not show any significant change over the 6 weeks. In addition, there were improvements in eccentric isokinetic peak torque/ body weight ratios at both 60º/sec and 180º/sec from pre-testing to post-testing in the eccentric training group only.

Askling et al in 2003 (29) study strength training programmed for the hamstring muscle group. They emphasized eccentric overloading that could affect the occurrence and severity of hamstring injuries during the subsequent competition season in elite male soccer players. Thirty players from two of the best premier-league division team in Sweden were divided into two groups; training and control groups. Both groups followed the same protocol; exception the training group was received additional specific hamstring training. Training group performed 1-2 times a week for 10 weeks by using a special device (Yo Yo^{TM} flywheel ergometer) aiming at specific eccentric overloading of the hamstring. Isokinetic hamstring strength and maximal

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running speed were measured in both groups before and after the training period. Moreover, all hamstring injuries were registered during the total observational period of 10 months. The results showed that there were significant increases in strength and speed in the training group. In addition, the occurrence of the hamstring strain injuries in the training groups (3/15) was lower than that in the control group (10/15).

Mjolsns et al in 2004 (39) compared eccentric and concentric hamstring strength training in well-trained soccer players. They investigated the effects of a 10-week training program with two different exercises; traditional hamstring curl (concentric training) and Nordic hamstring (focusing on the eccentric phase). The maximal torque was measured by a Cybex dynamometer before and after the training period. It was found that in the Nordic hamstring group, there was an 11% increase in eccentric hamstring torque measured at 60º/sec, and 7% increase in isometric hamstring strength at 90º, 60º and 30º of knee flexion but there was no effect on concentric quadriceps strength. There was a significant increase in the hamstring to quadriceps ratio from 0.89 $\pm$ 0.12 to 0.90 $\pm$ 0.17 Nm (11%) in the Nordic hamstring group. No change in the hamstring curl group.

Clark et al in 2005 (92) studied the effects of eccentric hamstring strength training on dynamic jumping performance and isokinetic strength parameters (a pilot study). Nine athletic male subjects performed eccentric training by Nordic hamstring exercise twice a week for four weeks. Isokinetic testing and vertical jump heights were assessed. The result showed significant increase in vertical jump height ($p = 0.04$), a significant decrease in quadriceps peak torque ($p = 0.01$), a significant reduction in hamstring position of peak torque from full knee extension and a significant hamstring position of peak torque difference between limb (dominant = 33.8 $\pm$ 9.5, nondominant = 24.9 $\pm$ 6.5, $p = 0.01$).

2.3 Neural Adaptation after Training

Training effects are related with formation of new coordination mechanisms at various levels of the central nervous system, including formation of new system of conditioned reflexes. Mechanisms of coordination should have a specific dependence

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on the sports event and on the training exercises used. Training adaptation entails developing the ability to recruit all motor units when needed to perform a strong contraction (93).

Mechanisms of neural adaptation in training are as follows (94):

1. Increased activation of agonists.
2. Selective recruitment of motor units within agonists.
3. Selective activation of agonists within a muscle group.
4. Co-contraction of antagonists.

These manifestations are essential not only to improve muscular strength and power, but also improve speed of movement and endurance.

The early changes in voluntary strength can be accounted for largely by neural factors, with a gradual increase contribution of hypertrophy factors as the training proceeds (94). There were difference in neural and muscle adaptation time (95)

Sale in 1983 found that an increase in strength after training resulted from voluntary strength and reflex potentiation. The reflex potentiation increased. It meant that the trained subjects had more readily recruit additional motor units and/or released the active motor unit with higher frequency. The excitability of alpha motor neurons together with motor unit synchronization was a major stimulus for hypertrophic factors in addition to increase muscular force [cited in Komi, 1986(96)]

In 1989, Narici et al (97) compared the time course of changes in cross sectional area, neural activation and force during strength training and detraining in quadriceps muscle. They concluded that time course of changes during training and detraining was the same time course. Moreover, they mentioned that 40% of quadriceps force production was due to an increase in cross sectional area whereas increased neural activation and change in architecture of muscle were 60% of force production.

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In 1994, Ploutz et al (98) concluded that strength increasing in early phase of resistance training was less related to muscle hypertrophy. The results were presented that only increase in cross sectional area could not improve the strength of the trained leg. The authors confirmed the result that neuromuscular activation was changed after training. The results were similar to other studies (56, 62, 96). They described that the physiological outcome of using less muscle to lift a load during training led to increased stress per unit area of the muscle that gradually evoked muscle hypertrophy. It took time at least 6-8 weeks to alter the cross sectional area (98). Staron in 1994 (99) found that in early 2 weeks of training, the fast fiber type conversions of type IIa to IIb should provide the gaining in muscle strength. Moreover, Staron indicated that skeletal muscle adaptation happened together with neural adaptation. In the detraining phase, the reduction in maximal neural activity happened prior to a gradually reducing contribution of muscle hypertrophy.

In 1999, Akima (100) found that increasing strength after 2 weeks of resistance training was mostly primarily caused by improved motor unit recruitment and contractile activation.

2.4 Muscle Soreness

Muscle soreness may occur after an acute resistance training session. Eccentric training mostly precipitates delayed onset muscle soreness (DOMS), especially in untrained persons after one to three days. The exact mechanisms of muscle soreness remain speculative. Several studies demonstrate that eccentric contraction may damage the basic ultrastructure of the muscle cell. The focus point of the damage is the Z-disk, a structure component that anchors the contractile protein actin (95).

The loss of structural integrity of the Z-disks may be the stimulus leading to the associated symptoms. DOMS have characterized by tenderness, local muscle stiffness, local edema, limited range of motion caused by edema, and pain, which varies from low-grade ache to severe pain (95). Moreover, the musculotendinous junction usually is the maximum point of tenderness. The heterogeneity of sarcomere

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length is also progressively increased after muscle injuries which has been found after eccentric exercises in the frog (101).

Many direct evidences which show the structural abnormalities after exercise, especially eccentric exercise including sarcolemmal disruption, transverse tubule system dilation, myofibrillar components distortion, sarcoplasmic reticulum fragmentation, cytoskeletal damaging, extracellular myofiber matrix changing, and mitochondria swollen (64). Moreover, when eccentric muscle contraction occurred, the actin and myosin cross-bridge were separated by mechanism of elongation of some sarcomeres rather than the use of an ATP-dependent detachment (102).

Mostly when subject feels pain or soreness, they would have protective mechanism not to produce voluntarily maximal force. However, soreness cannot be used to describe for reduction in strength because during strength is still decrease, the symptom of soreness does not appear (103). For example, Hasson et al (104) reported declined in isometric force of 33.4 percent and 12.1 percent decreases in peak isokinetic torque after high speed voluntary muscle contractions. Nevertheless, post exercise which strength of muscle decrease, it may be due to muscle fatigue or a combination both of muscle fatigue and muscle damage in addition to alteration of neural activation pattern (105, 106). Muscles soreness usually occurred within 24-48 hours after exercise and may last up to 10 days. Muscle damage may be showed an indirect in soreness and muscle stiffness (105, 107). Smith et al in 1991 (108) described an order of events to produce muscle soreness. Firstly, the damage of tissue is occurred. After 48 hours post exercise, numbers of monocytes peak at the site of injury which is the time of maximal soreness perception. These monocytes synthesize large amount of prostaglandins (PGE_2). Prostaglandin stimulates the afferent nerve ending in muscle that causes the sensation of soreness.

Strength loss, pain, muscle tenderness, and creatine kinase activity were significantly greater in the stiff compared with the compliant subjects on the days after eccentric exercise

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Eccentric training is associated with muscle pain and soreness and lead to the inhibition of strength improvement at the initial stage of eccentric training (68, 105). However, an adaptation response may recover rapidly (103, 107, 109). Some studies showed that delayed muscle soreness was eliminated by optimal warm up prior to exercise for example: stretching and cycle ergometer (34, 62, 109). In addition, eccentric exercise may reduce the post-exercise maximal muscular strength by 30% (39, 110).

2.5 Hamstring Injuries

Muscle injuries are general problem among athletes and in sports such as American football, football and sprint running. The injuries can occur in all muscles, but the most common site of muscle strain injury, especially in high-speed athletes, is the hamstring.

Hamstring injuries are common soft tissue injury in many sports such as soccer (12% of all injuries) (1), basketball (6% of all injuries) (2), Australian Rules football (16% of all injuries) (3), cricket (11% of all injuries) (3, 4), hurling (5), rugby (6%-15% of all injuries) (6-10), and athletics especially in sprinters (8, 11). In addition, pain, disability, time off sports, and high rate of recurrence frustrate for athletes, coaches, treating doctors and physiotherapists (12). They are often serious, causing long rehabilitation times and a distinct proneness to reinjury (2 3). Recent evidence suggests that hamstring strains can be separated at least two types; 1) during high speed running such as in sprinting (111) and football (1) and 2) during stretching movements carried out to an extreme range of motion (112).

Mechanism of hamstring injury in late swing phase of sprint running is eccentric contraction to decelerate forward progression of the tibia during the swing phase of gait. Eccentric contraction is generating intrinsic forces within the muscle at high velocity muscle contraction more than concentric contraction. Therefore, eccentric contraction at high velocity muscle contraction predisposes to injury higher than concentric contraction (20). In addition, hamstring injury may occur in stance phase of sprint running (22).

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The major factors of hamstring injury include previous hamstring injuries (13), inadequate flexibility (14-16), improper warm-up (17), excessive fatigue (1, 9, 18, 19), hamstring and quadriceps muscles imbalance or hamstring muscle weakness especially weakness of eccentric muscle strength (16, 20, 21). Jonhagen et al in 1994 (16) found that sprinters with a previous hamstring injury had significantly tighter hamstring than uninjured sprinters had. The uninjured sprinters had significantly higher eccentric hamstring torques at all angular velocities. In addition, they also had significantly higher concentric quadriceps and hamstring torques at 30º/sec but not at higher velocities. Orchard et al in 1997 (21) reported that injured hamstring muscles were weaker than the opposite leg in absolute values and hamstring-to-quadriceps muscle ratios. The result showed that hamstring muscle injury was significantly associated with a low hamstring to quadriceps peak torque ratio at 60 deg/sec on the injured side and a low hamstring muscle side to side peak torque ratio at 60 deg/sec.

Hamstring strength training is one essential factor that influences to prevent hamstring injury. Askling et al in 2003 demonstrated that the number of hamstring injuries decreased significantly after hamstring training of both concentric and eccentric actions (29).

2.6 Measurement of Muscle Performance

The objective of measurement of muscle performance are 1) Infer a patient' s functional status, 2) Describe disease and disabilities, and 3) Assess the effects of the treatment (113).

2.6.1 Muscle strength

The term "muscular strength" refers to a measure ability to exert maximal muscular force, either statically or dynamically.

Muscle strength has been associated with functional performance work productivity and efficiency of movement (114).

There are three different methods for muscle strength measurement : isometric, isotonic and isokinetic (115). All methods have determined the amount of external load that is overcome as the muscle attempts to contract against resistance (116).

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2.6.1.1 Isometric strength testing

Isometric strength is the section of muscle against an immovable resistance at a specific joint angle (116).

The measurement devices of isometric strength testing are cable tensiometer, hand-held dynamometer, back lift dynamometer, hand grip, and force transducer (83, 113). Hand-held dynamometer provides a quantitative measurement of muscle strength and has been shown to be more sensitive to change than manual muscle testing (117, 118). The hand-held dynamometer is a portable device which uses to objectively measure muscle force. Moreover, it is economical, easy to use and space-saving (119).

There are 2 techniques for measurement in HHD. For a “make” test, the examiner stabilizes the myometer in fixed position and the subject exerts maximal isometric contraction against the myometer for 3 to 5 seconds. The “break” technique, in contrast, the subject exerts a maxima1 force against the myometer and the tester applies sufficient resistance to just overcome the force exerted by the subject, thus causing the start of an eccentric contraction by the preloaded muscles. The resultant force of break technique is greater than that of “make” tests (120). However, limitation of this method is that it measures only static strength at one position (121).

2.6.1.2 Isotonic strength measurement

Isotonic strength measures dynamically with weights such as free weigths (barbells, dumbells, cuff weights, hydraulic systems, and machine weights (83, 113, 122). Isotonic strength measurement allows for a complete range of motion, although maximal muscle demand occurs during only a small portion of the movement. The strength is measured by testing 1 RM. The 1 RM is measured by testing the maximum amount of weight that a subject could lift through a joint’s range of motion for 1 repetition in one session. In addition, the strength can be measured in 10 RM (83, 113). The isotonic strength measurement, the resistance that offered to the moving body segment (skeletal lever) remains constant through the entire ROM.

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However, the resistance to the muscle varies because of the modifying effects of the lever system (123).

The limitations of isotonic strength measurement include the amount of contribution from accessory muscle groups, the inability to control velocity of testing, and the amount of loads limited to the weakest point in the ROM (83, 122).

2.6.1.3 Isokinetic strength measurement

Hislop and Perrine in 1967 (123) firstly introduced the concept of isokinetic dynamometers. Isokinetic dynamometers are widely used in the clinical and research settings as evaluation and rehabilitation tools. It has several advantages over other exercise modalities such as measuring and training of both concentric and eccentric contractions (124, 125). Moreover, it is effective in increasing strength and muscle hypertrophy (97, 126) and safety for exercise (122, 127).

Isokinetic strength testing is a measurement which has a constant speed with a variable resistance that accommodates to the individual throughout the entire ROM (122). Unlike other types of resistance training, there is no specified resistance to meet and the velocity of movement is controlled. At begin of each movement, acceleration from 0 degree per second takes place until the set velocity is achieved. After the set velocity is achieved, any force applied will be against the equipment when force applied equal reaction force (43). Force production will be varied throughout a joint's entire ROM because of the changes in biomechanical skeletal leverage (83, 122, 123). The maximal force occurs throughout the movement's range of motion except where acceleration at the start and deceleration at the end of movement (43). At the midrange of the ROM, whereas the muscle is at its optimum length-tension relationship for the binding of actin and myosin (83, 122, 123). More force will be produced as its greatest mechanical advantage, and thus the resistance increases proportionately (83, 122, 123).

The common parameters indicating the muscle strength are peak torque, total work, average power and percentage of h/q ratio. Torque is product of the

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force of muscle that generates through the joint to take movement by tone of muscle or the force cross-distance to pivot (123, 128). Peak torque (PT) is the highest torque of its location in the range of motion and become gold standard and reference point of strength of muscle (129). Total work is the product force times distance (129) or the area under the torque curve (123) which indicates the physiological efficiency of the muscle (130). Power indicates the work rate intensity or determines muscle performance. It is the work output of muscles at specific speeds of contraction. Power indirectly represents energy expenditure of the muscle. The percentage of h/q ratio presents the pattern of strength of hamstring compare to quadriceps muscles. The h/q ratio is a measurement of the relationship between strength of the hamstring and quadriceps muscle groups indicating joint stability (131).

2.6.2 Sprinting

Running velocity is one important performance for many sports. Sprinting includes acceleration phase and maximum speed phase. Sports scientists agreed that strength training can be also improved sprint performance (132). However, some studies suggested that improvements in sprint running performance are directly related to movement and velocity specificity (89, 133) and that strength may be transferred more specifically using similar mode of contraction (134).

The acceleration phase requires powerful extension of legs whereas maximum speed depends mainly on lower moments of inertia of leg and necessitates the backward and forward rotation of the legs (45). Therefore, specific training is required for each phase of a sprint event. In addition, strength training of the knee and hip extensors and the gluteus maximus are more likely to result in improvements of acceleration performance and improvements in hamstring power may result to a greater running velocity in maximum speed phase (45). The current device for measurement sprint velocity mostly used electric timing which measured by photocells (29, 135, 136).

The distance for measurement of acceleration phase of sprinting is 0 - 20 meters whereas the maximal speed phase is 20-50 meters (flying run) (29, 137).

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However, it has several factors influencing to sprint velocity measurement such as wind environment of testing, type of shoe, motivation of subject, and day time of testing.

Zafeiridis et al in 2005 (136) assessed running velocity in 0-50 m performance by using 5 pairs of photocells before and after resisted sled-pulling sprint training. The performance times were measured at 0-10 m, 10-20 m, 20-40 m, and 40-50 m. For the evaluation of sprint performance the participants executed 2 maximal 50 m runs. The run with the best performance time was used for the evaluation of the performance. Sprint training with 5 kg sled pulling for 8 weeks improved acceleration performance (0-20 m), while un-resisted sprint training improved performance in maximum speed phase (20-40 m) in non-elite athletes. It appears that each phase of sprint run demands a specific training approach.

2.7 Reliability of Isokinetic Measurement

The reliability of isokinetic measurement refers to the repeatability of the measure (46). Reliability of any measurement or instrument including isokinetic dynamometer is important which should be determined before using the device for collecting and evaluating the data (138). Parameters of isokinetic testing which need to be reported including the muscle(s) tested, the joint angle, the speed, and the unit of measurement being reported. In addition, peak torque, work, power, total work, average power, average peak torque are parameters which most measurements use for isokinetic testing (46).

Montgomery et al in 1989 (66) investigated the reliability of isokinetic knee muscular strength and endurance by using Biodex isokinetic dynamometer. They demonstrated that the reliability of peak torque was generally higher in slow velocities testing than in high velocities testing. The range of reliability of peak torque was from 0.75 to 0.92. They also reported that the reliability of knee extension was greater than knee flexion.

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Feiring et al in 1990 (139) investigated the test-retest reliability of concentric knee extension/flexion by testing with Biodex isokinetic system. They reported high reliability for peak torque and total work measurement at four testing speeds (60º, 180º, 240º and 300º/sec). The Biodex isokinetic concentric mode produced high statistically significant test-retest reliability when measured the muscular performance (r = 0.95 – 0.97). Feiring et al suggested that the Biodex was the reliable device to measure the muscular force production. The intraclass correlation of peak torque of knee extension was from 0.95 to 0.97 and work from 0.95 to 0.97. The intraclass correlation of peak torque of knee flexion was from 0.82 to 0.99 and work from 0.93 to 0.96.

Gross et al in 1991 (140) compared the reliability of knee measurement between Biodex and Cybex II. They founded that reliability of each isokinetic device was high. The reliability of Biodex (r = 0.67-0.97) was higher than that of Cybex II (r = 0.38-0.89). In addition, the intermachine reliability between Biodex and Cybex II was low (r = 0.41-0.93). The results indicated that each device could measure the muscle performance but the measurement of one device may not generalize to another device.

Steiner et al in 1993 (124) measured the reliability of eccentric isokinetic knee flexion and extension in healthy subjects and subjects who had a history of tibiofemoral pathology at 60º and 180º/sec by using LIDO active isokinetic dynamometer. Average peak torque, total work, and power were measured. Healthy subjects represented a higher reliability of knee flexion than subjects who had a tibio-femoral pathology. The reliability of knee extension was lower than knee flexion at both 60º and 180º/sec. The test-retest reliability of average peak torque was from 0.58 to 0.96, joint angle at peak torque from 0.01 to 0.69, total work from 0.63 to 0.93 and power 0.67 to 0.93.

Li et al in 1996 (18) assessed the reliability of the Cybex 6000 isokinetic on concentric and eccentric knee flexion and extension. They tested at the velocities of 60ºsec and 120º/sec and concluded that the intraclass correlation of all three parameters, peak torque, total work and average power, were high reliability at 120º/sec. At both velocities, peak torque showed greater test-retest reliability than total

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work and average power. The reliability of quadriceps muscle was better than that of hamstring muscle.

Pincivero in 1997 (141) investigated the test-retest reliability of the Biodex isokinetic dynamometer for concentric knee muscular strength and endurance. Testing procedure included two sessions which were separated by 7 days. Each session consisted of testing of muscular strength at 60º/sec and testing of muscular endurance at 180º/sec. Reliability of peak torque, total work, average power, and peak torque/body weight were good at both angular velocities whereas work fatigue index that presented a muscular endurance was low reliability.

Drouin et al in 2004 (142) assessed the mechanical reliability and validity of position, torque and velocity measurements of the Biodex System 3 isokinetic dynamometer. The result showed that the Biodex System 3 was valid and reliable measurements of torque and position.

2.8 Reliability of Isometric Test

Isometric strength measurement is developed from the subjective muscle force measurement or manual muscle test to strength measuring device such as the hand-held dynamometer (HHD) (119). Hand held dynamometer can be used to precisely indicate muscle force in actual unit (i.e., Newtons, kg, or lbs) (143).

Several studies had examined the reliability of isometric test (HHD). The hand held dynamometer is a portable instrument used to measure muscle force. It is relatively inexpensive, convenient, weigh less than 2 pounds, require no set-up, and can be used in many environments (144). Excellent reliability has been shown even with use of inexperienced examiners (144, 145)

Both methods make test and break test produce strength measurements that have excellent reliability, although the break technique produces higher values. Bohannon in 1988 demonstrated excellent reliable (r = 0.909 for make tests; r = 0.922

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for break tests) when using hand-held dynamometer to perform two make tests and two break tests on 27 young women.(120).

Knapik et al in 1983 (115) demonstrated an improved HHD reliability measurements by placing the muscle at a length where it was unable to produce maximum force. For knee extension, they reported maximum isometric forces at 60º-70º with decreasing values as the knee approached full range of motion in either direction. In addition, HHD measurements of knee flexion at 30º might be expected to be more reliable than HHD measurements at 70º of knee flexion.

Stratford et al in 1994 (146) compared make and break tests using a hand-held dynamometer and the Kin-Com. They determined whether intrasession test-retest reliability differs between make and break tests and strength tests. The result found a higher reliability coefficient for the make test compared with the break test for the HHD tests. The comparable reliability coefficients for the make and break tests were obtained from the Kin-Com device and the measured forces for the break tests were higher than the make tests.

Andrew et al in 1996 (147) reported that moderate to high relationships existed between the anthropometric characteristics of 150 subjects (gender, weight, and height) and knee isometric force measured by HHD. There were significant correlations between muscle force and gender ($r = -0.67$), weight ($r = 0.70$), and height ($r = 0.68$).

Factors which influence the reproducibility of quantification of isometric strength include point of force application, magnitude and duration of resistance offered, direction of force provided, test position, type of test used (make test and break test), prestretching, number of practice sessions, and encouragement (148).

Kilmer et al in 1997 (149) found the interrater reliability of force measures to be significantly higher in weaker subjects with hereditary motor and sensory neuropathies than healthy subjects.

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Dunn et al in 2003 (143) found good to high interrater reliability for measurements of knee extensor and flexor muscle force obtained by HHD. They described that the reliability was not influenced by symptom severity.

Burn et al in 2005 (150) showed intraclass correlation coefficients exceeding 0.9 for interrater and intrarater reliability in break and make test techniques.

From the literature review, the eccentric hamstring strength is important for prevention of hamstring injury. Many researches investigated the effectiveness of eccentric training in gaining muscle strength and muscle performance in various methods, protocols, and instrumentations. There was only one pilot study related to functional movement velocity of hamstring eccentric function conducted by Stanton et al (28). They measured only peak torque values. Therefore, the aim of the present study is to investigate the effects of fast eccentric hamstring strength training on hamstring performance.

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CHAPTER III
MATERIALS AND METHODS

3.1 Subject

The subjects of this study were healthy Thai males aged between 18 and 25 years. Subjects voluntarily participated in this study. The objective, process of testing and training, advantages of the study, prevention and safety features were explained to the subjects. The procedure of the study including possibility of muscle soreness was also informed. Each subject signed an informed consent and completed the health history questionnaire (Appendixes A-B). All subjects must have right leg dominance that was tested by kicking a ball, drawing a number eight on floor and picking up an eraser from floor (151).

The procedure of this study was approved by Ethical Committee on Research Involving Human Subject, Faculty of Graduate Studies, Mahidol University.

Inclusion criteria

1. Not participate regularly in resistive exercise or sport training.
2. No limitation of hip, knee and ankle joints.

Exclusion criteria

1. Having any previous hamstring strains in the past 6 months.
2. Having history of musculoskeletal problem of either or both lower extremities in the past 6 months.
3. Having history of knee injury or operation.
4. Having history of neuromuscular disorder.
5. Having history of cardiovascular disease such as heart disease, hypertension.

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3.2 Instrumentation

1) Biodex system III (BIODEX MEDICAL SYSTEMS, Inc., Shirley, New York). The system could provide concentric and eccentric isokinetic testing at speeds up to 500 and 300 degrees/second respectively.

The system consists of:

- Power head
- Adjustable chair
- Controller
- Power head attachment
- Calibration weight
- Keyboard and monitor
- Printer

Figure 3.1 Biodex system III.

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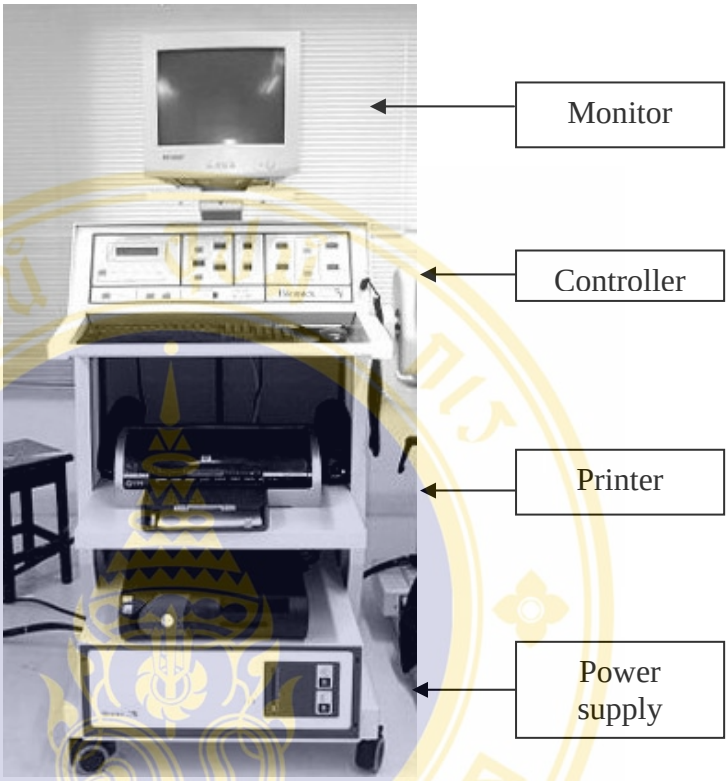

Figure 3.2 Controller of biodex system III.

Figure 3.3 Calibration weight.

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2) Infrared timing device: Newtest Powertimer 300-series, Finland.

The system consists of

- Three infrared photoelectric cells
- Controller
- Palms
- Three tripods

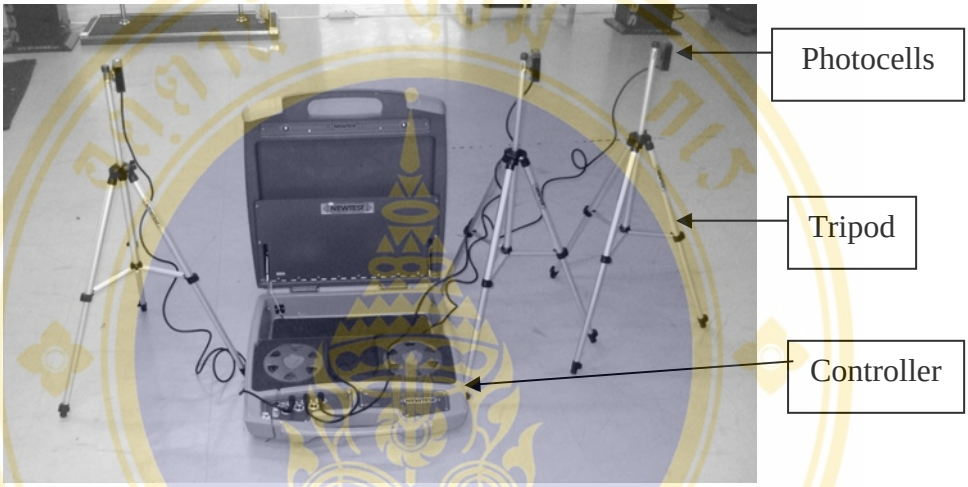

Figure 3.4 Controller of Newtest device.

Figure 3.5 Palm of Newtest device.

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3) Myometer: Lafayette Manual Muscle Test (MMT).

Lafayette MMT (model 01163, Lafayette Instrument Company) combines precision and accuracy with a new ergonomic design to provide accurate, objective and reliable result. This MMT registers 0.0 to 136.1 kg with a precision of 0.1 kg.

Figure 3.6 Lafayette manual muscle test.

4) Stop watch.

Figure 3.7 Stop watch.

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5) Weight resistance: sand bag 2 – 6 kg.

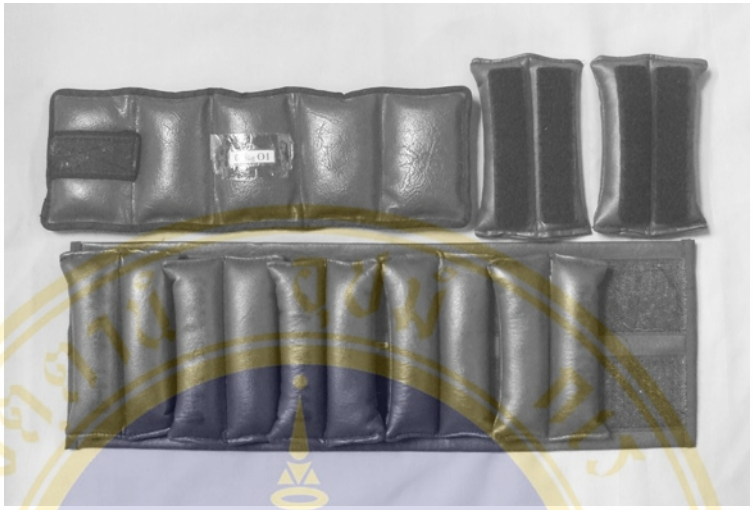

Figure 3.8 Weight resistance.

6) Velcro strap.

Figure 3.9 Velcro strap.

7) Stabilization straps.

Figure 3.10 Stabilization straps.

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3.3 Procedure

Subjects were randomly selected an identified label to be categorized into two groups; control and eccentric training groups. Subjects in the training group performed both testing and training programs. Subjects in the control received no exercise except testing program.

Testing programs included sprint testing, eccentric hamstring testing (break test), and strength testing (isokinetic testing). Strength testing was tested one day after sprint testing because strength testing may induce delay onset muscle soreness. Each subject reported muscle soreness level on the 10-cm visual analog scale immediately after isokinetic testing and fast eccentric hamstring training. Eccentric hamstring testing (break test) was measured in the first day of the 2^{nd}, 3^{rd} and 4^{th} week by testing only right leg. Strength testing was measured three times; at the beginning, 2^{nd} week and 4^{th} week by testing only right leg. Sprint testing was conducted two times; at the beginning and 4^{th} week.

Subjects in the training group would be trained eccentric hamstring muscle for both legs three times per week for 4 weeks.

Moreover, all subjects must not take any medication related the change of muscle properties e.g. muscle relaxant or doping agents within 24 hours prior to all testings.

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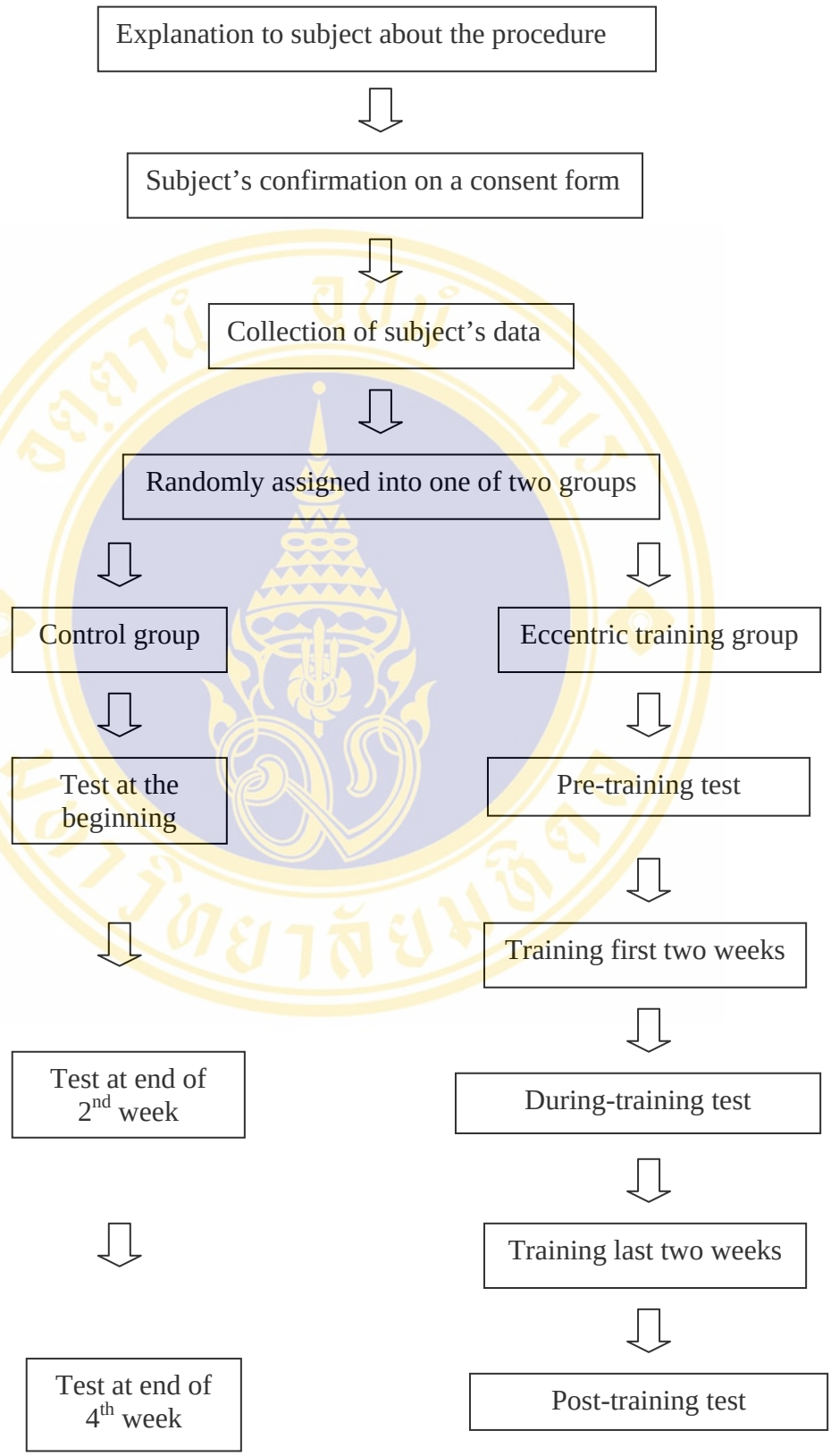

Figure 3.11 Procedure of the study.

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3.4 Sprint Testing Protocol

The sprint speed was assessed two times at the beginning of 1st week and the end of 4th week by using an infrared timing device (Newtest Powertimer 300-series, Finland). Each of the photocells was placed separately on a tripod, 1- 1.20 meters above the ground, so that they could sense the hip height of the passing bodies, the three photocells were arranged along the 50 meters track section in the following way: 1 m after the start point, 21 meters after the start point and 51meters after the start point.

The subjects started from an upright starting position without a starter. The first photocell was placed one meter after the start point in order to avoid the problem of the reaction time. Therefore, the subjects' reaction times were not included in the acceleration phase. Based on the above arrangement of the photocells, the subjects were timed for the following running sections: 0-20 meters and 20-50 meters.

Each subject performed a warm-up session prior to the sprint testing. The warm-up session consisted of stretching and running. Subjects performed a stretching protocol by sustaining each muscle for 15 seconds and repeated 3 times. The stretched muscles were quadriceps, hamstring and gastrocnemius muscles (Figures 3.12-3.14). After stretching, they performed running for 3 minutes, then a shuttle run 50 m. The subject performed 2 test trials. The researcher chose the trial with had fastest sprint speed of 20-50 meters, both sprint velocity 0-20 and 20-50 meters were recorded for data analysis. A 2-minute rest interval between test trials was allowed. After testing session, the subject performed a 3-minute running for cool down (29).

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Figure 3.12 Quadriceps muscle stretching.

Figure 3.13 Gastrocnemius muscle stretching.

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Figure 3.14 Hamstring muscle stretching.

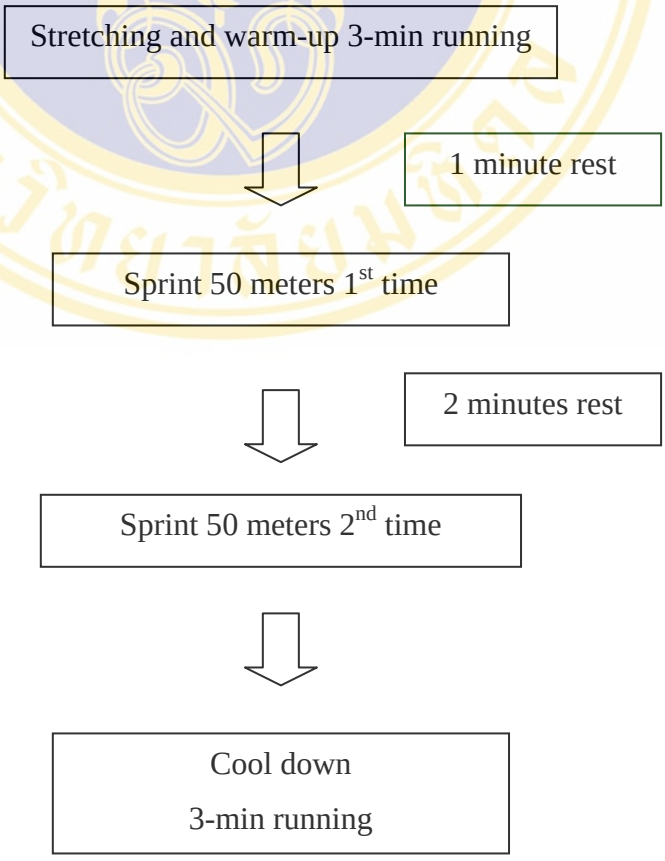

Figure 3.15 Sprint testing protocol.

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3.5 Eccentric Hamstring Testing (Break Test)

Eccentric strength of hamstring muscle by manual muscle test of both eccentric training and control groups were measured. Eccentric hamstring testing was performed on the first day of the second, third and fourth week of study period in order to calculated weight resistance of each subject in the training group.

Subjects were positioned in prone lying on a bed while hip angle was set at 30° flexion. The subject's knee was placed in 25° knee flexion using a reference line which was demonstrated in Figure 3.16.

The small towel was folded and placed above two finger breaths of the medial malleolus of the ankle joint to provide cushioning from applicator of the Lafayette manual muscle test. The applicator of the myometer was placed on small towel and the subject was asked to exert a maximum force against it. The tester applied sufficient resistance to overcome the force exerted by the subject. The tester applied a downward force over 1 second to allow the subject to adjust and recruited the maximum amount of muscle fibers. Additional force was applied until the muscle contraction begun to break and the limb begun to move. Then the myometer was moved away from the limb segment and the measured force was recorded. Single practice trial was performed before testing to ensure each subject understood the commands.

Testing was last no longer than 3 seconds and 3 repetitions were measured. A 1 minute rest was given between each repetition. The highest value of the break test force was used to calculate weight resistance of each subject in the training group. Ten percent of the highest force value was applied to weight resistance in that week. The eccentric hamstring testing was demonstrated in Figure 3.17.

The tester used the following standard verbal cues while measuring hamstring muscle force. "Do not lift your thigh off the bed during testing. Hold against myometer slowly and smoothly. One, two, three, hold!"

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Figure 3.16 The bed for eccentric hamstring testing.
a: A reference line for 25° knee flexion

Figure 3.17 Position of the eccentric hamstring testing (break test).

3.6 Isokinetic Testing

Before testing, procedure of testing, risk of injury and prevention features were explained to the subjects. Subject sat on the adjustable chair of the dynamometer at 85° inclination (external angle from the horizontal) with stabilization straps at the trunk, pelvis and thigh to prevent inaccurate joint movements (Figure 3.18).

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The tested right knee was positioned at 90° of flexion (0° = fully extended knee) and the axis of the dynamometer lever arm was aligned with the distal point of the lateral femoral condyle. The range of motion of the knee joint was 10° – 90° due to safety precautions. The 10° to 0° range of excursion (full extension) was avoided. This could be expected to result in a potentially hazardous combination of high muscle forces and tibial rotation. The latter was associated with the lock-unlock screw home movement that was mechanism of the knee joint at full extension.

Subjects were also instructed to hold their arms comfortably on the chest straps to further isolate knee joint flexion and extension movements (Figure 3.19).

Figure 3.18 Angle of the adjustable chair of the dynamometer.

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Figure 3.19 Position of subject.

Each subject underwent the general warm up session prior to the testing. The general warm up session consisted of stretching exercise and cycling on a stationary cycle ergometer (Bodyguard Ergometer 990). Each muscle was stretched 3 times by sustaining 15 seconds each time. The stretched muscles were quadriceps, hamstring and gastrocnemius muscles (Figures 3.11-3.13). These muscles were related to knee and hip joint movements that essentially used in testing. After stretching exercise, each subject performed cycling on a stationary cycle ergometer for 3 minutes (Figure 3.20) (92).

Subjects in both groups performed the same protocol of isokinetic testing. Subjects were tested concentric contraction of both hamstring and quadriceps muscles at 240°/sec by testing only right leg. Then, subjects were tested eccentric contraction of both hamstring and quadriceps muscles at 240°/sec. The testing was conducted three times; at the beginning before entering the program, 2nd and 4th week.

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Figure 3.20 Cycling on cycle ergometer.

After setting the position of the body on isokinetic dynamometer, subjects performed specific warm up 3 submaximal and 1 maximal repetitions of concentric contraction in order to familiar with the resistance and velocity. After 1 minute rest period, subjects performed 3 repetitions of maximal concentric contraction of knee extension and flexion at 240°/sec. A 2-minute rest was allowed before starting the eccentric testing. The warm-up for testing of eccentric strength consisted of 3 submaximal and 1 maximal repetitions of eccentric contraction. After 1 minute rest period, subjects were informed to perform 3 repetitions of maximal eccentric contraction of knee extension and flexion at 240°/sec. The testing protocol was demonstrated in Figure 3.21. During the test, the subject was verbally encouraged to move the knee as hard and fast as possible against knee attachment of dynamometer. The subject was allowed to see the computer screen for visual feedback on performance. Following testing session, subject was cooled down by cycling on a stationary cycle ergometer for 3 minutes.

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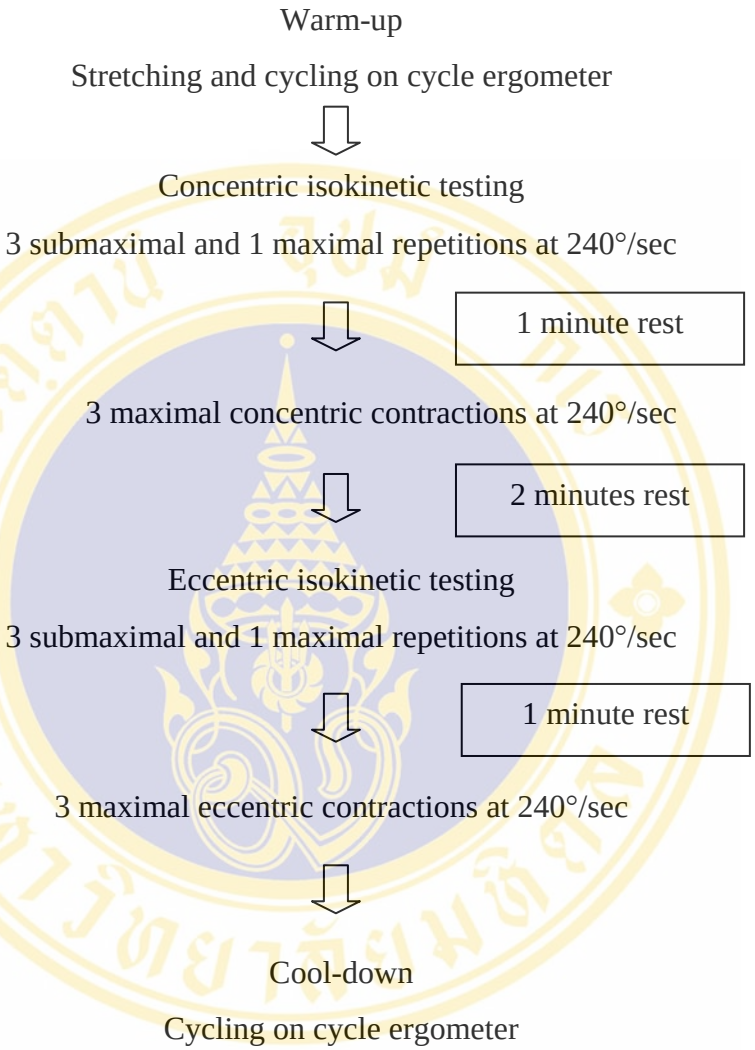

Figure 3.21 Isokinetic testing protocol.

3.7 Training Protocol

Subjects in the training group were trained eccentric contraction of hamstring muscle for both legs with three times per week for 4 weeks were trained. Prior to eccentric hamstring training, subjects performed a lower extremity flexibility exercises protocol by sustaining each muscle for 15 seconds and repeated 3 times. The stretched muscles were quadriceps, hamstring and gastrocnemius muscles of both legs (Figures 3.12-3.14).

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The subject was positioned in prone over a bed and hip angle was given approximately 30° flexion and knee angle approximately 90° flexion. The hip position replicated hip angle of late swing of sprinting. Following a start signal, the subject performed the exercise by rapidly extended the knee as fast as possible and decelerated at approximately 20° – 30° of knee flexion via an eccentric hamstring contraction, followed by a quick hamstring concentric contraction until knee angle approximately 90° (Figures 3.22 - 3.23). Every training session consisted of 4 sets with 12 repetitions with 1 minute rest between sets, and 1 minute rest between legs. The tester suggested the subjects not to lift their thighs off the bed during training.

The progressive resistance depended on eccentric strength testing (break test) of each subject at the first day of the 2nd, 3rd and 4th week. The first week, subjects were trained with no weight. For the second, third and fourth week; subjects were trained with sand bag at the weight of 10% of eccentric strength testing force.

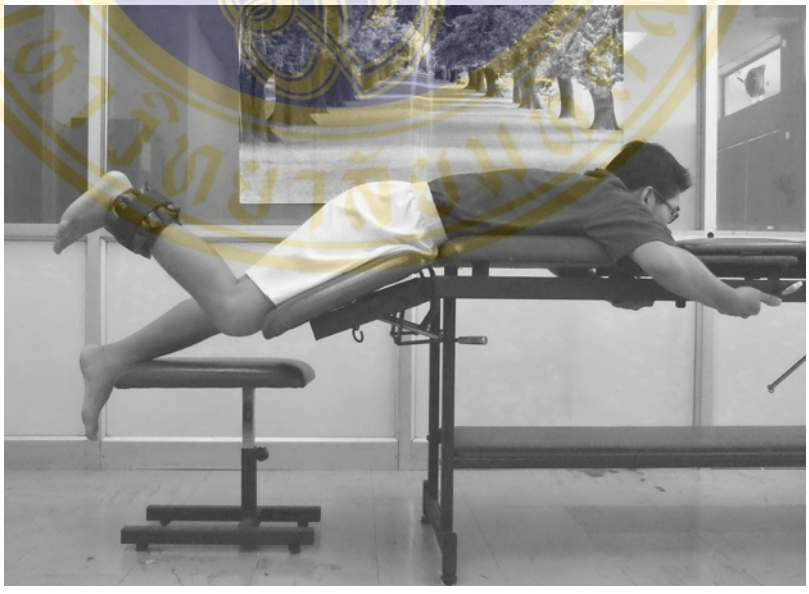

Figure 3.22 Starting position of fast eccentric hamstring training.

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Figure 3.23 Decelerate knee extension movement of fast eccentric hamstring training.

3.8 Data Analysis

The level of significant difference was set at p-value less than 0.05.

1. Kolmogorov-Smirnov Goodness of Fit test was used to determine the distribution of the data.

2. Two-way analysis of variance for repeated measures was used to test for differences in all data within each group throughout the study and between groups of the study in each time of measurements. The Bonferroni post hoc was used to test for multiple comparisons between two groups or between different times of measurement within each group if the results were statistically significant.

3. The unpaired t-test was used to test for the differences of subjects' characteristics between control and eccentric training groups.

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CHAPTER IV
RESULTS

4.1 Characteristics of Subjects

The subjects in this study were divided into two groups; control and eccentric hamstring training groups. Each group contained 15 male subjects. Both groups were similar in age, weight and height with no significant differences between groups ($p > 0.05$) as shown in Table 4.1.

Table 4.1 Subjects' characteristics of training and control groups (Mean ± SD)

Subjects' characteristics	Training group (n=15)	Control group (n=15)	p-value
Age (yrs)	21.27 ± 0.96	21.27 ± 0.96	1.000
Weight (kg)	66.73 ± 11.76	65.85 ± 9.00	0.820
Height (cm)	172.73 ± 5.48	171.47 ± 3.74	0.466

p -value from unpaired t-test

4.2 Effect of Training on Concentric Isokinetic Testing

4.2.1 Concentric isokinetic testing of quadriceps muscle

The value of peak torque of concentric isokinetic testing of quadriceps muscle of both groups and statistical analysis between two groups are presented in Table 4.2. Multiple comparisons among various times of measurement for each group are reported in Tables 4.3 - 4.4.

As shown in Table 4.2, there was no group effect ($p = 0.060$) but there were time effect ($p < 0.001$) and group × time ($p = 0.032$) interaction. From the Table 4.2, the data of peak torque of concentric isokinetic testing of quadriceps muscle at 1st week or baseline data were not significant differences between control and training

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groups (119.32 ± 14.30 and 126.07 ± 21.93 Nm respectively). There were significant differences in peak torque of quadriceps muscle in the 1st - 2nd week and 1st - 4th week ($p = 0.001$ and $p < 0.001$ respectively) in the training group whereas no significant difference was found in the control group, as shown in Tables 4.3-4.4. Moreover, the comparison between two groups at any time of measurement showed no difference except at the 4th week.

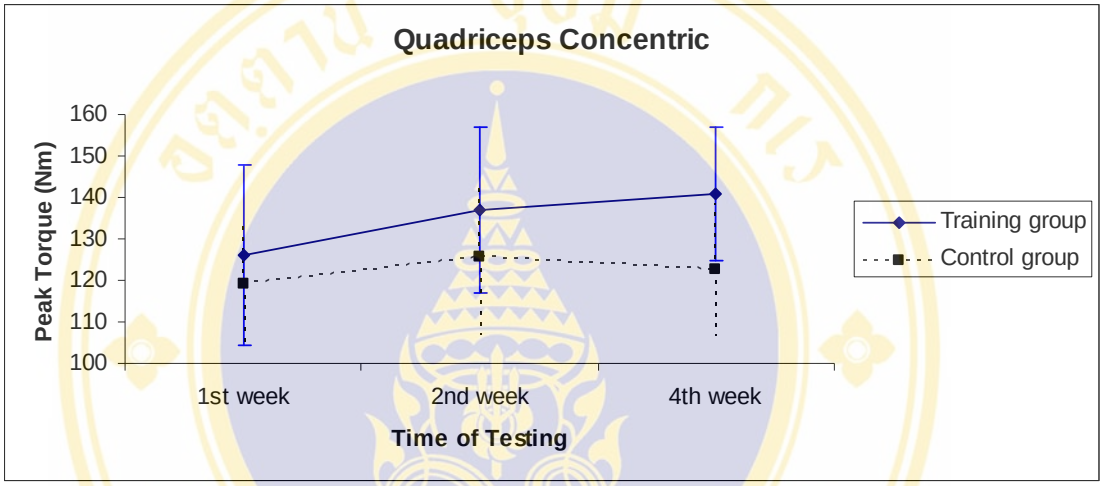

Figure 4.1 Peak torque of concentric isokinetic testing of quadriceps muscle at 1st, 2nd, and 4th week in eccentric training and control groups.

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Table 4.2 Comparison of peak torque of concentric isokinetic testing of quadriceps muscle between control and training groups

Peak torque (Nm)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	126.07 ± 21.93	119.32 ± 14.30	0.326
Week 2	136.81 ± 20.07	125.49 ± 18.40	0.118
Week 4	140.68 ± 16.09	122.74 ± 16.03	0.005*
p-value[a]	0.032*		
p-value[b]	< 0.001*		
p-value[c]	0.060		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

Table 4.3 Multiple comparison of concentric isokinetic testing of quadriceps muscle of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.070	0.876
Week 2	-	-	1.000
Week 4	-	-	-

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Table 4.4 Multiple comparison of concentric isokinetic testing of quadriceps muscle of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.001*	< 0.001*
Week 2	-	-	0.633
Week 4	-	-	-

4.2.2 Concentric isokinetic testing of hamstring muscle

The value of peak torque of concentric isokinetic testing of hamstring muscle of both groups and statistical analysis between two groups are presented in Table 4.5. Multiple comparisons among various times of measurement for each group are reported in Tables 4.6 - 4.7.

As shown in Table 4.5, there was no group effect ($p = 0.216$) but there were time effect ($p < 0.001$) and group × time ($p = 0.018$) interaction. The 1st week or baseline data of peak torque of concentric isokinetic testing of hamstring muscle in control and training groups were 73.44 ± 10.82 and 72.19 ± 13.88 Nm respectively. The comparison between two groups at baseline measurement had no difference ($p = 0.785$). The peak torque of concentric isokinetic testing of hamstring muscle increase significantly at week-2 measurement, and week-4 measurement in training group ($p < 0.001$), whereas no significant difference among 1st, 2nd and 4th week was found in the control group, as shown in Tables 4.6-4.7. In addition, the comparison between two groups at any time of measurement showed no difference except at the 4th week.

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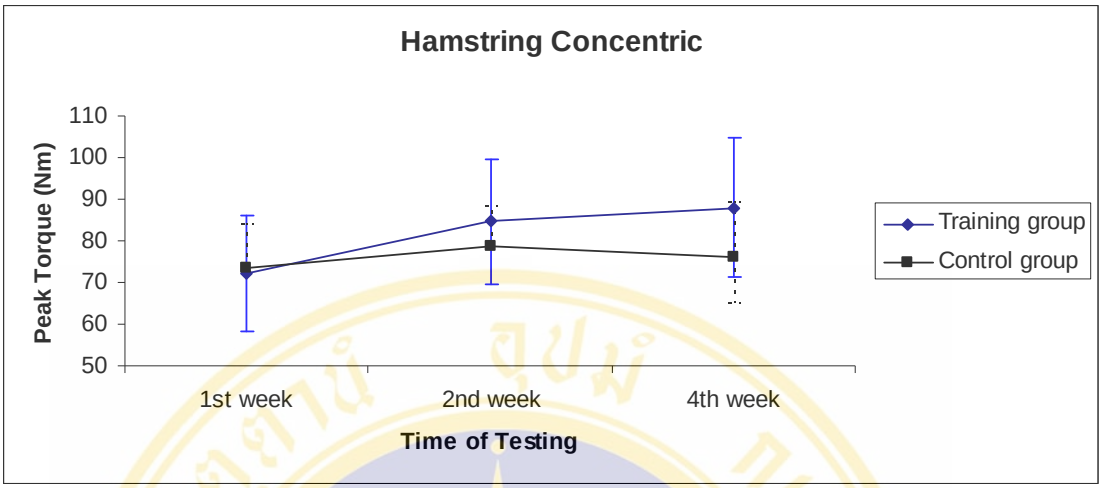

Figure 4.2 Peak torque of concentric isokinetic testing of hamstring muscle at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.5 Comparison of peak torque of concentric isokinetic testing of hamstring muscle between control and training groups

Peak torque (Nm)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	72.19 ± 13.88	73.44 ± 10.82	0.785
Week 2	84.62 ± 14.96	78.75 ± 10.13	0.218
Week 4	87.86 ± 16.71	76.19 ± 13.22	0.043*
p-value[a]	0.018*		
p-value[b]	< 0.001*		
p-value[c]	0.216		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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Table 4.6 Multiple comparison of concentric isokinetic testing of hamstring muscle of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.161	1.000
Week 2	-	-	0.964
Week 4	-	-	-

Table 4.7 Multiple comparison of concentric isokinetic testing of hamstring muscle of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	< 0.001*	< 0.001*
Week 2	-	-	0.636
Week 4	-	-	-

4.3 Effect of Training on Eccentric Isokinetic Testing

4.3.1 Eccentric isokinetic testing of quadriceps muscle

The value of peak torque of eccentric isokinetic testing of quadriceps muscle of both groups and statistical analysis between two groups are presented in Table 4.8. Multiple comparisons among various times of measurement for each group are reported in Tables 4.9 - 4.10.

From Table 4.8, there was no group effect ($p = 0.069$) but there were time effect ($p < 0.001$) and group × time ($p = 0.022$) interaction. The 1st week data of peak torque of eccentric isokinetic testing of quadriceps muscle in control and training groups were 182.52 ± 39.88 and 187.77 ± 31.71 Nm respectively with no significant difference ($p = 0.693$). In addition, the comparison between two groups at any time of measurement showed no difference except at the 4th week. The eccentric peak torque of quadriceps muscle in training group indicated significant difference at 2nd week and 4th week ($p = 0.002$, $p < 0.001$ respectively) compared to the first week whereas control group demonstrated no significant difference, as shown in Tables 4.9 - 4.10.

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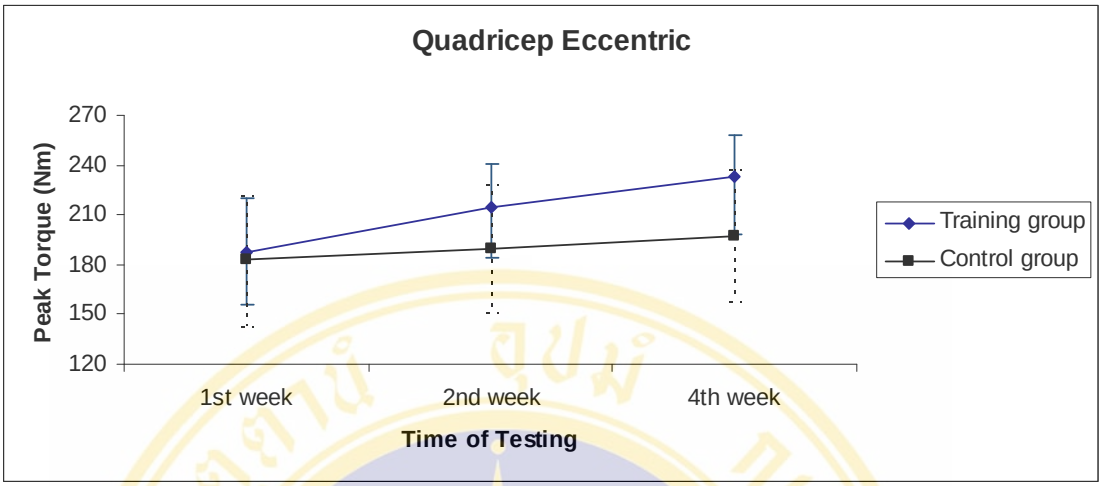

Figure 4.3 Peak torque of eccentric isokinetic testing of quadriceps muscle at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.8 Comparison of peak torque of eccentric isokinetic testing of quadriceps muscle between control and training groups

Peak torque (Nm)			
Time \ Group	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	187.77 ± 31.71	182.52 ± 39.88	0.693
Week 2	214.94 ± 30.90	189.59 ± 38.58	0.057
Week 4	232.85 ± 34.76	197.48 ± 39.65	0.015*
p-value[a]	0.022*		
p-value[b]	<0.001*		
p-value[c]	0.069		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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Table 4.9 Multiple comparison of eccentric isokinetic testing of quadriceps muscle of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.954	0.166
Week 2	-	-	1.000
Week 4	-	-	-

Table 4.10 Multiple comparison of eccentric isokinetic testing of quadriceps muscle of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.002*	< 0.001*
Week 2	-	-	0.114
Week 4	-	-	-

4.3.2 Eccentric isokinetic testing of hamstring muscle

The value of peak torque of eccentric isokinetic testing of hamstring muscle of both groups and statistical analysis between two groups are presented in Table 4.11. Multiple comparisons among various times of measurement for each group are reported in Tables 4.12 - 4.13.

From Table 4.11, there was no group effect ($p = 0.115$) but there were time effect ($p = 0.007$) and group × time ($p = 0.006$) interaction. The 1st week data of peak torque of eccentric isokinetic testing of hamstring muscle in control and training groups were 129.23 ± 25.17 and 133.67 ± 24.51 Nm respectively with no significant difference ($p = 0.628$).

The subjects in the training group indicated significant difference in eccentric hamstring torque at 2nd week and 4th week ($p = 0.004$, $p = 0.003$ respectively) whereas control group demonstrated no significant difference, as shown in Tables 4.12 - 4.13. However, the comparison between two groups demonstrated no significant difference except at the 4th week.

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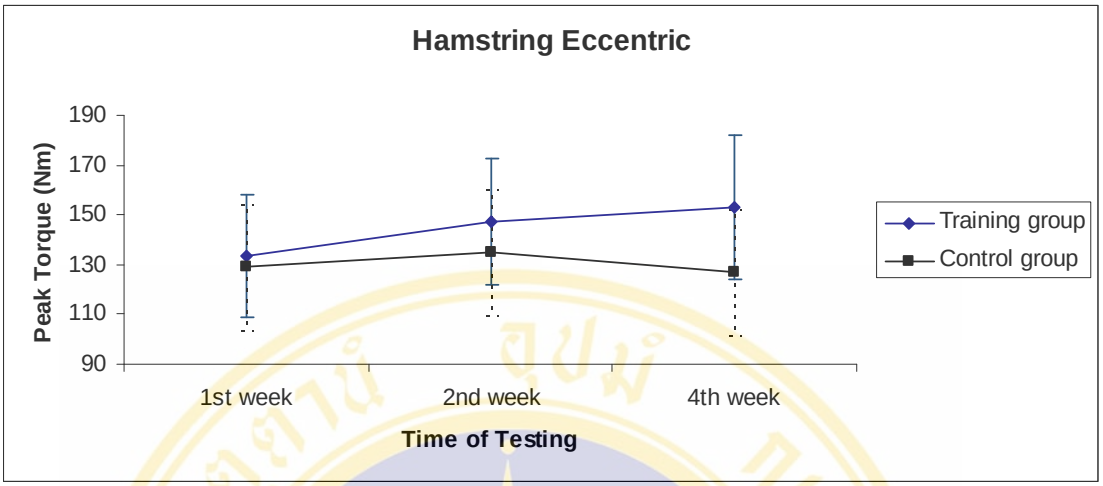

Figure 4.4 Peak torque of eccentric isokinetic testing of hamstring muscle at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.11 Comparison of peak torque of eccentric isokinetic testing of hamstring muscle between control and training groups

Peak torque (Nm)			
Time \ Group	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	133.67 ± 24.51	129.23 ± 25.17	0.628
Week 2	147.47 ± 25.50	135.19 ± 25.43	0.198
Week 4	153.11 ± 28.78	127.05 ± 25.30	0.014*
p-value[a]	0.006*		
p-value[b]	0.007*		
p-value[c]	0.115		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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Table 4.12 Multiple comparison of eccentric isokinetic testing of hamstring muscle of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.403	1.000
Week 2	-	-	0.082
Week 4	-	-	-

Table 4.13 Multiple comparison of eccentric isokinetic testing of hamstring muscle of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.004*	0.003*
Week 2	-	-	0.353
Week 4	-	-	-

4.4 Effect of Training on Eccentric Hamstring Torque at End Range

4.4.1 Eccentric hamstring torque at 20º of knee flexion

The value of eccentric hamstring torque at 20º of knee flexion of both groups and statistical analysis between two groups are presented in Table 4.14. Multiple comparisons among various times of measurement for each group are reported in Tables 4.15 - 4.16.

From Table 4.14, there were no group effect ($p = 0.105$) and time effect ($p = 0.374$) but there was group × time ($p = 0.008$) interaction. The 1st week data of eccentric hamstring torque at 20º of knee flexion in control and training groups were 118.44 ± 28.50 and 119.31 ± 31.13 Nm respectively without between group difference ($p = 0.937$). The subjects in training group got improvement in eccentric hamstring torque at 20º of knee flexion, whereas control group had no improvement. However, Two way ANOVA with repeated measures for the between-subjects and within-subjects indicated no significant difference but multiple comparison showed significant difference between groups at the 4th week and significant difference within training group at the 4th week compared to the 1st week.

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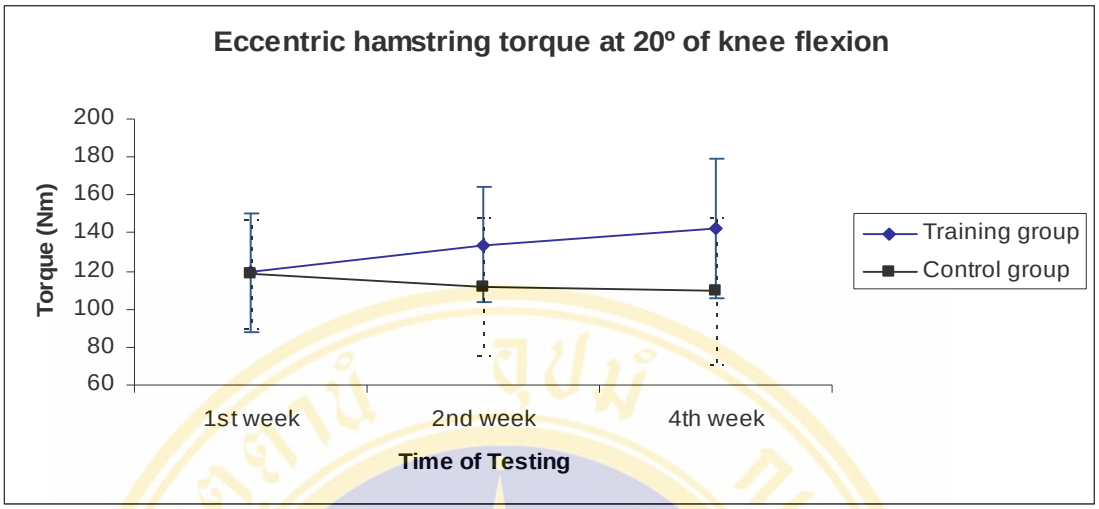

Figure 4.5 Eccentric hamstring torque at 20º of knee flexion at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.14 Comparison eccentric hamstring torque at 20º of knee flexion between control and training groups

Torque (Nm)			
Time \ Group	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	119.31 ± 31.13	118.44 ± 28.50	0.937
Week 2	133.71 ± 30.44	112.12 ± 35.95	0.087
Week 4	142.18 ± 36.93	109.58 ± 38.99	0.026*
p-value[a]	0.008*		
p-value[b]	0.374		
p-value[c]	0.105		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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Table 4.15 Multiple comparison of eccentric hamstring torque at 20º of knee flexion of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	1.000	0.857
Week 2	-	-	1.000
Week 4	-	-	-

Table 4.16 Multiple comparison of eccentric hamstring torque at 20º of knee flexion of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.110	0.027*
Week 2	-	-	0.551
Week 4	-	-	-

4.4.2 Eccentric hamstring torque at 15º of knee flexion

The value of eccentric hamstring torque at 15º of knee flexion of both groups and statistical analysis between two groups are presented in Table 4.17. Multiple comparisons among various times of measurement for each group are reported in Tables 4.18- 4.19.

In this study, there were no group effect ($p = 0.259$) and time effect ($p = 0.815$) but there was group × time ($p = 0.031$) interaction of eccentric hamstring torque at 15º of knee flexion. The 1st week or baseline data of eccentric hamstring torque at 15º of knee flexion in control and training groups were 96.73 ± 39.30 and 96.75 ± 41.36 Nm respectively without between group difference ($p = 0.999$).

There were no significant differences in eccentric hamstring torque at 15º of knee flexion among 1st, 2nd and 4th week in either training or control group, as shown in Tables 4.17 - 4.19.

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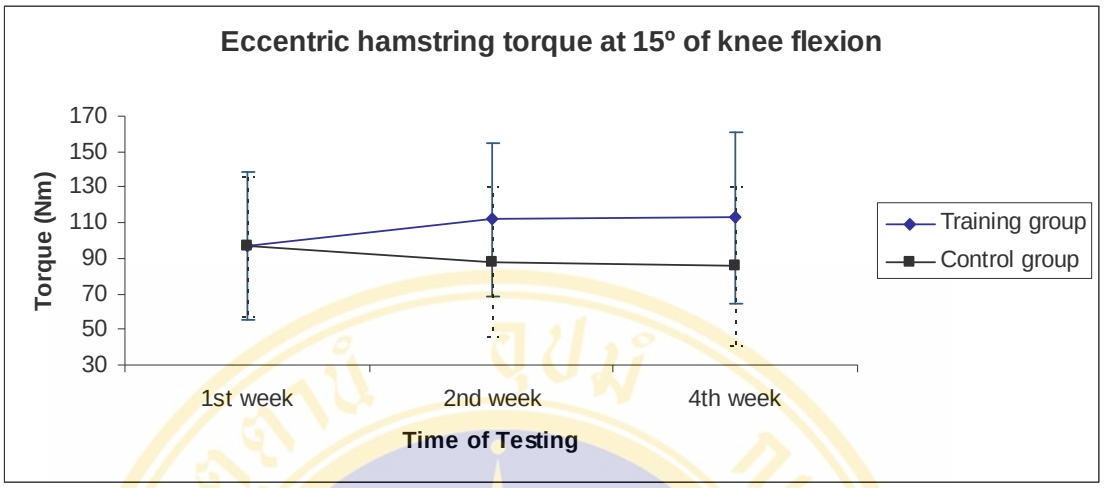

Figure 4.6 Eccentric hamstring torque at 15º of knee flexion at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.17 Comparison of eccentric hamstring torque at 15º of knee flexion between control and training groups

Torque (Nm)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	96.75 ± 41.36	96.73 ± 39.30	0.999
Week 2	111.68 ± 42.96	88.29 ± 42.29	0.144
Week 4	112.71 ± 48.52	85.94 ± 44.52	0.127
p-value[a]	0.031*		
p-value[b]	0.815		
p-value[c]	0.259		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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Table 4.18 Multiple comparison of eccentric hamstring torque at 15º of knee flexion of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.800	0.658
Week 2	-	-	1.000
Week 4	-	-	-

Table 4.19 Multiple comparison of eccentric hamstring torque at 15º of knee flexion of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	0.164	0.221
Week 2	-	-	1.000
Week 4	-	-	-

4.5 Effect of Training on Hamstring to Quadriceps Ratio

4.5.1 Hamstring concentric to quadriceps concentric ratio (Ham/Quad Con)

The value of Ham/Quad Con of both groups and statistical analysis between two groups are presented in Table 4.20.

There were no group effect ($p = 0.589$) time effect ($p = 0.293$) and group × time ($p = 0.126$) interaction. The 1st week or baseline data of Ham/Quad Con in control and training groups were 62.39 ± 10.09 and 57.41 ± 6.95% respectively without between group difference ($p = 0.127$). No change for the value of Ham/Quad Con was observed during training.

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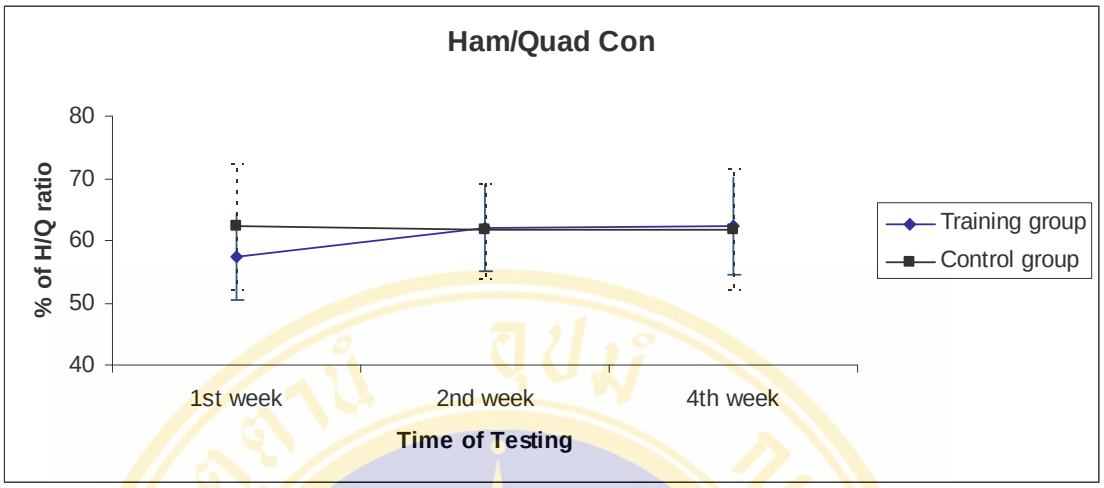

Figure 4.7 Ham/Quad Con ratio at 1st, 2nd, and 4th week in eccentric training and control groups.

Table 4.20 Comparison of percentage of Ham/Quad Con between control and training groups

Ham/Quad Con (%)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	57.41 ± 6.95	62.39 ± 10.09	0.127
Week 2	62.07 ± 7.04	61.67 ± 7.68	0.885
Week 4	62.31 ± 7.87	61.81 ± 9.77	0.878
p-value[a]	0.126		
p-value[b]	0.293		
p-value[c]	0.589		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

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4.5.2 Hamstring eccentric to quadriceps eccentric ratio (Ham/Quad Ecc)

The value of Ham/Quad Ecc of both groups and statistical analysis between two groups are presented in Table 4.21. Multiple comparisons among various times of measurement for each group are reported in Tables 4.22- 4.23.

In Table 4.21, there were no group effect ($p = 0.884$) and group × time ($p = 0.669$) interaction but there was time effect ($p = 0.009$). The 1st week or baseline data of Ham/Quad Ecc in control and training groups were 71.65 ± 8.78 and 71.81 ± 10.29% respectively without between group difference ($p = 0.965$).

The multiple comparison of time effect for both groups indicated no significant difference among 1st, 2nd, and 4th week of testing (see in Tables 4.22, 4.23).

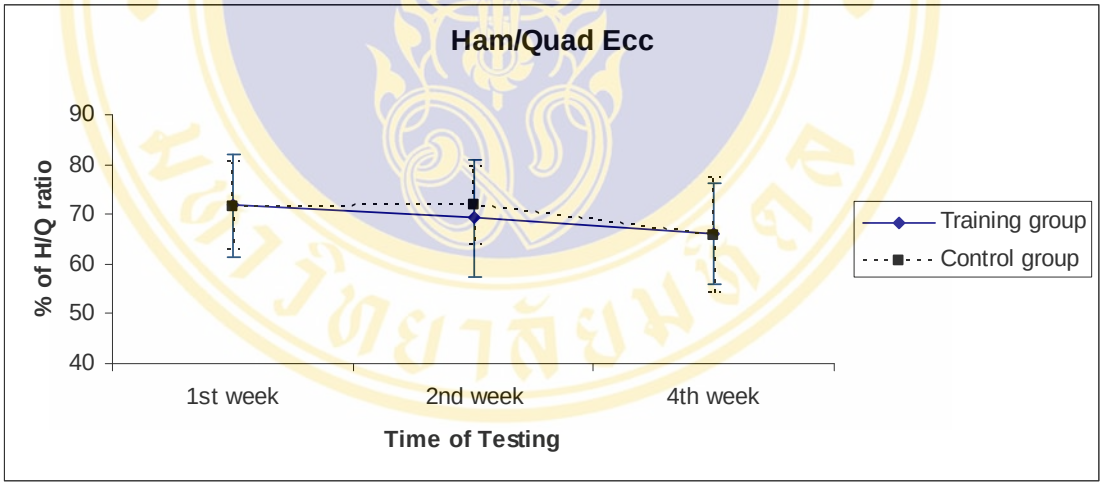

Figure 4.8 Ham/Quad Ecc ratio at 1st, 2nd, and 4th week in eccentric training and control groups.

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Table 4.21 Comparison of percentage of Ham/Quad Ecc between control and training groups

Ham/Quad Ecc (%)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	71.81 ± 10.29	71.65 ± 8.78	0.965
Week 2	69.22 ± 11.77	71.79 ± 7.71	0.486
Week 4	66.21 ± 10.13	65.58 ± 11.61	0.875
p-value[a]	0.669		
p-value[b]	0.009*		
p-value[c]	0.884		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

Table 4.22 Multiple comparison of percentage of Ham/Quad Ecc of control group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	1.000	0.172
Week 2	-	-	0.785
Week 4	-	-	-

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Table 4.23 Multiple comparison of percentage of Ham/Quad Ecc of training group among various times of measurement

Time	Week 1	Week 2	Week 4
Week 1	-	1.000	0.120
Week 2	-	-	0.076
Week 4	-	-	-

4.5.3 Hamstring eccentric to quadriceps concentric ratio (Ham Ecc/Quad Con)

The value of Ham Ecc/Quad Con of both groups and statistical analysis between two groups are presented in Table 4.24.

There were no group effect ($p = 0.787$), time effect ($p = 0.624$) and group × time ($p = 0.413$) interaction. The 1st week data of Ham Ecc/Quad Con in control and training groups were 108.33 ± 16.59 and 107.45 ± 18.34% respectively without between group difference ($p = 0.891$). No change for the value of Ham Ecc/Quad Con was observed in either training or control group.

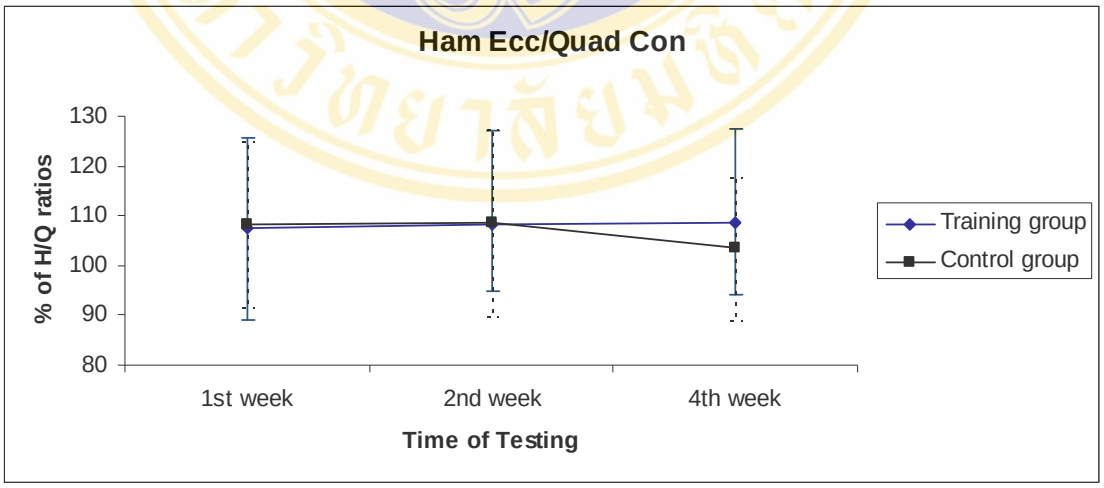

Figure 4.9 Ham Ecc/Quad Con at 1st, 2nd, and 4th week in eccentric training and control groups.

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Table 4.24 Comparison of percentage of Ham Ecc/Quad Con between control and training groups

Ham Ecc/Quad Con (%)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	107.45 ± 18.34	108.33 ± 16.59	0.891
Week 2	108.28 ± 13.50	108.58 ± 18.74	0.960
Week 4	108.72 ± 14.46	103.37 ± 14.23	0.317
p-value[a]	0.413		
p-value[b]	0.624		
p-value[c]	0.787		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

4.6 Effect of Training on Muscle Soreness

Means and standard deviations of visual analog scale (VAS) at the 2nd and 3rd week of eccentric training and control groups are presented in Table 4.25. At week 1st and 4th of training, no subject reported soreness on either quadriceps or hamstring muscle.

Table 4.26 presents number of subjects representing soreness at the 2nd and 3rd week in eccentric training and control groups. Subjects in the training group reported only soreness on hamstring muscle.

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Table 4.25 Means and standard deviations of VAS in eccentric training and control groups

Time/Group	VAS (cm)	
	Training	Control
	Mean ± SD	Mean ± SD
1st day of 2nd week	2.64 ± 1.95	0
2nd day of 2nd week	1.23 ± 1.81	0
3rd day of 2nd week	0.4 ± 1.06	0
1st day of 3rd week	0.4 ± 1.06	0
2nd day of 3rd week	0	0
3rd day of 3rd week	0	0

Table 4.26 Number of subjects representing muscle soreness subject in eccentric training and control groups

Time/Group	Number of soreness subjects	
	Training	Control
	Mean ± SD	Mean ± SD
1st day of 2nd week	10	0
2nd day of 2nd week	5	0
3rd day of 2nd week	2	0
1st day of 3rd week	2	0
2nd day of 3rd week	0	0
3rd day of 3rd week	0	0

From Table 4.26, the number of subjects in the training group complaining about soreness gradually decreased over the training period and disappeared after 3 weeks.

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4.7 Effect of Training on Sprint Velocity

4.7.1 Sprint velocity between 0-20 meters

Mean and standard deviations for sprint velocity between 0-20 meters of both groups and statistical analysis between two groups are presented in Table 4.27. Multiple comparisons among various times of measurement for each group are reported in Tables 4.28 - 4.29.

From the Table 4.27, there was no group effect ($p = 0.964$) but there were time effect ($p < 0.001$) and group × time ($p = 0.001$) interaction. The 1st week or baseline data of sprint velocity between 0-20 meters in control and training groups were 5.47 ± 0.24 and 5.33 ± 0.23 m/s respectively. The comparison between two groups at 1st week or baseline measurement had no significant difference ($p = 0.111$). There was no significant difference on sprint velocity for 0-20 meters in the control group. Eccentric training group showed significant increase in sprint velocity from 1st to 4th week, as shown in Tables 4.28 - 4.29.

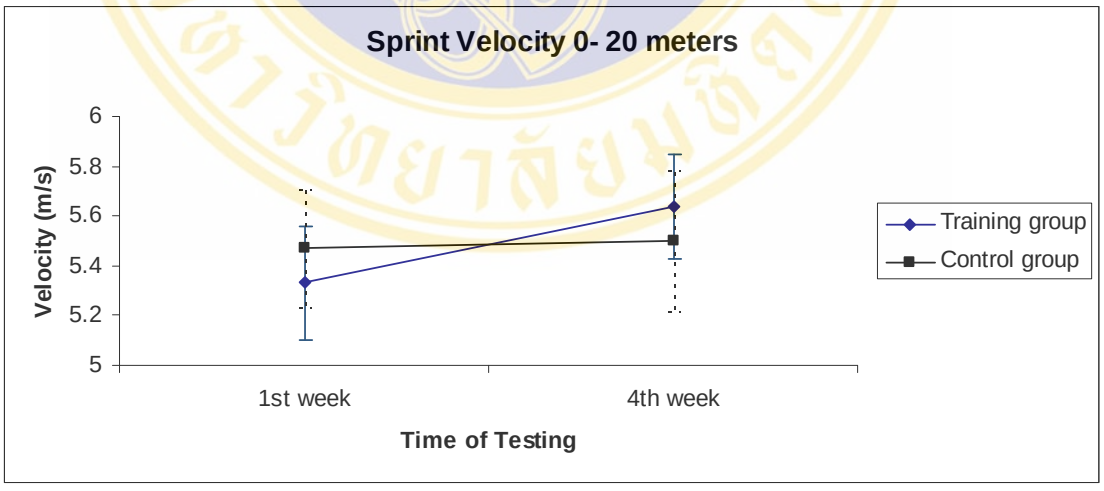

Figure 4.10 Sprint velocity for 0-20 meters at the 1st and 4th week in eccentric training and control groups.

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Table 4.27 Comparison of sprint velocity between 0-20 meters between control and training groups

Sprint velocity (m/s)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	5.33 ± 0.23	5.47 ± 0.24	0.111
Week 4	5.64 ± 0.21	5.50 ± 0.28	0.112
p-value[a]	0.001*		
p-value[b]	< 0.001*		
p-value[c]	0.964		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

Table 4.28 Multiple comparison of sprint velocity between 0-20 meters of control group among various times of measurement

Time	Week 1	Week 4
Week 1	-	0.668
Week 2	-	-

Table 4.29 Multiple comparison of sprint velocity between 0-20 meters of training group among various times of measurement

Time	Week 1	Week 4
Week 1	-	< 0.001*
Week 2	-	-

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4.7.2 Sprint velocity between 20-50 meters

Mean and standard deviations of sprint velocity between 20-50 meters of both groups and statistical analysis between two groups are presented in Table 4.30. Multiple comparisons among various times of measurement for each group are reported in Tables 4.31 - 4.32.

From the Table 4.30, there was no group effect ($p = 0.964$) but there were time effect ($p < 0.001$) and group × time ($p = 0.001$) interaction. The 1st week or baseline data of sprint velocity between 20-50 meters in control and training groups were 6.78 ± 0.52 and 6.74 ± 0.36 m/s respectively. There was no significant difference in control group whereas eccentric training group indicated significant increase from the 1st to 4th week, as shown in Tables 4.31 - 4.32.

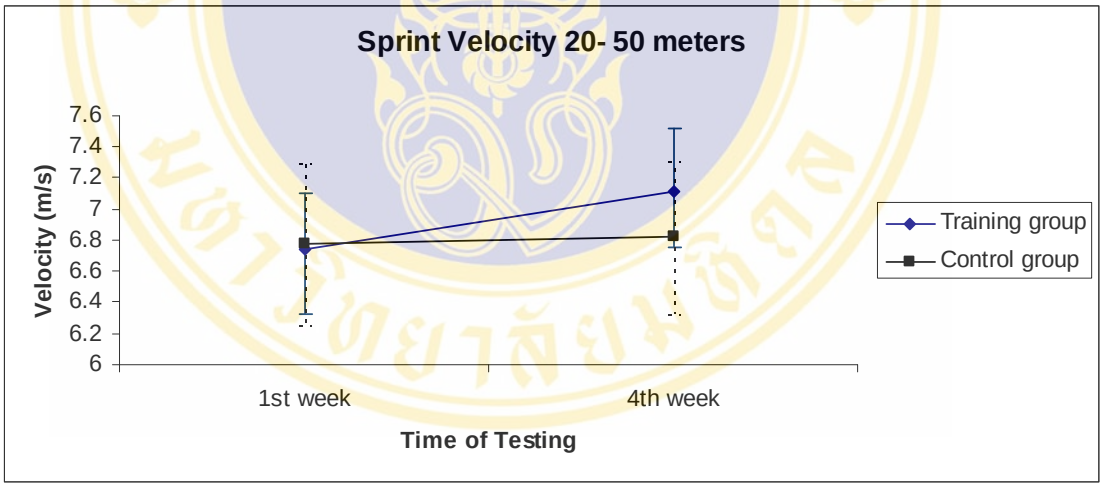

Figure 4.11 Sprint velocity for 20-50 meters at the 1st and 4th week in eccentric training and control groups.

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Table 4.30 Comparison of sprint velocity between 20-50 meters between control and training groups

Sprint velocity (m/s)			
Group / Time	Training group (n=15)	Control group (n=15)	p-value[d]
	Mean ± SD	Mean ± SD	
Week 1	6.74 ± 0.36	6.78 ± 0.52	0.814
Week 4	7.11 ± 0.41	6.82 ± 0.49	0.100
p-value[a]	< 0.001*		
p-value[b]	< 0.001*		
p-value[c]	0.460		

a = p-value from Two-way ANOVA with repeated measures for the interaction Group × Time

b = p-value from Two-way ANOVA with repeated measures for the within-subjects effects

c = p-value from Two-way ANOVA with repeated measures for the between-subjects effects

d = p-value from Two-way ANOVA with repeated measures for the between control and training groups at each time

Table 4.31 Multiple comparison of sprint velocity between 20-50 meters of control group among various times of measurement

Time	Week 1	Week 4
Week 1	-	0.282
Week 2	-	-

Table 4.32 Multiple comparison of sprint velocity between 20-50 meters of training group among various times of measurement

Time	Week 1	Week 4
Week 1	-	< 0.001*
Week 2	-	-

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CHAPTER V

DISCUSSION

5.1 Characteristics of Subjects

Subjects of two groups had no significant difference in age, weight, and height. The age group in this study ranged from 18 to 25 years because it has been reported that the strength of muscle increases up to 25 years old (81). Moreover, hormonal mechanism is one factor promoting strength and muscle hypertrophy that varies between male and female (99). In addition, the strength of a starting state of training also influenced on the training effect. The initial state of strength of training in men differed from women in that women was lower than men (152). It is a reason for the increasing of strength and muscle mass in women more than men after resistance training. Therefore, to reduce gender effect such as menstruation cycle and sex hormone (153) and the difference in strength of an initial state of training between men and women, only male subjects were included in the present study.

The subjects in this study were university students. It could be assumed that the activities of all subjects should be similar. The researcher also instructed the subjects to do the same routine activities and avoid any other specific training programs. It could be possible to conclude that the subjects in this study had the same characteristic. Therefore, the difference in muscle performance after training would be due to the effect of training.

5.2 Effect of Training on Concentric Isokinetic Testing

Although, the aim of the present study was to investigate the effects of fast eccentric hamstring strength training on hamstring performance but strength of concentric contraction of hamstring and quadriceps had increased.

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From the result of the present study, there was no group effect ($p = 0.060$) but there were time effect ($p < 0.001$) and group × time ($p = 0.032$) interaction. The data of peak torque of concentric isokinetic testing of quadriceps muscle at the 1st week or beginning program for the control group was 119.32 ± 14.30 Nm and the training group was 126.07 ± 21.93 Nm. The 1st week or baseline data were not different between control and training groups ($p = 0.326$). When the time changed, the peak torque of concentric isokinetic testing of quadriceps muscle in the training group increased significantly at week-2 and week-4 measurement ($p = 0.001$ and $p < 0.001$ respectively) but no change was observed in the control group. Therefore, the increasing of peak torque of concentric isokinetic testing of quadriceps muscle of training group would be due to the effect of training not due to the learning effect of concentric isokinetic testing. The improvement of concentric peak torque of quadriceps muscle may be due to characteristic of training of the present study. From starting position of this training (knee flexion 90º), the subject performed the exercise by rapidly extended the knee as fast as possible and decelerated at approximately 20º – 30º of knee flexion via an eccentric hamstring contraction. During knee extension, quadriceps muscle performed fast concentric contraction. Therefore, it could increase concentric quadriceps strength.

The result of the present study demonstrated that there was no group effect ($p = 0.216$) but there were time effect ($p < 0.001$) and group × time ($p = 0.018$) interaction. The 1st week or baseline data of peak torque of concentric isokinetic testing of hamstring muscle in control and training groups were 73.44 ± 10.82 and 72.19 ± 13.88 Nm respectively. The 1st week or baseline data between two groups had no difference ($p = 0.785$). The training group showed an increase in peak torque of concentric isokinetic testing of hamstring muscle after training. At 2nd and 4th week, the value of peak torque of concentric isokinetic testing of hamstring muscle in the training group increase significant ($p < 0.001$), whereas control group remained no change when compared to pre-starting program. Therefore, the improvement of the peak torque of concentric isokinetic testing of hamstring muscle of training group would be due to the effect of training not due to the learning effect of concentric isokinetic testing. The increasing of peak torque of concentric contraction of hamstring muscle was due to

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characteristic of the training by concentric contraction in the knee flexion phase; from knee extension position to knee flexion (starting position). Therefore, characteristic of this training could increase concentric hamstring muscle strength. Although, the p-value from Two-way ANOVA with repeated measures for the between-subjects effects showed no significant difference for both peak torque of hamstring and quadriceps muscles, the multiple comparison between two groups showed significant difference at 4^{th} week. This may be due to a small number of sample size. The increasing sample size of the study could lead to an increase significant difference between groups.

5.3 Effect of Training on Eccentric Isokinetic Testing

Strength training has been supported as a preventive measure in order to avoid hamstring muscle injuries especially eccentric hamstring strength (28). Eccentric training appears also to be interesting from a functional point of view as eccentric actions are one part of the functional repertoire of hamstring muscle group. Moreover, there are theories, which state that the strain injury would occur during eccentric hamstring actions (22). Although, training protocol in the present study was modified from the study of Stanton et al (28) which was different from other hamstring training (29, 39, 91, 92), it could increase eccentric hamstring strength.

The result of the study found that there was no group effect ($p = 0.115$) but there were time effect ($p = 0.007$) and group × time ($p = 0.006$) interaction. The 1^{st} week measurement, peak torque of eccentric hamstring muscle of both groups showed no significant difference ($p = 0.628$). In the training group, the peak torque of eccentric hamstring muscle had significant increase from 1^{st} – 2^{nd} weeks (133.67 ± 24.51 vs 147.47 ± 25.50 Nm) and 1^{st} – 4^{th} weeks (133.67 ± 24.51 vs 153.11 ± 28.78 Nm) whereas no difference was indicated in the control group. The p-value from Two-way ANOVA with repeated measures for the between-subjects effects had no significant difference ($p = 0.115$). However, the comparison between two groups at 4^{th} week showed significant difference ($p = 0.014$). These results indicated that this training technique was the specificity of eccentric training (44, 154).

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For the peak torque of eccentric quadriceps muscle, there was no group effect ($p = 0.069$) but there were time effect ($p < 0.001$) and group × time ($p = 0.022$) interaction. Within training group, the significant difference at 2nd week and 4th week ($p = 0.002$, $p < 0.001$ respectively) was found compared to 1st week whereas control group was observed no significant difference, as shown in Tables 4.9 - 4.10. Two-way ANOVA with repeated measured for the between-subjects effects showed no significant difference ($p = 0.069$). Moreover, the comparison between two groups at any time of measurement showed no difference except at 4th week. It may be due to a wide range of standard deviation. Therefore, the increasing sample size of the study may be decrease the value of standard deviation and lead to an increase significant difference between groups.

The increasing of peak torque of eccentric quadriceps muscle might be due to characteristic of training. From knee extension position (approximately 20º – 30º of knee flexion), hamstring functions fast concentric contraction until knee angle approximately 90º flexion (starting position). This phase, quadriceps muscle would contract fast eccentric for stabilizing knee joint. Therefore, this might be due to concentric contraction of hamstring and would lead to eccentric contraction of quadriceps muscle. However, the subject had no report of quadriceps muscle soreness after training.

The improvement of eccentric strength might be result from many reasons. It involves both neural and muscular alterations. Mechanisms of neural adaptation in training were increased activation of agonists, selective recruitment of motor units within agonists, selective activation of agonists within a muscle group and co-contraction of antagonists (94).

The present study demonstrated that changing in peak torque of eccentric quadriceps and hamstring muscles were found in the first two weeks and 4 weeks of training for fast eccentric strength training group. However, for 4 weeks training, values of all parameters increased more than the 2 weeks training (see Tables 4.8, 4.11). The strength gained in the first two weeks was particularly caused by an

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adaptation of neural factors and the strength increased after 6-8 weeks of training was caused by muscular hypertrophy (56, 58, 62, 96, 98). Four weeks of resistive training could gradually gain muscle strength but not as much as 6-8 weeks of training or be able to increase size of the muscles. This could lead to nonsignificant difference in muscle strength between two and four weeks of training.

Several studies investigated result of strength training in increasing strength together with muscle hypertrophy (36, 37, 67). It was found that there was inconsistency in period of the adaptation in muscle hypertrophy. These inconsistency results depended on sensitivity of measurement devices used to assess muscle size, the initial state of training, intensity and duration of training. The large improvement in eccentric force was not caused by learning effect of testing because prior to the testing, all subjects in this study were asked to practice several times until they familiarized to eccentric isokinetic testing.

5.3 Effect of Training on Eccentric Hamstring Torque at End Range

Eccentric hamstring strength at end range of knee extension was interesting to investigate. From a hamstring injury perspective, hamstring muscle strain occurs during eccentric muscle action at late swing phase which is at end range of knee extension (20).

Two-way ANOVA with repeated measures demonstrated that there were no group effect ($p = 0.105$) and time effect ($p = 0.374$) but there was group × time ($p = 0.008$) interaction. The eccentric hamstring torque at 20º of knee flexion at 1st week of control and training groups were 118.44 ± 28.50 and 119.31 ± 31.13 Nm respectively with no significant difference ($p = 0.937$). Another angle of eccentric hamstring torque of the present study was 15º of knee flexion. The result of the study found that there were no a group effect ($p = 0.259$) and time effect ($p = 0.815$) but there was Group × Time ($p = 0.031$) interaction. The 1st week or baseline data of eccentric hamstring torque at 15º of knee flexion in control and training groups no significant difference ($p = 0.999$).

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The findings of our study demonstrated that eccentric hamstring torque at 20º of knee flexion in the training group increased at the 4th week, whereas control group had no improvement. However, it had no significant difference for the between-subjects and within subjects ($p > 0.05$) effects at either 20º or 15º of knee flexion.

The increasing of eccentric hamstring torque at end range may be due to characteristics of training. During training, hamstring muscle contracted eccentrically at end range of knee extension for breaking the knee extension movement. These could increase eccentric hamstring torque at end range of knee extension. The present study found that eccentric hamstring torque at 20º was more than that of 15º which supports the previous study, 20º-30º of knee flexion was the angle of maximum torque of hamstring muscle (155). Moreover, the increasing of torque at end range of knee extension had effective for decelerating or breaking the knee extension especially in late swing of sprinting, and such an improvement can potentially prevent hamstring strains.

5.4 Effect of Training on Hamstring to Quadriceps Ratio

Isokinetic torque ratios of maximal isokinetic hamstring muscle strength relative to maximal isokinetic quadriceps muscle strength (h/q ratio) is a parameter commonly used to describe the muscle strength properties about the knee joint. The hamstring to quadriceps ratio has been used in clinical and in the laboratory as an indicator of the knee stability or balance of strength among muscles spanning the knee (156). The conventional h/q ratio and the functional h/q ratio were investigated in the present study.

5.4.1 Ham/Quad Con

The findings of this study demonstrated that h/q ratio concentric contraction had no significant differences among 1st, 2nd, and 4th weeks both for training and control groups. The concentric conventional h/q ratio of training group was approximately 60% (see Table 4.20). This confirmed that the participants in the present study were healthy subjects without any knee impairment (157). The results of the study showed that this training program did not effect the Ham/Quad Con. It was

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due to improvement of concentric strength of both quadriceps and hamstring muscle (see Table 4.2 and Table 4.5).

5.4.2 Ham/Quad Ecc

The result of the present study demonstrated that there were no group effect ($p = 0.884$) and group × time ($p = 0.669$) interaction but there was time effect ($p = 0.009$). At 1st week, the Ham/Quad Ecc in control and training groups were 71.65 ± 8.78 and 71.81 ± 10.29% respectively without between group significant difference ($p = 0.965$). The value of the Ham/Quad Ecc in the training group gradually decreased from the 1st to 4th week but no significant difference was found among 1st, 2nd, and 4th weeks (see in Tables 4.21, 4.23). The eccentric conventional h/q ratio had no report of normal value. However, the result of the present indicated that this training program was not effect the Ham/Quad Ecc because it could increase eccentric strength of both quadriceps and hamstring muscle (see Tables 4.8. 4.11).

5.4.3 Ham Ecc/Quad Con

Co-activation of muscle groups is known to occur and takes place through opposing contraction modes (158). During knee extension, quadriceps would be contracting concentrically while the hamstring, or stabilizer, would be contracting eccentrically. Our study, a functional h/q ratio used only Ham Ecc/Quad Con. Ham Ecc/Quad Con strength ratio was calculated by expressing eccentric hamstring muscle strength relative to concentric quadriceps muscle strength. A Ham Ecc/Quad Con of 1.0 or 100% is the point equality of eccentric hamstring and concentric quadriceps muscle contraction (159).

The result of this study demonstrated that there were no group effect ($p = 0.787$), time effect ($p = 0.624$) or group × time ($p = 0.413$) interaction. After training, the subjects had no change of the value of Ham/Quad Con from the 1st week. Therefore, it appeared that training protocol of the present study did not effect the Ham Ecc/Quad Con torque ratio in healthy subjects. It may be due to this training technique could increase eccentric strength of hamstring muscle and concentric strength of quadriceps muscle (see Tables 4.2. 4.11).

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In training group, Ham Ecc/Quad Con had values approximated 107-109% at 1st, 2nd, and 4th weeks of measurement (see Table 4.24). It could be indicates a potential for high stability of the knee joint during dynamic knee extension actions associated with high speed movement (159). At high speeds, Ham Ecc/Quad Con in young athletes is provided by Kellis et al (160), who observed almost identical values, 107-118% in young soccer players of similar age. Moreover, adult athletes, the Ham Ecc/Quad Con ratios of 105% for soccer and 101% for track athletes were reported (161).

The h/q ratio in the present study was calculated by using peak torque values of the knee flexors and the knee extensors generated during a concentric or eccentric contractions at a fast specific angular speed (240º/s). The findings of this study demonstrated no significant of h/q ratio of Ham/Quad Con, Ham/Quad Ecc or Ham Ecc/ Quad Con among 1st, 2nd and 4th week either in eccentric training or control group. Thus, this training program did not effect the h/q ratio because it could improve both quadriceps and hamstring muscles strength (see in Tables 4.2, 4.11). In other words, the training program in the present study had no effect on the stability of knee joint.

5.5 Effect of Training on Muscle Soreness

The eccentric training is associated with muscle pain and soreness and leads to the inhibition of the strength improvement (68, 105). Researcher recorded muscle soreness level by asking the subjects and reported on the 10-cm visual analog scale immediately after testing and training.

Muscle soreness can be caused by many factors from various activities. There are three types of muscle soreness classified by the onset of pain and soreness perception. Those are 1) rapid onset muscle soreness, 2) sudden onset muscle soreness (muscle cramp), and 3) delayed onset muscle soreness. For the present study, rapid onset muscle soreness and delayed onset muscle soreness occurred in the subjects of the training group. Rapid onset muscle soreness or ischemic pain usually happens while or immediately after doing activities or exercise. It is caused by decrease in blood flow to muscle from sustained or rhythmic concentric and isometric contractions. The depletion of blood flow stimulates onset of muscle pain. The

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severity of pain depends on energy expenditure (162). For delayed onset muscle soreness (DOMS), it is discomfort or pain (dull aching pain) in muscles that have been contracted eccentrically in unaccustomed exercise. Eccentric contractions cause greater fatigue, soreness, and damage than isometric and concentric contractions. The soreness occurs 1 to 2 days after exercise at the musculotendinous junction initially (163, 164).

Muscle soreness values for eccentric training group were 2.64 ± 1.95, 1.23 ± 1.81, 0.4 ± 1.06, and 0.4 ± 1.06 centimeters at the 1st day of 2nd week, 2nd day of 2nd week, 3rd day of 2nd week and 1st day of 3rd week respectively while control group no soreness. Muscle soreness may occur after an acute resistance training session. Eccentric training mostly precipitates delayed onset muscle soreness (DOMS), especially in untrained persons or a novel bout of eccentric exercise after one to three days. However, the symptom of muscle soreness disappeared or reduced after the repeated bouts and adaptation response may recover rapidly (103, 107, 165, 166). For the present study, the number of subjects complaining about soreness gradually decreased over the training period and disappeared after 3 weeks (10/15 after the 1st day training of 2nd week, 5/15 after the 2nd day training of 2nd week, 2/15 after the 3rd day training of 2nd week and 2/15 after the 1st day training of 3rd week). Some studies showed an immediate strength loss of 30-50% after exercise and required time to recover (103, 107, 109, 165, 167-169). However, muscle soreness did no disturb either testing or training because the testing of present study was not measured immediately after training. Enoka in 1996 suggested (63) that the eccentric exercise program which was the progressive training pattern did not produce any muscle injury and severe muscle soreness. An adequate rest day between the eccentric training sessions was another factor that would reduce muscle pain (170). Beside some studies showed that delayed muscle soreness was eliminated by optimal warm up prior to exercise for example: stretching and cycle ergometer (34, 62, 165). Subjects in the present study were asked to warm up by stretching and cycling on a stationary cycle ergometer before testing. Moreover, they were asked to perform stretching and training 1 set before the actual training. However, the symptom of muscle soreness still occur. This would be due to the eccentric contraction with fast velocity training as mentioned.

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5.6 Effect of Training on Sprint Velocity

5.6.1 Sprint velocity between 0-20 meters

Sprint velocity for acceleration phase of the training group increased significantly in the 1^{st} – 4^{th} weeks (5.33 ± 0.23 vs 5.64 ± 0.21 m/s) whereas no change in the control group (5.47 ± 0.24 vs 5.50 ± 0.28 m/s). Acceleration relies on powerful extensions of lower extremity joints (154). Therefore, improvements in strength of the knee and hip extensors are more likely to result in improvements of acceleration performance. In our study, knee extensors strength had increased significantly. Thus, it is possible that this training protocol improved acceleration performance.

5.6.2 Sprint velocity between 20-50 meters

Maximum speed phase is one characteristic of sprint event, which necessitates the backward and forward rotation of the legs (154) .The improvements in hamstring power may result to a greater running velocity in maximum speed phase.

The results of the present study demonstrated that the sprint velocity between 20-50 meters of the eccentric training group increased significantly in the 1^{st} – 4^{th} weeks (6.74 ± 0.36 vs 7.11 ± 0.41 m/s) but it remained unchanged in the control group (6.78 ± 0.52 vs 6.82 ± 0.49 m/s). Therefore, it was expected that after fast eccentric strength training the participants would improve running velocity in maximum speed phase by improvements of hamstring power. Although, this training protocol was different from other studies (29, 136), it could also increase sprint velocity such as studied of Askling et al (29). Askling et al (29) studied eccentric strength training program for the hamstring muscle group. The results showed significant increases in strength and maximum speed in the training group.

5.7 Clinical Implications and Further Study

The main objective of this study was to investigate the effects of a program of the fast eccentric strength training on hamstring muscle performance. Isokinetic dynamometer provided the quantitative data of peak torque, eccentric hamstring torque at end range of knee extension (15º and 20º of knee flexion), Ham/Quad Con,

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Ham/Quad Ecc, and Ham Ecc/Quad Con. Moreover, infrared timing device was used to investigate sprint velocity; acceleration phase and maximum speed phase. These parameters were the indicators to determine muscular performance. The findings of the present study indicated that the training protocol used could improve muscle performance within 4 weeks.

Although, training protocol in the present study was different from other studies (29, 39, 91) but it could also increase muscle performance; strength and sprint velocity whereas did not effect on the stability of knee joint and had mild soreness in 2^{nd} - 3^{rd} week of training. This training technique can be applied in eccentric hamstring training because this training protocol requires little equipment, simple, and similar to functional movement. Therefore, the results of this study could be a guideline for planning the training program to improve hamstring muscle performance. For early stage of rehabilitation, this technique should be applied with care because muscle soreness and myofibrillar damage could occur with fast eccentric training.

For further study, firstly, it is interesting to investigate, whether or not the simple training technique in this study could increase muscle performance in athletes. Secondly, whether or not this fast eccentric hamstring strength training program could prevent the occurrence and severity of hamstring injuries during competition season.

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CHAPTER VI
CONCLUSION

This study investigated the effects of fast eccentric strength training on hamstring muscle performance in healthy male subjects. All subjects had no health problem that could interrupt training and testing. Subjects were randomly divided into two groups; fast eccentric strength training and control groups. The subjects in fast eccentric strength training group were trained 3 times per week for 4 weeks. The parameters were quadriceps and hamstring peak torque, eccentric hamstring torque at end range of knee extension (15^{o} and 20^{o} of knee flexion), h/q ratio of concentric contraction (Ham/Quad Con), h/q ratio of eccentric contraction (Ham/Quad Ecc), and h/q ratio of hamstring eccentric contraction and quadriceps concentric contraction (Ham Ecc/Quad Con), sprint velocity in acceleration phase (0-20 m) and sprint velocity in maximum speed phase (20-50 m). Evaluations were performed at 1^{st}, 2^{nd}, and 4^{th} weeks of measurement.

After two and four weeks of training, the fast eccentric hamstring strength training group could significantly increase concentric quadriceps peak torque, concentric hamstring peak torque, eccentric quadriceps peak torque, eccentric hamstring peak torque, eccentric hamstring torque at end range of knee extension, sprint velocity in acceleration and maximum speed phases ($p<0.05$) whereas the control group remained unchange. In addition, Ham/Quad Con, Ham/Quad Ecc, and Ham Ecc/Quad Con of both groups showed no significant differences among days of testing.

In conclusion, this study indicated that the fast eccentric hamstring strength training which consisted of 4 sets per time, 3 times a week for 4 weeks was sufficient to increase strength for both hamstring and quadriceps muscles and to improve sprint velocity. The training program did not effect on the stability of knee joint in healthy young male subjects.

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APPENDIX

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APPENDIX A
PARTICIPANT INFORMATION SHEET

(เอกสารแนะนำสำหรับอาสาสมัคร)

ในเอกสารนี้อาจมีข้อความที่ท่านอ่านแล้วยังไม่เข้าใจ โปรดสอบถามหัวหน้าโครงการวิจัย หรือผู้แทนให้ช่วยอธิบายจนกว่าจะเข้าใจดี ท่านอาจจะขอเอกสารนี้กลับไปอ่านที่บ้านเพื่อปรึกษาหารือกับญาติพี่น้อง เพื่อนสนิท แพทย์ประจำตัวของท่าน หรือแพทย์ท่านอื่น เพื่อช่วยในการตัดสินใจเข้าร่วมการวิจัย

ชื่อโครงการ ผลการฝึกความแข็งแรงแบบยืดยาวออกอย่างเร็วต่อความสามารถของกล้ามเนื้อ hamstring

ชื่อผู้วิจัย นายพงษ์ชัย วัชรเขื่อนขันธ์

สถานที่วิจัย คณะกายภาพบำบัดและวิทยาศาสตร์การเคลื่อนไหวประยุกต์ อาคารสำนักงานมหาวิทยาลัยมหิดล ชั้น6 เชิงสะพานสมเด็จพระปิ่นเกล้า โทรศัพท์ 0-2433-7092

ผู้ให้ทุน ไม่มี

โครงการวิจัยนี้ทำขึ้นเพื่อศึกษาผลการฝึกความแข็งแรงกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) แบบยืดยาวออกอย่างเร็ว ซึ่งประโยชน์ที่คาดว่าจะได้รับคือ สามารถนำข้อมูลที่ได้จากการศึกษาวิจัยครั้งนี้ไปเป็นแนวทางการวางแผนโปรแกรมการฝึกหรือโปรแกรมฟื้นฟูสำหรับผู้บาดเจ็บกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) รวมทั้งเป็นการป้องกันการบาดเจ็บในการเล่นกีฬาที่ต้องมีการวิ่งด้วยความเร็วสูงระยะสั้น

ท่านได้รับเชิญให้เข้าร่วมการวิจัยนี้ เพราะท่านเป็นผู้ที่มีคุณสมบัติครบถ้วน ตามเกณฑ์ที่ผู้วิจัยกำหนด คือ ไม่เคยมีการบาดเจ็บกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) ไม่มีประวัติการความผิดปกติทางระบบกระดูกและกล้ามเนื้อของขาข้างใดข้างหนึ่งภายใน 6 เดือนก่อนเริ่มการศึกษา ไม่ได้อยู่ระหว่างการออกกำลังกายแบบมีแรงต้านหรือฝึกการเล่นกีฬาใด ๆ ไม่มีการจำกัดการเคลื่อนไหวของข้อสะโพก ข้อเข่าหรือข้อเท้า และถนัดขาขวา

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โครงการวิจัยนี้จะมีผู้เข้าร่วมการวิจัยทั้งสิ้น 40 คน ระยะเวลาที่ใช้ในการวิจัยเดือนตุลาคม 2549 ถึง ตุลาคม 2550

เมื่อท่านเข้าร่วมการวิจัยแล้ว สิ่งที่ท่านจะต้องปฏิบัติตามขั้นตอนการดำเนินการวิจัยมีดังต่อไปนี้

ขั้นตอนการเตรียมการ

ผู้วิจัยทำการอธิบายวัตถุประสงค์ ขั้นตอนการศึกษา ประโยชน์ของการศึกษา ความเสี่ยงในการวิจัย รวมทั้งการป้องกันและความปลอดภัยของการศึกษานี้ จากนั้นผู้เข้าร่วมการวิจัยลงนามในใบยินยอมเข้าร่วมวิจัย

ผู้วิจัยสัมภาษณ์ประวัติทั่วไปและประวัติความเจ็บป่วย เช่น โรคประจำตัว และการบาดเจ็บ รวมทั้งได้รับการวัดความดันโลหิตจากผู้วิจัย

ผู้เข้าร่วมการวิจัยทุกคน จะได้รับการทดสอบความถนัดของขา โดยการให้เตะลูกฟุตบอล เอาปลายขาวาดเป็นรูปเลขแปดบนพื้น และใช้เท้าเก็บยางลบบนพื้น

ขั้นตอนการเก็บข้อมูล

ท่านจะได้รับการทดสอบความแข็งแรงของกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) และ กล้ามเนื้อต้นขาด้านหน้า (quadriceps muscle) ก่อนการฝึก สัปดาห์ที่ 2 และ 4 หลังจากการฝึก รวมทั้งทดสอบความเร็วในการวิ่งระยะสั้น ก่อนและหลังการฝึก โดยวิธีการทดสอบและการฝึกมีดังต่อไปนี้

1. <u>ทดสอบความแข็งแรงของกล้ามเนื้อ</u> ท่านจะได้รับการทดสอบความแข็งแรงของกล้ามเนื้อต้นขาด้านหลังและกล้ามเนื้อต้นขาด้านหน้า ทั้งแบบหดสั้นและแบบยืดยาวออกจากเครื่องไอโซไคเนติกส์ ซึ่งเป็นเครื่องวัดความแข็งแรงของกล้ามเนื้อ ที่ความเร็ว 240º/วินาที โดยท่านจะได้รับการอธิบายวิธีการทดสอบ ความเสี่ยงที่อาจจะเกิดขึ้นและแนวทางการป้องกันจากการทดสอบนี้ ผู้วิจัยจะทดสอบขาข้างที่ถนัดที่เป็นขาขวาเพียงข้างเดียวเท่านั้น ให้ท่านอบอุ่นร่างกายทั่วไป โดยการปั่นจักรยานอยู่กับที่ 3 นาที ด้วยกำลัง 50 วัตต์ จากนั้นทำการยืดกล้ามเนื้อขาข้างที่จะทำการทดสอบ ได้แก่ กล้ามเนื้อต้นขาด้านหลัง กล้ามเนื้อน่อง และกล้ามเนื้อต้นขาด้านหน้า กล้ามเนื้อละ 3 ชุด ทำค้างชุดละ 15 วินาที

ต่อจากนั้นผู้วิจัยจะทำการปรับท่าทางของท่าน โดยให้ท่านนั่งบนที่นั่งของเครื่องไอโซไคเนติกส์ ผู้วิจัยจะปรับที่นั่งให้ข้อตะโพกงอ 95º ปรับให้แกนหมุนของข้อเข่าตรงกับแกนหมุนของเครื่อง นำสายรัด รัดที่บริเวณหน้าอก กระดูกเชิงกราน ต้นขาและข้อเท้า (สายรัดจะไม่แน่นจนท่าน

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รู้สึกอึดอัด หรือหายใจไม่สะดวกในขณะทำการทดสอบ) และตั้งค่าให้มีช่วงการเคลื่อนไหวของข้อเข่าเป็น 10º - 90º คือมุมที่ข้อเข่าเหยียดสุด (0º)

การทดสอบจะแบ่งเป็น 2 ช่วง ช่วงที่หนึ่งจะเป็นการทดสอบความแข็งแรงของกล้ามเนื้อต้นขาด้านหลังและกล้ามเนื้อต้นขาด้านหน้าแบบหดสั้น (concentric contraction) ที่ความเร็ว 240º/วินาที เริ่มจากการอบอุ่นร่างกายโดยใช้เครื่องไอโซไคเนติกส์เพื่อให้ท่านมีความคุ้นเคยกับความเร็วและแรงต้าน โดย 1 รอบ ประกอบด้วยการให้ออกแรงเหยียดเข่า (concentric contraction) จนกระทั่งมุมข้อเข่าถึงมุม10 º ที่ได้ตั้งค่าไว้ และให้งอเข่าจนเข่างอ 90º (concentric contraction) การอบอุ่นร่างกายโดยใช้เครื่องไอโซไคเนติกส์นี้จะให้ท่านทำ 4 รอบ โดย 3 รอบแรกใช้แรงต่ำกว่าแรงสูงสุดที่จะทำได้ จากนั้นให้ออกแรงมากที่สุดเท่าที่จะสามารถทำได้อีก 1 รอบ พัก 1 นาที และจึงเริ่มทำการทดสอบจริง โดยการทดสอบจริงจะทำ 3 รอบ โดยให้ท่านใช้แรงมากที่สุดเท่าที่จะสามารถทำได้ของตนเอง จากนั้นให้พัก 2 นาที เพื่อเริ่มการทดสอบช่วงที่สองต่อไป

การทดสอบช่วงที่สองจะเป็นการทดสอบความแข็งแรงของกล้ามเนื้อต้นขาด้านหลังและกล้ามเนื้อต้นขาด้านหน้าแบบยืดยาวออก (eccentric contraction) ที่ความเร็ว 240º/วินาที ซึ่งขั้นตอนการทดสอบจะเหมือนกับการทดสอบความแข็งแรงของกล้ามเนื้อกล้ามเนื้อต้นขาด้านหลังและกล้ามเนื้อต้นขาด้านหน้าแบบหดสั้น ที่ความเร็ว 240º/วินาที ที่กล่าวไปแล้วในข้างต้น แต่จะมีความแตกต่างเรื่องทิศทางการเคลื่อนไหวของเครื่องไอโซไคเนติกส์จะตรงข้ามกับการให้แรงต้านของท่านต่อเครื่องไอโซไคเนติกส์ โดย 1 รอบ ประกอบด้วยการให้ออกแรงงอเข่า ซึ่งขณะท่านพยายามออกแรงงอเข่านี้ การเคลื่อนไหวของข้อเข่าจะเกิดขึ้นในทิศทางเหยียดเข่า (eccentric contraction) จนกระทั่งข้อเข่าถึงมุม 10º ที่ได้ตั้งค่าไว้ จากนั้นให้ออกแรงเหยียดเข่า ซึ่งขณะที่ท่านพยายามเหยียดเข่านี้ การเคลื่อนไหวของข้อเข่าจะเกิดขึ้นในทิศทางงอเข่า จนเข่างอ 90º (eccentric contraction)

หลังการทดสอบให้ท่านทำการ cool-down โดยการปั่นจักรยานอยู่กับที่ 3 นาที ด้วยความหนัก50 วัตต์ จากนั้นทำการยืดกล้ามเนื้อขาข้างที่ทำการทดสอบได้แก่ กล้ามเนื้อต้นขาด้านหลัง กล้ามเนื้อน่อง และกล้ามเนื้อต้นขาด้านหน้า กล้ามเนื้อละ 3 ชุด ทำค้างชุดละ 15 วินาที

2. <u>ทดสอบความเร็วในการวิ่ง</u> ให้ท่านทำการอบอุ่นร่างกายโดยยืดกล้ามเนื้อขา ประกอบด้วย กล้ามเนื้อต้นขาด้านหลัง กล้ามเนื้อน่อง และ กล้ามเนื้อต้นขาด้านหน้าของขาทั้ง 2 ข้างและวิ่ง 3 นาที ก่อนทำการทดสอบ จากนั้นให้ท่านทำการทดสอบโดยการวิ่ง 50 เมตร ให้เร็วที่สุด 2 ครั้ง การวัดความเร็วจะใช้เครื่องวัดพลวัต 3 ตัว วางที่ตำแหน่งเริ่มต้น ระยะทาง 20 เมตรและ 50 เมตร เพื่อวัดความเร็วในช่วง 0-20 เมตร และความเร็วในช่วง 20-50 เมตร ท่านจะได้รับการพัก 2 นาที ระหว่างการ

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วิ่งแต่ละครั้ง ผู้วิจัยจะนำความเร็วในการวิ่งช่วง 20-50 เมตร ที่ดีที่สุดมาวิเคราะห์ข้อมูลต่อไป และภายหลังการทดสอบให้ท่านวิ่ง 3 นาที เพื่อทำการ cool-down

การทดสอบความแข็งแรงของกล้ามเนื้อโดยใช้เครื่องไอโซไคเนติกส์และการทดสอบความเร็วในการวิ่งจะทำการทดสอบคนละวัน โดยจะทำการทำสอบความเร็วในการวิ่งก่อนแล้วพัก 1 วัน จากนั้นจึงทำการทดสอบความแข็งแรงของกล้ามเนื้อต่อไป และภายหลังการทดสอบความแข็งแรงของกล้ามเนื้อจะเว้นช่วง 2 วัน และเริ่มทำการฝึกต่อไป

3. <u>การฝึกความแข็งแรงกล้ามเนื้อต้นขาด้านหลัง (hamstring muscle) แบบยืดยาวออก</u> ท่านจะได้รับการฝึกทั้ง 2 ขา โดยจะได้รับการวัดแรงแบบคงที่สูงสุดของกล้ามเนื้อต้นขาด้านหลังของขาขวาด้วยเครื่องวัดแรงกล้ามเนื้อแบบมือจับ (hand held dynamometer) ในวันแรกของทุกสัปดาห์ของการฝึก และท่านจะได้รับการฝึกความแข็งแรงของกล้ามเนื้อต้นขาด้านหลังแบบยืดยาวออก 3 ครั้ง/สัปดาห์ เป็นเวลา 4 สัปดาห์ โดยก่อนเริ่มการฝึกแต่ละครั้ง ท่านจะทำการยืดกล้ามเนื้อต้นขาด้านหลัง กล้ามเนื้อน่อง และ กล้ามเนื้อต้นขาด้านหน้าของขาทั้ง 2 ข้าง จากนั้นให้ท่านอยู่ในท่าเริ่มต้นโดยนอนคว่ำบนเตียงนอนที่ปรับให้ข้อสะโพกอยู่ในท่างอประมาณ 30º และข้อเข่าอยู่ในท่างอประมาณ 90˚ เมื่อได้ยินสัญญาณบอกให้เริ่มออกกำลังให้ท่านเหยียดเข่าออกไปอย่างเร็วที่สุดเท่าที่จะทำได้ และชะลอจนเกือบจะหยุดที่ข้อเข่างอประมาณ 20º-30º จากนั้นให้งอเข่าขึ้นมา จนข้อเข่างอกลับมาอยู่ประมาณ 90º เท่าเดิม จากนั้นค่อยเริ่มทำการเหยียดเข่าออกไปอย่างเร็วอีกครั้ง ทำสลับไปมาจำนวน 12 ครั้งต่อชุด ทำ 3 ชุดต่อ 1 ขา พัก 1 นาทีระหว่างชุด และพัก 1 นาที ก่อนที่จะเริ่มฝึกทำขาอีกข้าง โดยจะมีการเพิ่มความยากตามลำดับดังนี้

<u>สัปดาห์ที่1</u> ทำการออกกำลังกายโดยไม่มีการถ่วงน้ำหนัก จำนวน 12 ครั้งต่อชุด 3 ชุดต่อวันต่อขา 1 ข้าง เป็นเวลา 3 วัน

<u>สัปดาห์ที่2</u> ทำการออกกำลังกายโดยมีถุงน้ำหนักถ่วงที่ข้อเท้า ที่มีน้ำหนักเท่ากับ 10% ของแรงกล้ามเนื้อต้นขาด้านหลังขณะยืดยาวออกที่สูงสุด ซึ่งวัดจากวันแรกของสัปดาห์ที่ 2 ของการฝึก จำนวน 12 ครั้งต่อชุด 3 ชุดต่อวันต่อขา 1 ข้าง เป็นเวลา 3 วัน

<u>สัปดาห์ที่3</u> ทำการออกกำลังกายโดยมีถุงน้ำหนักถ่วงที่ข้อเท้า ที่มีน้ำหนักเท่ากับ 10% ของแรงกล้ามเนื้อต้นขาด้านหลังขณะยืดยาวออกที่สูงสุด ซึ่งวัดจากวันแรกของสัปดาห์ที่ 3 ของการฝึก จำนวน 12 ครั้งต่อชุด 3 ชุดต่อวันต่อขา 1 ข้าง เป็นเวลา 3 วัน

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<u>สัปดาห์ที่4</u> ทำการออกกำลังกายโดยมีถุงน้ำหนักถ่วงที่ข้อเท้า ที่มีน้ำหนักเท่ากับ 10% ของแรงกล้ามเนื้อต้นขาด้านหลังขณะยืดยาวออกที่สูงสุด ซึ่งวัดจากวันแรกของสัปดาห์ที่ 4 ของการฝึกจำนวน 12 ครั้งต่อชุด 3 ชุดต่อวันต่อขา 1 ข้าง เป็นเวลา 3 วัน

หากเกิดผลข้างเคียงที่ไม่พึงประสงค์จากการวิจัยครั้งนี้ ทางคณะผู้วิจัยจะยุติการวิจัยโดยทันทีและจะให้ท่านได้รับการรักษาที่เหมาะสมต่อสภาพการณ์นั้น ๆ หรือหากผู้เข้าร่วมวิจัยมีข้อสงสัยที่เกี่ยวกับการวิจัยสามารถติดต่อสอบถามได้ที่ นายพงษ์ชัย วัชรเขื่อนขันธ์ อาคารสำนักงานมหาวิทยาลัยมหิดล (เดิม) ชั้น 4 198/2 ถ.เชิงสะพานพระปิ่นเกล้า แขวงบางยี่ขัน เขตบางพลัด กทม. 10700 เบอร์โทรศัพท์ 02-433-7092, 08-6326-8162ได้ทุกเวลา

การวิจัยนี้ไม่มีค่าตอบแทนที่จะได้รับ และไม่มีค่าใช้จ่ายใด ๆ ที่ท่านจะต้องรับผิดชอบ

หากมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ทราบโดยรวดเร็วไม่ปิดบัง

ข้อมูลส่วนตัวของท่านจะถูกเก็บรักษาไว้ ไม่เปิดเผยต่อสาธารณะเป็นรายบุคคล แต่จะรายงานผลการวิจัยเป็นข้อมูลส่วนรวม ข้อมูลของท่านเป็นรายบุคคลอาจมีคณะบุคคลบางกลุ่มเข้ามาตรวจสอบได้ เช่น ผู้ให้ทุนวิจัย สถาบันหรือองค์กรของรัฐที่มีหน้าที่ตรวจสอบ คณะกรรมการจริยธรรมฯ เป็นต้น

ท่านมีสิทธิ์ถอนตัวออกจากโครงการการวิจัยเมื่อใดก็ได้ โดยไม่ต้องแจ้งให้ทราบล่วงหน้า และการไม่เข้าร่วมการวิจัยหรือถอนตัวออกจากโครงการวิจัยนี้จะไม่มีผลกระทบต่อการบริการและการรักษาที่ สมควรจะได้รับแต่ประการใด

ข้าพเจ้าได้อ่านรายละเอียดในเอกสารนี้ครบถ้วนแล้ว และยินยอมเข้าร่วมในการศึกษาวิจัยครั้งนี้ด้วยความสมัครใจ

ลงชื่อ/.....วันที่ .....

(……)

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APPENDIX B
CONSENT FORM

(หนังสือแสดงเจตนายินยอมเข้าร่วมการวิจัย)

การวิจัยเรื่อง ผลการฝึกความแข็งแรงแบบยืดยาวออกอย่างเร็วต่อความสามารถของกล้ามเนื้อ hamstring (Effect of fast eccentric strength training on hamstring muscle performance)

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

ก่อนที่จะลงนามในใบยินยอมให้ทำการวิจัยนี้ ข้าพเจ้าได้รับการอธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการวิจัย วิธีการวิจัย อันตราย หรืออาการที่อาจเกิดขึ้นจากการวิจัย รวมทั้งประโยชน์ที่จะเกิดขึ้นจากการวิจัยอย่างละเอียด และมีความเข้าใจดีแล้ว

ผู้วิจัยรับรองว่าจะตอบคำถามต่าง ๆ ที่ข้าพเจ้าสงสัยด้วยความเต็มใจ ไม่ปิดบังซ่อนเร้น จนข้าพเจ้าพอใจ

ข้าพเจ้ามีสิทธิที่จะบอกเลิกการเข้าร่วมโครงการวิจัยนี้เมื่อใดก็ได้ และเข้าร่วมโครงการวิจัยนี้โดยสมัครใจ และการบอกเลิกการเข้าร่วมการวิจัยนี้ จะไม่มีผลต่อการรักษาที่ข้าพเจ้าจะพึงได้รับต่อไป

ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะที่เกี่ยวกับตัวข้าพเจ้าเป็นความลับ และจะเปิดเผยได้เฉพาะในรูปที่สรุปผลการวิจัย การเปิดเผยข้อมูลเกี่ยวกับตัวข้าพเจ้าต่อหน่วยงานต่าง ๆ ที่เกี่ยวข้องกระทำได้เฉพาะกรณีจำเป็นด้วยเหตุผลทางวิชาการเท่านั้น

ผู้วิจัยรับรองว่าหากเกิดอันตรายใด ๆ จากการวิจัยดังกล่าว ข้าพเจ้าจะได้รับการรักษาพยาบาล โดยไม่คิดมูลค่าตามมาตรฐานวิชาชีพ และจะได้รับการชดเชยรายได้ที่สูญเสียไประหว่างการรักษา พยาบาลดังกล่าว ตลอดจนเงินทดแทนความพิการที่อาจเกิดขึ้น

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ผู้วิจัยรับรองว่าหากมีข้อมูลเพิ่มเติมที่ส่งผลกระทบต่อการวิจัย ข้าพเจ้าจะได้รับการแจ้งให้ทราบ โดยไม่ปิดบังซ่อนเร้น

ข้าพเจ้าได้อ่านข้อความข้างต้นแล้ว และมีความเข้าใจดีทุกประการ และได้ลงนามในใบยินยอม นี้ด้วยความเต็มใจ

ลงนาม ..... ผู้ยินยอม
ลงนาม ..... พยาน
ลงนาม ..... พยาน

ในกรณีที่ผู้ยินยอมตนให้ทำการวิจัยไม่สามารถอ่านหนังสือได้ จะต้องได้รับการยินยอมในขณะ ที่ยังมีสติสัมปชัญญะ และระบุข้อความไว้ตามนี้ ข้าพเจ้าไม่สามารถอ่านหนังสือได้ แต่ผู้วิจัยได้อ่าน ข้อความในใบยินยอมนี้ให้แก่ข้าพเจ้าฟังจนเข้าใจดีแล้ว ข้าพเจ้าจึงลงนาม หรือประทับลายนิ้วแม่มือขวา ของข้าพเจ้าในใบยินยอมนี้ด้วยความเต็มใจ

ลงนาม ..... ผู้ยินยอม
ลงนาม ..... พยาน
ลงนาม ..... พยาน

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APPENDIX C

SCREENING QUESTIONNAIRE (IN THAI)

(แบบสัมภาษณ์ข้อมูลผู้เข้าร่วมการวิจัย)

เลขที่.....

ส่วนที่ 1 ข้อมูลทั่วไปของผู้เข้าร่วมการวิจัย

ชื่อ-สกุล.....เพศ.....อายุ.....ปี.....เดือน

น้ำหนัก.....กิโลกรัม ส่วนสูง.....เซนติเมตร

โทรศัพท์..... E-mail address.....

สำหรับผู้วิจัย
ขาข้างที่ถนัด..... ความดันโลหิต =.....มิลลิเมตรปรอท

ส่วนที่ 2 ข้อมูลทางด้านสุขภาพ

โปรดตอบคำถามต่อไปนี้ตามความเป็นจริง โดยทำเครื่องหมาย ✓ ลงใน ☐ หรือ เติมข้อความลงในช่องว่างที่เว้นไว้ ดังนี้

1. ท่านมีปัญหาอาการบาดเจ็บของระบบกระดูกและกล้ามเนื้อของขาข้างใดข้างหนึ่งหรือทั้งสองข้าง เช่น อาการปวดกล้ามเนื้อหรือไม่

☐ ไม่มี ☐ มี

2. ท่านเคยได้รับบาดเจ็บหรือได้รับการผ่าตัดที่ข้อเข่า หรือไม่

☐ ไม่เคย ☐ เคย

3. ท่านเคยมีประวัติเป็นโรคทางระบบประสาท และ/หรือโรคทางระบบหัวใจและหลอดเลือดหรือไม่

☐ ไม่เคย ☐ เคย

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4. ขณะนี้ท่านมีการออกกำลังกายแบบมีแรงต้านหรือฝึกเล่นกีฬาใด ๆ หรือไม่

☐ ไม่มี ☐ มี

5.ขณะนี้ท่านมีปัญหาทางด้านสุขภาพ และ/หรือมีภาวะเครียด หรือไม่

☐ ไม่มี ☐ มี

6. ท่านมีโรคประจำตัวหรือเคยมีประวัติการเจ็บป่วยที่สำคัญ หรือไม่

☐ ไม่มี ☐ มี

ถ้ามี โปรดระบุ.....

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APPENDIX D

DATA COLLECTION FORM

No…….

1. Personal information

Name……....Lastname…….Gender….....Age……..years

Weight……..kg. Height…….cm

2. Groups

☐ Control group ☐ Eccentric training group

3. Isokinetic testing

3.1 Positioning Chair

1. Chair Front/Back =……
2. Chair Height =……
3. Chair Rotation =……
4. Seatback Tilt =……
5. Seatback Fore/Aft =……
6. Attachment Length =……

3.2 Limb weight =……Nm.

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Evaluation of strength

1. 1st testing

Side : Right		Hamstring muscle 240 degrees/second		Quadriceps muscle 240 degrees/second	
Number of repetitions : 3		Concentric contraction	Eccentric contraction	Concentric contraction	Eccentric contraction
Peak torque (PT)	N-M (degrees)				
Peak torque/Body weight (kg)	%				
Hamstring : Quadriceps ratio	%	Con/con		Ecc/ecc	

2. 2nd testing

Side : Right		Hamstring muscle 240 degrees/second		Quadriceps muscle 240 degrees/second	
Number of repetitions : 3		Concentric contraction	Eccentric contraction	Concentric contraction	Eccentric contraction
Peak torque (PT)	N-M (degrees)				
Peak torque/Body weight (kg)	%				
Hamstring : Quadriceps ratio	%	Con/con		Ecc/ecc	

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3. 3rd testing

Side : Right		Hamstring muscle 240 degrees/second		Quadriceps muscle 240 degrees/second	
Number of repetitions : 3		Concentric contraction	Eccentric contraction	Concentric contraction	Eccentric contraction
Peak torque (PT)	N-M (degrees)				
Peak torque/Body weight (kg)	%				
Hamstring : Quadriceps ratio	%	Con/con		Ecc/ecc	

4. Speed testing

	1st testing		2nd testing	
	1st	2nd	1st	2nd
Sprint velocity 0-20 m. (m/s)				
Sprint velocity 20 -50 m. (m/s)				

5. Isometric test

Hamstring muscle (Right side)

1. **1st testing** =…… **kg.**
2. **2nd testing** =…… **kg.**
3. **3rd testing** =…… **kg.**

6. Resistance weight

1. **2nd week of training** =…… **kg.**
2. **3rd week of training** =…… **kg.**
3. **4th week of training** =…… **kg.**

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7. Delay onset muscle soreness

1st week

1st time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

2nd time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

3rd time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

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2nd week

1st time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

2nd time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

3rd time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

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3rd week

1st time

---

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

2nd time

---

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

3rd time

---

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

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4th week

1st time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

2nd time

no symptom very severe

Area……...

Time of soreness…….....

Note……...

…….....

3rd time

no symptom very severe

Area……...

Time of soreness…….....

Note……..

……

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APPENDIX E

THE ETHICAL COMMITTEE ON RESEARCH INVOLVING HUMAN SUBJECT

No. MU 2006-193

Documentary Proof of Ethical Clearance
The Committee on Human Rights Related to
Human Experimentation
Mahidol University, Bangkok

Title of Project: Effect of Fast Eccentric Strength Training on Hamstring Muscle Performance
(Thesis for Master Degree)

Principle Investigator: Mr. Pongchai Watcharakuenkhan

Name of Institution: Faculty of Physical Therapy and Applied Movement Sciences

Approved by the Committee on Human Rights Related to Human Experimentation

Signature of Chairman: .....
(Professor Dr.Srisin Khusmith)

Signature of Head of the Institute: .....
(Professor Dr.Pornchai Matangkasombut)

Date of Approval: - 9 OCT 2006

Date of Expiration: - 8 OCT 2007

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APPENDIX F
DETERMINATION OF BREAK TEST TRIALS

The purpose of this study was to determine the appropriate number of break test trials that subjects could exert maximum hamstring eccentric force for each session.

Healthy ten male subjects participated in this study. Age of subjects ranged from 18 to 25 years. All subjects were explained method of break test. Each subject was allowed to practice 3- submaximal break test. Then, each subject was asked to prone on the bed while hip angle was set approximately 30º flexion and the small towel was folded and placed over the mark to provide cushioning from applicator of the Lafayette manual muscle test. The applicator of the myometer will be placed above two finger breaths of the medial malleolus of the ankle joint and the subject will be asked to exert a maximum force against it. Subjects performed five maximum hamstring eccentric forces (break technique) against the applicator. The additional force was applied until the muscle contraction began to break and the limb begins to move. Each trial was performed with 1 minute apart. The maximum forces of break test of each subject are shown in the Table F.1

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Table F.1 The data of maximum forces of break test for five trials

No.	Maximum forces of break test (kg.)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
1	25	27.5	27.5	25.5	27
2	27.2	28.1	28.8	26.7	27.1
3	29.2	31.9	30	28.8	29.2
4	24.3	24.2	26.6	26.1	25.2
5	35.3	37.8	35.5	35.2	35
6	30.5	31.9	31.4	31.4	31
7	30.7	33.8	33.8	33.9	30.8
8	30	33.3	33	31.6	32
9	30	30.3	30.2	30.2	29.8
10	35	39.8	35.4	35.8	38.8
Mean $\pm$ SD	29.72$\pm$3.64	31.86$\pm$4.70	31.22$\pm$3.15	30.52$\pm$3.73	30.59$\pm$4.02

The result of this study showed that nine participants could produce to maximum force in three trials. Six subjects could exert maximum force in the 2nd trial, two subjects in the 3rd trial and one subject in the 2nd and 3rd trial. One subject produced maximum force in the 4th trial.

Therefore, the subjects in this study will be asked to perform 3 trials of break test in order to reach the maximum force of break test. The highest value of maximum force of break test will be used to calculate resistance weight of each subject in the training group.

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APPENDIX G
MUSCLE ACTIVITY OF TRAINING TECHNIQUE

The purpose of this pilot study was to analyse the muscle activity of the training technique used in the present study. Five healthy male subjects participated in the study. Age of subjects ranged from 18 to 25 years. All subjects were explained method of testing. Before testing, subjects were asked to wear short pants for attaching the surface EMG electrodes. Subjects performed a lower extremity flexibility exercises protocol by stretching each muscle for 15 seconds and repeated 3 times. The stretched muscles were quadriceps, hamstring and gastrocnemius muscles of both legs (figures 3.12-3.14). Surface electromyography with 3 channels was used to analyse the muscle activity during training. The subjects' skin were rubbed with alcohol to gain minimum resistance, then 3 sets of silver/silver chloride surface electrodes were placed over the muscle bellies of vastus lateralis (VL), biceps femoris (BF), and semitendinosus (ST) using anatomical landmarks and reference lines described by Rainoldi et al in 2004 (169). The EMG electrodes were placed along the muscle fiber orientation with the inter-electrode distance being at 2.5 cm.

After that, subject was positioned in prone over a bed and hip angle was set approximately 30° flexion and knee angle approximately 90° flexion. The hip position replicated hip angle of late swing of sprinting. Following a start signal, the subject performed the exercise by rapidly extendeds the knee as fast as possible and decelerated at approximately 20^{o} – 30^{o} of knee flexion via an eccentric hamstring contraction, followed by a quick hamstring concentric contraction until knee angle approximately 90^{o} (Figures 3.22 - 3.23). Surface EMG was recorded throughout the test.

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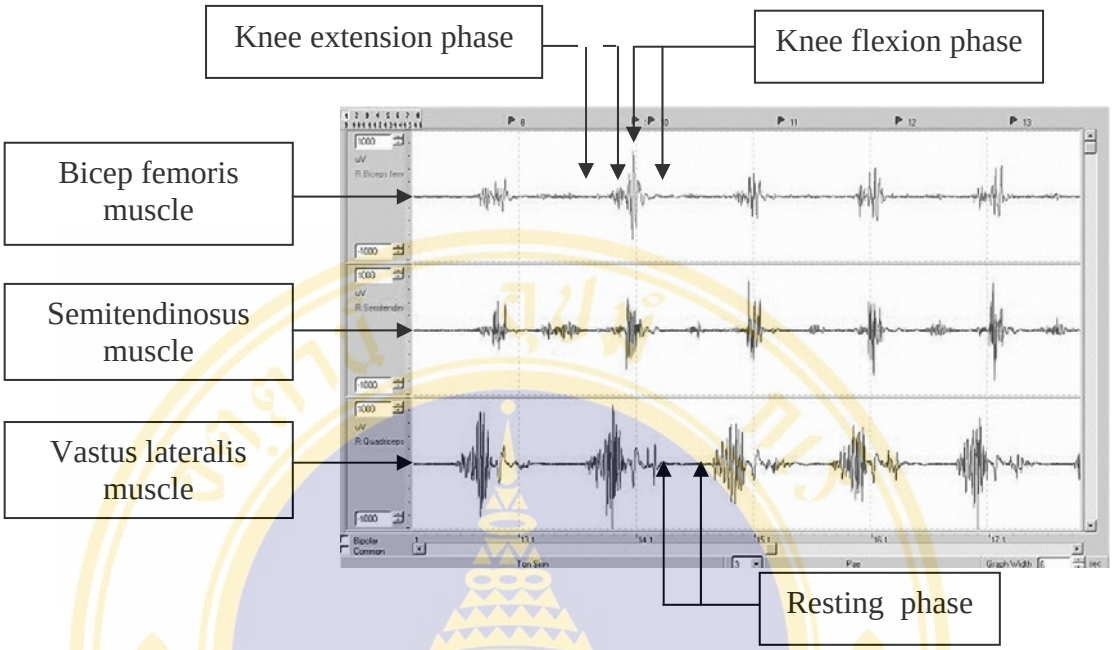

Figure G.1 EMG signal of muscle activity during training.

From figure G.1, the EMG activity of quadriceps muscle were indicated by fast concentric contraction whereas hamstring muscle had few activity during knee extension phase. In knee flexion phase, the EMG activity of hamstring muscle occurred during fast concentric contraction until knee angle approximately 90º flexion (starting position). Hamstring muscle was generated high EMG activities before changing eccentric contraction to concentric contraction.

Therefore, eccentric hamstring contraction was activated during eccentric contraction to concentric contraction phase during training.

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APPENDIX H
RESULT OF PILOT STUDY

This pilot study aimed to investigate the effects of fast eccentric hamstring strength training on hamstring performance. Ten healthy males with aged between 18 and 25 years participated in this pilot study. All subjects were randomly divided into two groups: eccentric training group and control group. Each group consisted of five subjects. The differences in subjects' characteristics between control and eccentric training groups were tested by unpaired t-test. There were no significant differences in characteristics of subjects ($p > 0.05$) as shown in Table H.1. Eccentric training group was trained fast eccentric exercise of both legs whereas control group was not trained. Program of training was 3 sessions/week for four weeks by using protocol as presented in the methodology (see chapter 3). The isokinetic tests were performed at the 1st (pre-training), end of 2nd week of training, and end of 4th week of training. The sprint testing were tested at the pre-training (1st week) and post-training (end of 4th week).

Means and standard deviations of concentric and eccentric peak torque of knee extensor and flexor muscles are presented in Tables H.2-4. Means and standard deviations of percentage of h/q ratio in two groups are presented in Tables H.5-7. Means and standard deviations of sprint velocity are presented in Tables H.8-9.

Table H.1 Means and standard deviations of age, weight and height of subjects in training and control groups

	Eccentric training group (n=4)		Control group (n= 4)		p-value*
	Mean	SD	Mean	SD	
Age (yrs)	21.50	1.29	22.25	0.96	0.387
Weight (kg)	74.50	13.18	73.63	10.26	0.920
Height (cm)	170.25	4.50	171.25	2.50	0.711

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Table H.2 Means and standard deviations of peak torque (Nm) of concentric isokinetic testing of quadriceps and hamstring muscle at 240º/sec in eccentric training and control groups

Groups	Peak torque (Nm)					
	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Training group						
knee extensor	141.50	15.69	150.18	10.13	149.08	9.68
knee flexor	80.68	9.54	90.15	12.79	88.00	12.21
Control group						
knee extensor	125.83	6.92	133.40	9.57	132.83	10.99
knee flexor	78.53	10.96	82.70	4.56	75.33	14.67

Table H.3 Means and standard deviations of peak torque (Nm) of eccentric isokinetic testing of quadriceps and hamstring muscle at 240º/sec in eccentric training and control groups

Groups	Peak torque (Nm)					
	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Training group						
knee extensor	201.55	53.68	228.43	42.91	233.20	34.64
knee flexor	151.70	30.55	161.23	29.20	168.43	24.63
Control group						
knee extensor	204.13	42.83	221.15	45.80	218.10	20.76
knee flexor	150.60	22.21	167.75	11.45	147.13	26.45

Table H.4 Eccentric peak torque (Nm) and angle of peak torque of hamstring muscle at 240º/sec in eccentric training and control groups

Groups	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Eccentric training group	151.70 (29.50°)	30.55 (6.25°)	161.23 (27.25°)	29.20 (0.50°)	168.43 (28.00°)	24.63 (3.37°)
Control group	150.60 (22.75°)	20.31 (7.54°)	167.75 (26.50°)	20.83 (2.08°)	147.13 (27.00°)	26.45 (4.08°)

Table H.5 Means and standard deviations of percentage of h/q ratio (con/con) at 240º/sec in eccentric training and control groups

Groups	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Eccentric training group	57.30	7.02	59.85	5.47	58.90	6.28
Control group	62.55	9.22	62.08	2.47	56.43	8.02

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Table H.6 Means and standard deviations of percentage of h/q ratio (ecc/ecc) at 240º/sec in eccentric training and control groups

Groups	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Eccentric training group	76.53	7.15	71.72	15.66	72.30	3.74
Control group	74.75	9.19	77.28	9.27	67.73	8.23

Table H.7 Means and standard deviations of percentage of h/q ratio (ecc/con) at 240º/sec in eccentric training and control groups

Groups	1st week		2nd week		4th week	
	Mean	SD	Mean	SD	Mean	SD
Eccentric training group	107.57	21.87	107.07	16.68	113.24	17.34
Control group	119.78	16.89	126.04	9.07	113.21	22.93

Table H.8 Means and standard deviations of sprint velocity between 0-20 meters (m/s) in eccentric training and control groups

Groups	Sprint velocity (m/s)				
	1st week		4th week		Percent of mean difference between pre-post training
	Mean	SD	Mean	SD	
Eccentric training group	5.24	0.21	5.58	0.24	6.86
Control group	5.55	0.15	5.63	0.31	1.38

Table H.9 Means and standard deviations of sprint velocity between 20- 50 meters (m/s) in eccentric training and control groups

Groups	Sprint velocity (m/s)				
	1st week		4th week		Percent of mean difference between pre-post training
	Mean	SD	Mean	SD	
Eccentric training group	6.42	0.30	6.83	0.38	6.45
Control group	6.75	0.43	6.81	0.44	1.04

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APPENDIX I
SAMPLE SIZE CALCULATION

Regarding the study design of this study, F-value from one way analysis of variance for repeated measures was calculated for hamstring eccentric strength of both groups. Then, number of sample size was estimated from Table sample sizes needed for the analysis of variance for $\alpha = .05$ (172).

The sample size of the study is 15 subjects per group.

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APPENDIX J

RAW DATA OF THE STUDY

Table J.1 Characteristics of subjects in training and control groups

Subjects No.	Eccentric training group			Control group		
	Age (yrs)	Weight (kg)	Height (cm)	Age (yrs)	Weight (kg)	Height (cm)
1	21	70	170	23	88	168
2	23	73	165	23	74	171
3	22	62	176	21	66	172
4	20	93	170	22	66.5	174
5	20	93	170	21	60.8	171
6	21	72	176	21	70	172
7	22	48	167	22	68	170
8	21	78	174	21	55	165
9	21	70	185	21	51	173
10	21	70	180	21	62.5	178
11	20	78	178	22	57	173
12	21	56	169	20	75	173
13	22	60	170	21	67	167
14	23	53	168	20	62	167
15	20	64	174	20	65	178
Mean	21.27	66.73	172.73	21.27	65.85	171.47
SD	0.96	11.76	5.48	0.96	9.00	3.74

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Table J.2 Concentric peak torque (Nm) at 1st week, 2nd, and 4th weeks of quadriceps muscle at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	136.1	144.6	144.6	128.7	140.8	136.8
2	120.6	131.1	134.1	116.3	120.2	137.6
3	140.1	155	159.6	132.5	140.1	140.4
4	126.4	139.3	138.3	125.8	132.5	116.5
5	163.4	161.8	160.5	112.6	113.7	108.5
6	134.4	150.7	146.6	145.9	166.9	156.2
7	89.3	96.6	106.1	139.9	138.8	100.3
8	146.7	152.2	151.6	98.6	113.3	116.2
9	156.9	163.2	165.6	97.5	108.9	101.4
10	122.1	145.7	141.3	115.3	136.7	134.8
11	126.2	132.8	137.9	109.1	107.8	107.7
12	94.8	119.6	134.1	118.7	90.4	123.8
13	111.5	117.7	130.3	123.7	121.9	121.3
14	94.4	103.9	114.9	101.7	119	112.3
15	128.2	138	144.7	123.5	131.3	127.3
Mean	126.07	136.81	140.68	119.32	125.49	122.74
SD	21.93	20.07	16.09	14.30	18.40	16.03

Table J.3 Eccentric peak torque (Nm) at 1st week, 2nd, and 4th weeks of quadriceps muscle at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	257	232.2	262.6	263.1	289.2	248.9
2	184.2	221.2	210.7	204.8	203.2	210
3	219.4	286.6	263.4	163.2	189.6	192.6
4	129.1	207.6	208.3	185.4	202.6	210
5	200.7	187.3	198.5	153.3	164.8	167.2
6	191.7	185.6	280.9	182.9	207.4	193.6
7	139.4	167	166.8	174.5	181.3	211.7
8	155.5	177.9	195.3	125.1	168.5	162.8
9	171.8	250.2	277.3	131.4	165.4	144.4
10	194.5	216.4	255.5	147.7	147.7	137.4
11	210.5	221.7	253.8	181	146.9	145.2
12	177.7	188.1	256.3	205.1	181.4	265.2
13	187.8	221.1	225.2	169.5	150	204.9
14	191	229.1	198.8	190.1	199.4	224.2
15	206.2	232.1	239.4	260.7	246.4	244.1
Mean	187.77	214.94	232.85	182.52	189.59	197.48
SD	31.71	30.90	34.76	39.88	38.58	39.65

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Table J.4 Concentric peak torque (Nm) at 1st week, 2nd, and 4th weeks of hamstring muscle at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	77.6	87.5	89	81.9	88.8	92.1
2	64.4	87.3	79.5	82.9	77.8	78.3
3	93.4	102.1	95.1	86.9	82.6	74.4
4	70.6	73.3	71.7	62.4	81.6	56.5
5	81.1	97.7	90	69.5	61.4	63
6	82.1	74.7	95.3	86.1	98.3	90.5
7	43.1	50.8	59.2	73.7	70.5	56
8	92.5	90.1	82.2	52.8	63.4	70.5
9	74.1	112.5	132.3	67.1	81.8	73.9
10	76.6	86.9	105	53.5	67.6	69.8
11	81.5	86.1	87.2	78.1	74.4	64.9
12	55.2	69.2	74.5	74.3	85.7	92.6
13	56	75.8	79.8	74.6	84.7	78.6
14	65.2	79.9	81.5	84	87.4	97.9
15	69.4	95.4	95.6	73.8	75.2	83.8
Mean	72.19	84.62	87.86	73.44	78.75	76.19
SD	13.88	14.96	16.71	10.82	10.13	13.22

Table J.5 Eccentric peak torque (Nm) at 1st week, 2nd, and 4th weeks of hamstring muscle at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	175.7	178.5	192.6	182.7	184.9	177.5
2	119.7	138.1	125.2	143.8	162.9	154.4
3	173.2	177.5	186	144.4	161.8	143.4
4	109.9	117.7	142.3	131.5	161.4	142.7
5	148	171.2	152.8	117.6	129.4	104
6	141.9	145	153.6	127.7	158.7	157.4
7	112	121.4	128.3	136	126.8	85.8
8	124.8	146.3	151.9	98.3	109.4	106.4
9	133	182.5	212.3	104.8	115.2	110.6
10	170.4	183.2	185.7	110.6	106.4	95
11	108.7	113.9	118.3	99.1	111.8	113.5
12	101.3	121.5	129.5	119.7	129.9	134
13	122.5	132.4	141.1	128.2	104.9	126.8
14	118.8	127.1	122.1	116.6	118.8	122.2
15	145.1	155.7	155	177.4	145.6	132.1
Mean	133.67	147.47	153.11	129.23	135.19	127.05
SD	24.51	25.50	28.78	25.17	25.43	25.30

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Table J.6 Eccentric hamstring torque (Nm) at 20º of knee flexion at 1st week, 2nd, and 4th weeks at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	174.1	161.1	184.2	177.2	177.8	179.0
2	113.3	128.3	133.3	130.9	158.0	151.0
3	166.7	171.6	178	131.4	145.8	133.5
4	58.5	98	136.3	135.8	124.5	151.6
5	123	154	168.2	110.7	120.2	67.0
6	126.1	150.1	143.9	101.5	151.3	152.9
7	88.5	98.7	110.6	128.8	101.5	40.0
8	108.9	122.7	134.2	84.4	93.6	80.4
9	124.0	174.5	200.3	78.8	92.4	84.6
10	156.5	173.0	178.8	102.2	44.0	87.5
11	88.7	77.5	54.1	99.2	94.9	68.2
12	91.3	107.1	112.7	105.5	74.2	101.4
13	118.9	123.0	135.0	126.1	73.3	119.2
14	114.2	121.6	114.7	94.1	110.8	116.1
15	137.0	144.4	148.4	170.0	119.5	111.3
Mean	133.67	147.47	153.11	129.23	135.19	127.05
SD	24.51	25.50	28.78	25.17	25.43	25.30

Table J.7 Eccentric hamstring torque (Nm) at 15º of knee flexion at 1st week, 2nd, and 4th weeks at 240º/sec in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	158.3	146.8	171	162.7	162.8	162.9
2	89.6	113	84.9	103.7	144.2	133.6
3	150.5	153.6	161.6	119.4	108.5	111.1
4	40.9	76.6	112.2	118.0	110.4	129.9
5	98.6	122.5	72.8	98.1	107.3	37.1
6	110.4	149.9	132.3	78.3	132.7	130.3
7	0	0	0	117.9	65.0	46.1
8	93.6	102.3	115.3	63.0	83.1	54.8
9	104.4	156.2	181.5	0.0	0.0	0.0
10	137.3	152.4	156.0	83.7	56.5	63.8
11	62.7	58.0	46.5	86.3	73.2	49.8
12	69.2	89.8	98.3	78.3	45.6	81.0
13	110.2	114.2	119.4	112.4	49.4	105.6
14	102.1	107.0	105.7	72.9	101.4	106.1
15	123.5	132.9	133.1	156.2	84.3	77.0
Mean	96.75	111.68	112.71	96.73	88.29	85.94
SD	41.36	42.96	48.52	39.30	42.29	44.52

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Table J.8 Percentage of h/q ratio (con/con) at 1st week, 2nd week and 4th week in eccentric training and control groups at 240º/sec

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	57.1	60.5	61.5	63.7	63.1	71.31
2	53.4	66.6	59.3	71.3	64.7	56.9
3	66.6	65.9	59.6	65.6	58.9	53
4	55.9	52.6	51.8	49.6	61.6	48.5
5	49.6	60.4	56.1	61.7	54	58.1
6	61.1	51.5	65	59	58.9	57.9
7	48.3	52.6	55.8	52.7	50.8	55.9
8	63	59.2	54.3	53.6	55.9	60.7
9	47.2	68.9	79.8	68.8	75.1	72.9
10	62.7	59.7	74.3	46.4	49.5	51.8
11	64.6	64.8	63.3	78.8	66.5	57.2
12	58.2	57.8	55.5	62	66	69.1
13	50.2	64.4	61.3	60.3	69.5	64.8
14	69.1	76.9	70.9	82.6	73.4	87.1
15	54.1	69.2	66.1	63.7	63.1	71.31
Mean	119.31	133.71	142.18	118.44	112.12	109.58
SD	31.13	30.44	36.93	28.50	35.95	38.99

Table J.9 Percentage of h/q ratio (ecc/ecc) at 1st week, 2nd week and 4th week in eccentric training and control groups at 240º/sec

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	68.4	76.87	73.3	69.4	63.9	71.3
2	65	62.4	59.4	70.2	80.2	73.5
3	78.9	61.9	70.6	88.5	85.3	74.5
4	85.1	56.7	68.3	70.9	79.7	68.0
5	73.7	91.4	77	76.7	78.5	62.2
6	74.0	78.1	54.7	69.8	76.5	81.3
7	80.3	72.7	76.9	77.9	69.9	40.5
8	80.3	82.2	77.8	78.6	64.9	65.4
9	77.4	72.9	76.6	79.8	69.6	76.6
10	87.6	84.7	72.7	74.9	72.0	69.1
11	51.6	51.4	46.6	54.8	76.1	78.2
12	57.0	64.6	50.5	58.4	71.6	50.5
13	65.2	59.9	62.7	75.6	69.9	61.9
14	62.2	55.5	61.4	61.3	59.6	54.5
15	70.4	67.1	64.7	68.0	59.1	54.1
Mean	71.81	69.22	66.21	71.65	71.79	65.58
SD	10.29	11.77	10.13	8.78	7.71	11.61

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Table J.10 Percentage of h/q ratio (ecc/con) at 1st week, 2nd week and 4th week in eccentric training and control groups at 240º/sec

Subjects No.	Eccentric training group			Control group		
	1st week	2nd week	4th week	1st week	2nd week	4th week
1	129.10	123.44	133.20	142.0	131.3	129.8
2	99.25	105.34	93.36	123.6	135.5	112.2
3	123.63	114.52	116.54	109.0	115.5	102.1
4	86.95	84.49	102.89	104.5	121.8	122.5
5	90.58	105.81	95.20	104.4	113.8	95.9
6	105.58	96.22	104.77	87.5	95.1	100.8
7	125.42	125.67	120.92	97.2	91.4	85.5
8	85.07	96.12	100.20	99.7	96.6	91.6
9	84.77	111.83	128.20	107.5	105.8	109.1
10	139.56	125.74	131.42	95.9	77.8	70.5
11	86.13	85.77	85.79	90.8	103.7	105.4
12	106.86	101.59	96.57	100.8	143.7	108.2
13	109.87	112.49	108.29	103.6	86.1	104.5
14	125.85	122.33	106.27	114.7	99.8	108.8
15	113.18	112.83	107.12	143.6	110.9	103.8
Mean	107.45	108.28	108.72	108.33	108.58	103.37
SD	18.34	13.50	14.46	16.59	18.74	14.23

Table J.11 VAS at 2nd week in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st day	2nd day	3rd day	1st day	2nd day	3rd day
1	4.10	3.90	3.00	0	0	0
2	4.00	3.60	0	0	0	0
3	4.30	0	0	0	0	0
4	3.50	0	0	0	0	0
5	4.20	3.70	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	3.60	0	0	0	0	0
9	3.50	0	0	0	0	0
10	3.90	3.50	3.00	0	0	0
11	0	0	0	0	0	0
12	4.50	0	0	0	0	0
13	0	0	0	0	0	0
14	4.00	3.80	0	0	0	0
15	0	0	0	0	0	0
Mean	2.64	1.23	0.4	0	0	0
SD	1.95	1.81	1.06	0	0	0

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Table J.12 VAS at 3rd week in eccentric training and control groups

Subjects No.	Eccentric training group			Control group		
	1st day	2nd day	3rd day	1st day	2nd day	3rd day
1	3.00	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	3.00	0	0	0	0	0
11	0	0	0	0	0	0
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	0	0	0	0
Mean	0.4	0	0	0	0	0
SD	1.06	0	0	0	0	0

Table J.13 Sprint velocity between 0-20 meters at 1st week and 4th week in eccentric training and control groups

Subjects No.	Eccentric training group		Control group	
	1st week	4th week	1st week	4th week
1	5.40	5.63	5.36	5.45
2	5.35	5.67	5.72	5.74
3	4.93	5.89	5.54	5.28
4	5.35	5.50	5.58	5.88
5	5.27	5.31	5.33	5.47
6	5.28	5.47	5.93	5.92
7	5.19	5.53	5.26	5.02
8	5.28	5.54	5.56	5.64
9	5.25	5.96	5.39	5.51
10	5.68	5.60	5.66	5.54
11	5.13	5.47	5.63	5.62
12	5.68	5.96	4.92	4.94
13	5.25	5.54	5.55	5.66
14	5.78	5.98	5.34	5.33
15	5.18	5.59	5.32	5.44
Mean	5.33	5.64	5.47	5.50
SD	0.23	0.21	0.24	0.28

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Table J.14 Sprint velocity between 20- 50 meters at 1st week and 4th week in eccentric training and control groups

Subjects No.	Eccentric training group		Control group	
	1st week	4th week	1st week	4th week
1	7.02	7.31	6.38	6.28
2	6.83	7.11	6.82	6.84
3	6.20	6.81	6.46	6.63
4	6.46	7.10	7.33	7.20
5	6.19	6.30	7.00	7.04
6	6.88	7.07	7.81	7.87
7	7.02	7.24	6.11	6.29
8	6.47	6.73	6.93	6.84
9	7.39	8.00	6.82	6.80
10	6.88	7.06	7.01	7.12
11	6.28	6.49	6.85	6.82
12	7.12	7.46	5.69	5.84
13	6.68	7.38	7.30	7.42
14	7.00	7.39	6.80	6.81
15	6.69	7.13	6.39	6.53
Mean	6.74	7.11	6.78	6.82
SD	0.36	0.41	0.52	0.49

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