การรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้าในผู้สูงอายุที่ออกกำลังกายชนิดต่าง ๆ

นางสาว ทัศนา จารุชาต

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

สาขาวิชาเวชศาสตร์การกีฬา

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ปีการศึกษา 2552

ANKLE JOINT POSITION SENSE OF ELDERLY ENGAGED IN DIFFERENCE TYPES OF EXERCISE

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A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science Program in Sports Medicine

Faculty of Medicine

Chulalongkorn University

Academic Year 2009

Thesis Title	ANKLE JOINT POSITION SENSE OF ELDERLY ENGAGED IN DIFFERENCE TYPES OF EXERCISE.
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ทัศนา จารุชาต : การรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้าในผู้สูงอายุที่ออกกำลังกายชนิดต่าง ๆ. (ANKLE JOINT POSITION SENSE OF ELDERLY ENGAGED IN DIFFERENCE TYPES OF EXERCISE.) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.นพ. สมพล สงวนรังศิริกุล, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม : อ.นพ. วสุวัฒน์ กิติสมประยูรกุล จำนวน 148 หน้า.

การวิจัยเชิงวิเคราะห์นี้มีวัตถุประสงค์เพื่อศึกษาการรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้าของผู้สูงอายุในกลุ่มที่ออกกำลังกายด้วยรูปแบบที่ต่างกัน และกลุ่มที่ไม่ออกกำลังกาย กลุ่มตัวอย่างเข้าร่วมโครงการวิจัย ได้แก่ ผู้สูงอายุไทย อายุระหว่าง 60-70 ปี จำนวน 160 คน แบ่งออกเป็น 4 กลุ่ม กลุ่มละ 40 คน ได้แก่ กลุ่มเดิน ไท้จี๋ วิ่งเหยาะ และกลุ่มที่ไม่ออกกำลังกาย ผู้เข้าร่วมวิจัยทั้งหมดเข้ารับการทดสอบการรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้าแบบ Passive reproduction โดยทำการทดสอบในท่ายืน แล้วทำการเคลื่อนข้อเท้าข้างทดสอบด้วยเครื่องวัดการรับรู้ตำแหน่งของข้อเท้าที่ความเร็ว 0.25 องศาต่อวินาทีไปยังตำแหน่งเป้าหมายที่กำหนดไว้ และให้ผู้เข้าร่วมวิจัยรับรู้ถึงตำแหน่งเป้าหมายนั้นๆ แล้วจึงคาดคะเนตำแหน่งข้อเท้าของตนเองให้ตรงกับตำแหน่งเป้าหมาย ค่ามุมที่ผิดพลาดจากตำแหน่งเป้าหมายจะได้รับการบันทึก การทดสอบนี้จะดำเนินการ 2 ครั้งในแต่ละลักษณะการเคลื่อนไหวของข้อเท้า รวมทั้งสิ้น 4 แบบ ได้แก่ Inversion, Eversion, Plantarflexion และ Dorsiflexion ทั้งนี้ ยังมีการทดสอบความแข็งแรงของกล้ามเนื้อขาด้วย Senior's chair stand test รวมถึงการทดสอบการทรงตัวด้วยวิธีเอื้อมมือ (Functional reach test), การเดิน (Timed up&Go test; TUG), Single leg stance test และเครื่องวัดการทรงตัว BalanceCheck โดยให้ยืนบนแผ่นรับแรงแล้วทดสอบ ดังนี้ Anterior-posterior (A-P) center of pressure (CoP) excursion, Lateral center of pressure (CoP) excursion, Direction of maximum instability ทั้งแบบลืมตา หลับตาบนพื้นแข็งและพื้นนุ่ม

ผลการศึกษาพบว่า ในช่วง 1 ปีที่ผ่านมา กลุ่มที่ไม่ได้ออกกำลังกายมีอัตราการล้มร้อยละ 30 กลุ่มเดินมีอัตราการล้มร้อยละ 25 กลุ่มวิ่งเหยาะมีอัตราการล้มร้อยละ 24.24 และกลุ่มไท้จี๋มีอัตราการล้มน้อยที่สุดร้อยละ 22.50 จากการทดสอบการรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้า พบว่า กลุ่มที่ออกกำลังกายสามารถรับความรู้สึกเกี่ยวกับตำแหน่งข้อเท้าได้ดีกว่ากลุ่มที่ไม่ออกกำลังกายอย่างมีนัยสำคัญทางสถิติในการทดสอบการเคลื่อนข้อเท้าแบบ Eversion Plantarflexion และ Dorsiflexion ($p<0.05$) ส่วนการทดสอบความแข็งแรงของกล้ามเนื้อขา กลุ่มวิ่งเหยาะสามารถทำการทดสอบได้ดีกว่ากลุ่มอื่น การทดสอบการทรงตัวด้วยวิธีเอื้อมมือและการเดิน พบว่า กลุ่มออกกำลังกายทุกชนิดทำการทดสอบได้ดีกว่ากลุ่มที่ไม่ออกกำลังกายอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) สำหรับการทดสอบการทรงตัวด้วย Single leg stance test พบว่า กลุ่มออกกำลังกายทุกชนิดทำเวลาในการทดสอบได้ดีกว่ากลุ่มที่ไม่ออกกำลังกายอย่างมีนัยสำคัญทางสถิติ ($p<0.05$) และในการทดสอบการทรงตัวด้วยเครื่องวัดการทรงตัว BalanceCheck นั้น พบว่า การทรงตัวของกลุ่มไท้จี๋ดีกว่ากลุ่มอื่นๆ ในการทดสอบ Lateral CoP excursion ขณะยืนหลับตาบนพื้นแข็งและพื้นนุ่ม ($p<0.05$) จากการศึกษาครั้งนี้ สามารถสรุปได้ว่า ผู้สูงอายุที่ออกกำลังกายไท้จี๋มีการรับความรู้สึกเกี่ยวกับตำแหน่งของข้อเท้าและมีความสามารถในการทรงตัวดี รวมถึงกลุ่มวิ่งเหยาะที่มีความแข็งแรงของกล้ามเนื้อขามาก มีอัตราการล้มต่ำ

สาขาวิชา เวชศาสตร์การกีฬา ลายมือชื่อนิสิต ทัศนา จารุชาต

ปีการศึกษา 2552 ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์หลัก สมพล สงวนรังศิริกุล

ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์ร่วม

4974725530 : MAJOR SPORTS MEDICINE

KEYWORDS : ELDERLY / FALL / EXERCISE / PROPRIOCEPTION / JOINT POSITION SENSE

TUSSANA JARUCHART : ANKLE JOINT POSITION SENSE OF ELDERLY ENGAGED IN DIFFERENCE TYPES OF EXERCISE. THESIS ADVISOR : ASSOC. PROF. SOMPOL SANGUANRUNGSIRIKUL, M.D., MSc. THESIS CO-ADVISOR : WASUWAT KITISOMPRAYOONKUL, M.D., 148 pp.

The objective of the study is to determine ankle joint position sense (JPS) of elderly engaged in difference types of exercise and no exercise. Subjects in this study were 160 Thai elderly aged 60-70 years old. They were classified in 4 groups, 40 persons per group, i.e. walking, tai chi, jogging, and non-exercise group. All of them were tested ankle JPS by passive reproduction test during weight bearing. The test foot was passively moved through a target position by an apparatus at a constant speed, 0.25 degrees per second. After that, the subjects indicate the joint position when they perceived that the target position had been reached. Mean values of two trials in each movement (total 4 movements i.e. inversion, eversion, plantarflexion, and dorsiflexion) were used for analysis. Furthermore, leg strength was tested with Senior's chair stand test. The balance assessments were tested consequently with functional reach test, timed up&go test (TUG), single leg stance test, and the force platform test (BalanceCheck®) which presence of anterior-posterior (A-P) center of pressure (CoP) excursion, lateral center of pressure (CoP) excursion, and direction of maximum instability with eyes open and eyes closed either on a hard or soft surface.

This study found that the non-exercise group had fall rate 30%, walking group 25%, jogging group 24.24%, and tai chi group 22.50%. Regarding joint position sense (JPS) test, exercise groups had significantly better ankle JPS for eversion, plantarflexion, and dorsiflexion in comparison with non-exercise group ($p<0.05$). Whereas the leg strength of jogging group was greater than other groups. Otherwise, all three exercise groups had significantly better reaching distance and time of TUG test in comparison with non-exercise group ($p<0.05$). The single leg stance time of all types of exercise groups were significantly better than non-exercise group ($p<0.05$). Finally, the lateral CoP excursion with eyes closed on hard and soft surface of tai chi group were significantly better than other groups ($p<0.05$). In conclusion, active elderly, tai chi practitioners, has best ankle proprioception and balance control, whereas jogging group has leg strength better than other groups. Their improvements in ankle proprioception and lower limb strength might reduce fall rate.

Field of Study : Sports Medicine Student's Signature Tussana Jaruchart

Academic Year : 2009 Advisor's Signature Sompol Sanguanrungsirikul

Co-advisor's Signature Wasuwat K.

ACKNOWLEDGEMENTS

The success of this thesis can be attributed to the extensive support and assistance from my advisor, Associate Professor Sompol Sanguanrungsirikul, M.D., MSc., and my co-advisor, Wasuwat Kitisomprayoonkul, M.D. I deeply thank them for their valuable guidance and consultation in this research. I wish to thank to Associate Professor Duangporn Thong-Ngam, M.D., Assistant Professor Pasakorn Watanatada, M.D., Ph.D., and Professor Ratree Sudsuang, Ph.D. for their suggestions in this study. Moreover, my expression also extends to thank you the Office of Sports and Recreation Development, Bureau of Sports Science for allowing me in using BalanceCheck Force Platform to analyze center of pressure excursion in this study.

I am very grateful to thank the entire volunteers for their participation as subjects in this study. I would like to gratefully acknowledge that this thesis is successfully completed by Ratchadapiseksompotch Fund., Faculty of Medicine, Chulalongkorn University.

I wish to express my special thanks to all of the staff and my colleagues at Faculty of Medicine, Chulalongkorn University for their kindness and co-operation during this study. My sincere thanks are also extended to Mr. Visarut Nopparat for his helpful guidance and support the program analysis of the ankle joint position data.

Finally, I am grateful to my family and my friends for their love, support, entire care, and warmest encouragement throughout this study.

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CHAPTER I
INTRODUCTION

Background and Rationale

In Thailand, like in other developing countries, the elderly group (adults over the age of 60 years), represents a growing segment of our population. It has been estimated that Thai population will represent about more than 15.3% in the year 2020 (B.E. 2563) as a result of a progress of medical service and public health. With the advancing age, the health problems have taken on ever increasing importance (สถาบันเวชศาสตร์ผู้สูงอายุ กรมการแพทย์ กระทรวงสาธารณสุข, 2548). The Thai elderly group is especially prone to fall more than 20% of the total Thai elderly population (สมนึก กุลสถิตพร, 2549). Fall in older adults also are associated with decreased confidence in movement and balance (Steinmetz and Hobson, 1994; Stoize et al., 2004). Loss of confidence, or fear of falling, often results in decreased physical activity that, in turn, may perpetuate further decline in postural stability and quality of life (Fletcher and Hirdes, 2004).

Balance is a fundamental skill that is compromised with advancing age (Shkuratova et al., 2004). Balance impairment in older adults increases the risk for falls (Tinetti et al., 1988). Fall incidents and the ensuing injury process are multifactorial. Environmental hazards, such as loose carpets and badly visible steps can play a role, but do so usually in combination with intrinsic factors (Tideiksaar, 1997). Stable locomotion and even stable stance depend on adequate cardiovascular function, in particular cerebral blood flow (Carey and Potter, 2001) and adequate proprioception (Bloem et al., 2003). When moving through a variable and unpredictable environment, visual contrast sensitivity and depth perception are crucial for detection of environmental hazards (Lord, 2006).

A number of studies have identified risk of factors for falling. These can be classified as either intrinsic (e.g., lower extremity weakness, poor grip strength, balance disorders, functional and cognitive impairment, and visual deficits) or extrinsic (e.g., polypharmacy) and environmental factors such as poor lighting, loose carpets, and lack of bathroom safety equipment). The American Geriatrics Society, British Geriatrics Society, and American

Academy of Orthopaedic Surgeons Panel on Falls Prevention ranked the risk factors and summarized the relative risk of falls for person with each risk factor. There appears to be both the intrinsic and extrinsic factors as important as risk factors for falling. The factors that primarily considered as fall risk, based on muscle weakness, history of falls, gait deficit and balance deficit with respective range at 1.5-10.3, 1.7-7.0, 1.3-5.6, and 1.6-5.4 times (American Geriatrics Society, 2001).

Throughout the human life span the functions of several physiological systems dramatically change, including proprioception. The somatosensory system and, specifically, the proprioceptive system, are critically involved in the sensory control of balance. Impaired proprioception leads to less accurate detection of body position changes. Altered neuromuscular control of the lower limb and consequently poor balance resulting from changes in the proprioceptive function could be related to the high incidence of harmful falls that occur in old age subjects (Ribeiro and Oliveira, 2007). It has been suggested that all age groups were more dependent on proprioception than on vision for the maintenance of balance (Colledge et al., 1994). Thus, decline in lower limb proprioception has been linked to balance problems found in the elderly (Horak et al., 1989; Lord and Ward, 1994; Manchester et al., 1989; Woollacott et al., 1986).

The proprioception, especially, the ankle proprioception, is very important for the elderly to maintain proper postural control (Xu et al., 2004). Besides that, a decrease in proprioception could lead to abnormal joint biomechanics during functional activities such as walking over the period of time. A theory currently being evaluated is that changes in proprioception result in changes in joint function that may lead to degenerative joint disease (Starkey and Johnson, 2006). These changes correlate with changes in muscle fiber types and directly affect the performance of both the activities of daily living and sports (Starkey and Johnson, 2006; Bostrom and Buckwalter, 2002). Moreover, changes in proprioception may be a sensitive method for detecting subclinical osteoarthritis (Skinner et al., 1984). Therefore, it might be important to develop and implement strategies to attenuate the age-related decline in proprioception. One strategy to reduce the incidence of poor proprioception and falls with aging may be regular physical activity (Petrella et al., 1997; Ribeiro and Oliveira, 2007).

Once proprioceptive deficiencies have been identified, rehabilitation and conditioning programs should be developed and implemented. Training allows to counteract age-related balance impairment (Campbell et al., 1997) and may improve postural control by acting on balance sensors (Hu and Woollacott, 1994; Perrin et al., 1999) or on the motor response through an increase of muscular strength (Wolfson et al., 1996). Postural control may rely upon the proper use and function of sensory afferences, but could also depend on the muscular strength of the lower limbs (Gauchard et al., 1999). Another point is that, devices currently used for neuromuscular control responsibility costs are expensive. For this reason, given muscle training program often implemented in clinical technique, with devices such as balance board, trampoline, fitball or foam board, but also need clinician to provide appropriate training program and closely take care of elderly for preventing a harmful fall (สมนึก กุลสถิตพร, 2549).

Interestingly, there are different kinds of exercise have been shown to have different on balance. It has been showed that regular exercise of proprioceptive nature might be beneficial to retain or regain balance (Ribeiro and Oliveira, 2007). Additionally, improvements in proprioception can be obtained via regular activity performed both depend on resistance training and independent of heavy muscle loading (Thompson et al., 2003). According to the reports, physical activity improving muscle strength can also improve proprioception. The improvement in muscle strength with exercise might yield better control of movement, which, as a consequence, could enhance joint proprioception under weight bearing conditions (Petrella et al., 1997).

It should be note that regular physical activity seems to be a beneficial strategy to preserve proprioception and prevent fall among older subjects (Ribeiro and Oliveira, 2007). Although many studies have indicated that adoption of regular physical activity can attenuate the age-related decline in many physiology systems, few studies have been conducted to examine the effects of exercise on proprioception of old people, especially the effects of different kinds of exercise (Ribeiro and Oliveira, 2007; Xu et al., 2004). Moreover, there has been no study conducted by comparing between ankle proprioception of the elderly with and without exercise. This study examined the ankle joint position sense of elderly engaged in difference types of exercise.

Research questions

Primary research question: Is there a difference on ankle joint position sense between elderly with exercise and non-exercise?

Secondary research question: Is there a difference on ankle joint position sense of elderly engaged in walking, tai chi, and jogging?

Objectives

1. To determine ankle joint position sense of elderly engaged in difference types of exercise and have no exercise by passive reproduction joint position sense test.

2. To determine balance control and fall rate of elderly engaged in difference types of exercise and have no exercise.

Hypothesis

Ankle joint position sense of elderly with exercise better than elderly without exercise.

Conceptual Framework

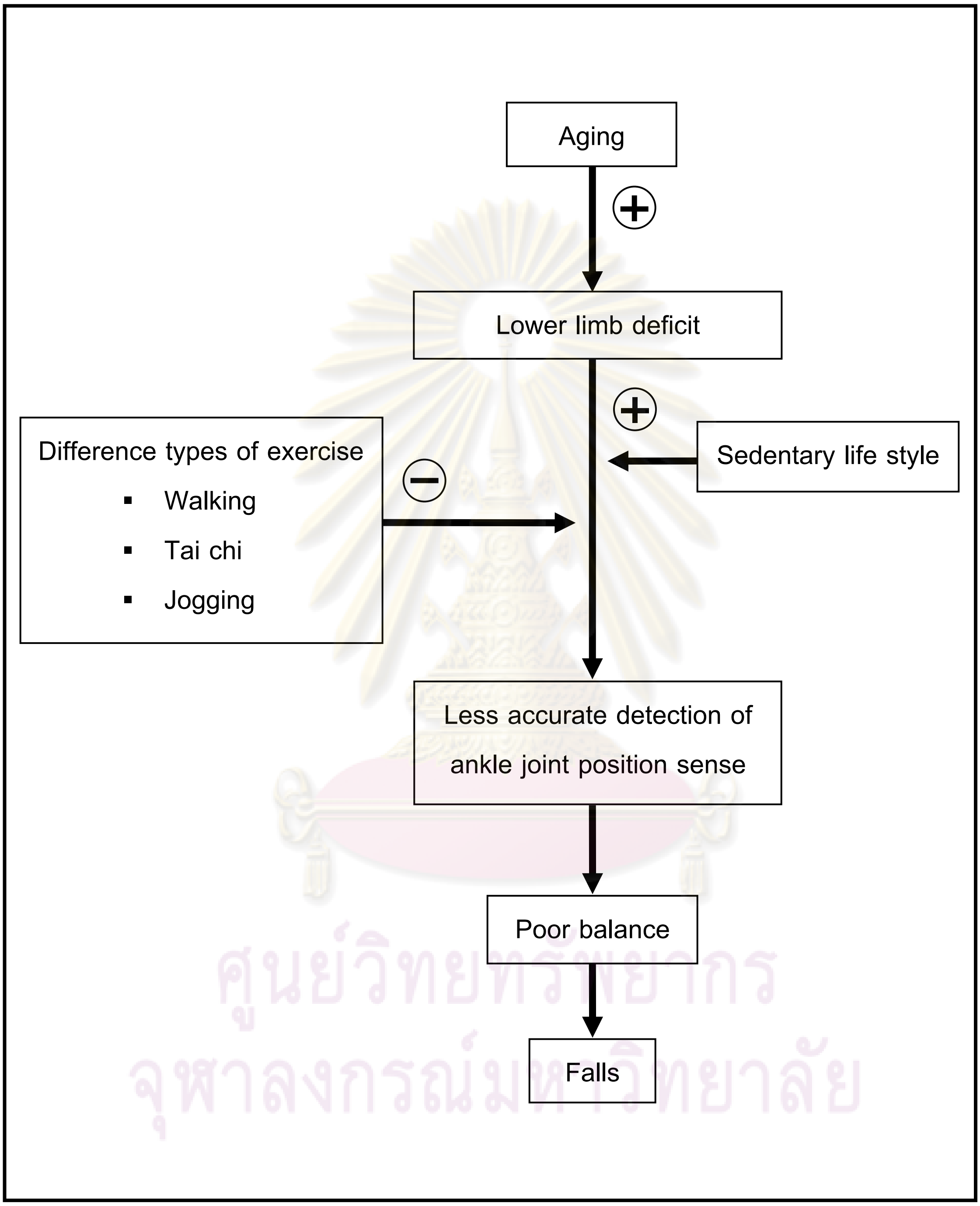


Fig 1.1 Conceptual framework

Scope of research

This study is an analytical research design which analytical descriptive study of Thai elderly men and women who engaged in regular exercise as either walking, tai chi, or jogging participated as subjects and having non-exercise group as a control group.

The study approval was obtained from the University Ethics Committee. Written informed consent was obtained from each subject prior to participation. On attendance, subjects were given the details of the research procedure and risk involved, and reminded of their right to withdraw at any stage.

Assumptions

1. The equipments were calibrated for standard accuracy and reliability.

2. All volunteers participated as subjects in this study are voluntary.

3. All subjects were asked to refrained from consuming alcohol, caffeine, or food for 2 hours and having no vigorous activities for 24 hours before the first test sessions (Hermione et al., 2006).

Limitations

1. The elderly people participated as subjects who were recruited following the inclusion criteria.

2. Accuracy of fall history from questionnaire relies on participants.

3. The result of study may not be refer to the general population in all age or the other kind of sports/exercise.

Key Words

Elderly, Fall, Exercise, Proprioception, Joint position sense

Operational definition

1. Elderly is defined as the older men and women aged 60 to 70 years old.

2. Fall is defined as any involuntary change from a starting position of bipedal support (standing, walking, bending, reaching, etc.) to a position of no longer being supported by both feet, accompanied by (partial or full) contact with the ground or floor.

3. Exercise, a type of physical activity, is defined as a planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness. According to this study, it has been studied in the elderly human subjects who participate in regular exercise as either walking, tai chi, or jogging. The following calculation of recommended level of physical activity are used:

Sufficient physical activity is presented in one of the three ways:

1) Undertaking 150 minutes of moderate intensity physical activity on five or more sessions or 60 minutes of vigorous intensity physical activity in the previous week.

2) Undertaking 150 minutes of total physical activity where moderate and vigorous activity (weighted by two) are summated in the previous week.

3) Energy expenditure of 800 kilocalories per week.

(An initiative of the Premier's Physical Activity Taskforce, 2003)

Insufficient physical activity is some activity but not enough to reach the levels required for 'sufficient' (An initiative of the Premier's Physical Activity Taskforce, 2003).

Vigorous activity is physical activity requiring >6 METS (Centers for Disease Control, 2006) according to previous studies about cost of energy expenditure. (Ainsworth et al., 2000; Centers for Disease Control, 2006).

Moderate activity is physical activity requiring 3-6 METS (Centers for Disease Control, 2006) according to previous studies about cost of energy expenditure. (Ainsworth et al., 2000; Centers for Disease Control, 2006).

METs of each activity calculated from Ainsworth et al. (2000).

Kcal/min = METs of activity x 3.5 x body weight in kg.)/200 (ACSM's guidelines, 2006)

4. Proprioception is defined as an awareness of position and movement of a part of body with elimination of visual guidance (For details, see in Chapter II page 14).

5. Joint position sense (JPS), a component of proprioception, is determines the subject's ability to comprehend a presented joint angle and then, once removed, may be conducted in either passively or actively reproduce the same joint angle. Joint position testing, termed the repositioning test, is method of proprioception testing. Passive reproduction method is used to measure joint position sense in this study (For details, see in Chapter II page 23-25).

Expected benefits and applications

1. Understanding the effect of difference types of exercise (walking, tai chi, or jogging) on ankle joint position sense in the elderly.

2. To realize the effectiveness of balance control and the risks associated with fall in elderly with exercise and have no exercise.

3. Providing recommendation for types of exercise that reduce evidence of proprioception deterioration with aging.

4. This will later lead to a greater understanding of how specific treatment strategies can be used clinically to improve proprioceptive and neuromuscular function in lower extremity rehabilitation.

5. Providing the preliminary data for the further research.

CHAPTER II
REVIEW LITERATURES

Balance

Ragnarsdottir (1996) stated that balance is often described as a complex motor skill and is also often referred to as postural control. These terms “balance” and “postural control” are used by some authors as synonyms for the concept of the mechanism by which the human body prevents itself from falling or losing balance (Ragnarsdottir, 1996). In addition, in *Lephart’s Textbook of Proprioception and neuromuscular control,* balance refers to the process of maintain the center of gravity within the body’s base of support. Similar to postural control, it represents a complex interplay between the sensory and motor systems and involves perceiving environmental stimuli, responding to alterations in the body’s orientation within the environment, and maintaining the body’s center of gravity within the base of support (Carr and Shepherd, 2000; Shumway-Cook and Woollacott, 1995). Balance has also been viewed as a pre-requisite for functional competence because it is vital to performance of activities of daily living. In addition, good balance is considered necessary to perform activities with great force, with great speed or in a great amount (Ragnarsdottir, 1996).

Researchers (Bacsi and Colebatch, 2005; Kristinsdottir et al., 2001; Colledge et al., 1994; Lord et al., 1991) have concluded that individuals were more dependent on proprioception than on vision to maintain balance and to safely accomplish the majority of activities of daily living, but must integrate information from multiple sensory systems as task complexity and challenge to postural stability increase. In the same way, the ability to maintain balance requires the integration of vision, vestibular and peripheral sensation, central coordination and the neuromuscular response (Lephart et al., 1997; Overstall, 2003). Even though an age-related decline in function can be demonstrated in all parts of this system and as a result, one of third of population over 65 years falls each year.

Static and dynamic balance

The balance of the human body in the standing position is frequently divided into static and dynamic. The term static balance, physiological postural sway, as defined by Swift (1984) is continuous corrective movements around the center of gravity of a body, designed to maintain postural control in the upright position while standing still. The term dynamic balance on the other hand has been discuss by Berg et al. (1989) that is more useful to describe functional states of balance: maintenance of a position, postural adjustments to voluntary movements, and reactions to outside perturbation to posture.

Neuromuscular Control and Joint Stabilization

Muscular activity and joint motion, performed either consciously, are the products of multisite sensory input which is received and processed by the brain and spinal cord. The perception and execution of musculoskeletal control and movement are mediated primarily by the central nervous system (CNS). The CNS receives input from 3 main subsystems: the somatosensory system; the vestibular system; and the visual system (Tyldesley, 1989) (Fig 2.1).

<u>Sensory input</u>

Somatosensory system

The somatosensory system appears to be the primary contributor of feedback for postural control during quiet stance as compared to the visual and vestibular systems (Colledge et al., 1994; Lord and Ward, 1994; van Deursen and Simoneau, 1999), as the postural control system utilizes sensory information related to movement and posture from peripheral sensory receptors (e.g., muscle, joint, and cutaneous receptors) (Lephart et al., 2000). The information from somatosensory receptors is integrated in the central nervous system (CNS) to perceive the sensation of joint position and movement (Diener and Dichgnas, 1988; Lephart et al., 1998).

The somatosensory system, often referred to as proprioception, functions to detect sensory stimuli such as touch, pain, pressure and movements such as joint displacement (Tyldesley, 1989). This system receives input from the peripheral articular and musculotendinous receptors concerning in muscle length and tension, in addition to information regarding joint position and motion. Afferent nerves, also referred to as mechanoreceptors, are located within the skin, in the musculotendinous unit and within the bone, joint ligaments, and joint capsule (Kennedy, 1982; Tyldesley, 1989; Nyland, 1994).

Cutaneous receptors

Cutaneous afferents contribute minimally to joint proprioception, while the contribution of mechanoreceptors (muscle spindle receptors and joint receptors) is much greater (Lephart et al., 1998). However, the information of cutaneous receptors provide supplements the joint position sense and movement (Lundy-Eckman, 2002). For example, the cutaneous receptors on the plantar surface of the foot deliver information about the site and force of weight-bearing activities (Robbins et al., 1995, Kennedy and Inglis, 2002; Perry, 2006), and research by Burke et al. (1989) has demonstrated that cutaneous receptors influence muscle activity in the lower extremities.

Articular receptors

Mechanoreceptors originating in the joint capsule, bone and ligaments serve as range limit detectors, sensors of joint compression, and potentially provide for extreme range joint protection by signaling the presence of noxious intense stimuli (Grigg and Hoffman, 1982). There are 2 types of articular mechanoreceptors, quick-adapting (QA) and slow-adapting (SA), which vary based upon their response to a continuous stimulus. Whereas the QA receptors decrease their discharge near the onset of a continuous stimulus, the SA receptors' response is to continue their discharge (Boyd, 1954). The sensation of joint motion is thought to be mediated by QA mechanoreceptors, while SA receptors may play more of a role in joint position sense and sensation of changes in joint position (Johansson et al., 1991).

Muscle receptors

Muscle receptors provide a necessary complementary neural contribution in addition to the information of joint sensibility from the articular receptors. Muscle spindle and Golgi tendon sensory receptors (proprioceptors) provide the nervous system with continuous feedback about the status of each muscle (Kevin et al., 1996). Muscle spindle afferents respond as a function of muscle length to contribute to joint proprioception. These slow-adapting (SA) receptors, located within skeletal muscle, maintain a symbiotic relationship with articular receptors to result in sensation of joint motion, joint acceleration and joint position, in addition to sensation of pain (Grigg, 1975; Baxendale, 1988). Golgi tendon organs (GTO) located in the tendons near their junction with the muscles serve as SA type of afferent receptor. They are responsible for sending information about tension in the muscle or rate of change of tension (Guyton, 1986; Vander, 1990). The GTO is designed to serve as a protective mechanism to relax a muscle that is being overstretched (Vander, 1990).

Vestibular system

The second subsystem supplying the CNS with sensory input is the vestibular system receives information from the vestibules and semicircular canals of the ear, which can be used in 3 different ways in order to maintain body posture. This information can be used to maintain body posture by controlling eye musculature so as to maintain visual focus when the head changes position, to maintain upright posture and for conscious awareness of body and joint position, and motion (Guskiewiex, 1996).

Visual system

The visual system, the third subsystem contributing to CNS sensory input, also contributes to the maintenance of balance. This system provides the body with visual cues for use as reference points in orientating the body in space. It is generally agreed that, under normal condition, the somatosensory and visual subsystems are the primary mediators of balance and postural awareness (Lephart et al., 1998).

<u>The culmination of gathered and process information</u>

Information gathered by the somatosensory, vestibular and visual system is processed at 3 distinct levels of motor control: the spinal level; the brain stem; and the higher brain centers. The spinal level represents proprioceptive afferent connections on to Aα and especially Aγ motor neurons for producing reflexes designed to protect joints against potentially harmful stress. The brain stem processes information from the 3 CNS subsystems via the cerebellum neuclei for (subconscious) regulation of postures, balance and movement. The higher brain centers, the cerebral cortex, is the only proprioceptive afferent destination which allows perception. Proprioception at this level is essential for proper muscle and joint functions in sports, activities of daily living, and occupational tasks. The cerebral cortex are responsible for cognitive programming of musculoskeletal motion (Stillman, 2002; Lephart, 1993; ประวิตร เจนวรรธนะกุล, 2551). The culmination of gathered and processed information results in conscious awareness of joint position and joint motion sensibility that contribute to motor programming, unconscious joint stabilization through protective spinal-mediated reflexes and the maintenance of posture and balance (Tyldesley et al., 1989; Lephart and Henry, 1995; Lephart and Henry, 1996; Voight and Cook, 1996).

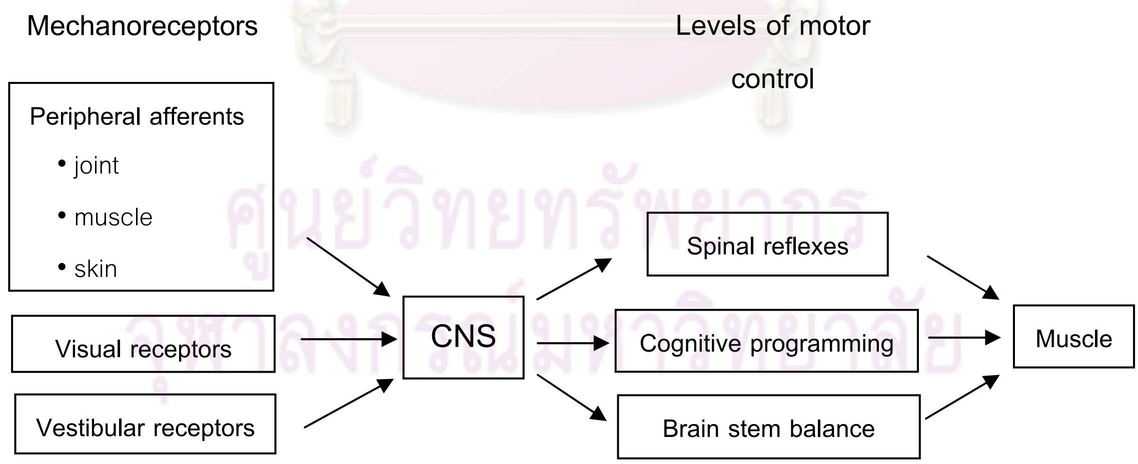


Fig 2.1 Neuromuscular control pathways (reproduced from Lephart & Henry, 1996 with permission)

Proprioception

Definition of proprioception

A review of the orthopaedic and musculoskeletal rehabilitation literature identifies many different versions of definitions for the terms associated with joint proprioception and neuromuscular control. In *Goetz's Textbook of Clinical Neurology,* proprioception is defined as any postural, positional, or kinetic information provided to CNS by sensory receptors in muscles, tendons, joints, or skin (Goetz, 1999). Other texts define proprioception as "awareness of the position and movements of our limbs, fingers, and toes derived from receptors in the muscles, tendons and joints" (Adums et al., 1997). Sherrington's classical definition of proprioception is all neural inputs (afferent information) originating from joints, muscles, tendons, and associated deep tissue proprioceptors or mechanoreceptors. These proprioceptive signals are projected to the CNS for processing, which ultimately regulates reflexes and motor control (Sherrington, 1906).

Another point is that, proprioception refers to conscious and unconscious appreciation of joint position, while kinesthesia is the sensation of joint motion. Conscious awareness of joint motion and position is proper joint function in sports, activities daily living, and occupational tasks, while unconscious proprioception modulates muscle function and initiates reflex stabilization (Lephart, 1997).

However, a more advanced definition of the sensory functions that encompass human proprioceptive function is clearly needed. These functions were described as sensation of passive movements, sensation of active movements, sensation of position, and appreciation or sensation of position, and appreciation or sensation of heaviness and resistance (Ellenbecker and Bleacher, 2004).

According to Stedman's Medical Dictionary (2000), proprioception refers to the sense or perception of the position and movement of the body, especially its limbs, and is independent of vision (Janwantanakul, 2001). Consequently, the term "proprioception" is suitable for the purpose of this study, used in order to refer the perception of joint position.

Classification of the senses

Several authors proposed that there are two distinguish types of proprioception; first, position sensation or static proprioception is defined as the ability to detect the position of body parts or means conscious perception of the orientation of difference parts of body with respect to another. Second, movement sensation or dynamic proprioception is defined as the ability to detect the actual movement of the limb which includes information about the velocity and direction of movement at which a limb changes its position (Clark and Horch, 1986; Hogervorst and Brand, 1998; Lephart and Henry, 1996; Guyton and Hall, 1996). Both components of proprioception are important for generation of smooth and coordinated movements, maintenance of normal body posture, regulation of balance and postural control, and motor learning and relearning (Pickard, 2003; Tsang, 2003).

Contribution of proprioception

Postural control depends on the ability to extract peripheral sensory inputs, integrate this information within the central nervous system (CNS), and coordinate and execute an appropriate musculoskeletal system response. It is of particular interest that proprioception is an essential component of postural control, providing orientation information about passive and active movements and positions of the joints (Westlake et al., 2007). Colledge and his colleagues (1994) studied the relative contributions to balance of vision, proprioception, and the vestibular system in different age groups. They found all age groups were more dependent on proprioception than vision for the maintenance of balance. Camicioli et al. (1997) also showed that disruption of proprioceptive input was the most important determinant of quantitative balance performance in the subjects older than 80 years. Thus proprioception may greatly influence postural stability, and a decline in proprioception with aging could be associated with the increased propensity of elderly individuals to fall (Petrella et al., 1997; Westlake et al., 2007).

Additionally, the position and movement sense are commonly linked during daily activities. Information gained during movement to a position may help localise the end position, while information gained about the start and end positions can be used deduce features of the interposed movement (Stillman, 2002). Several researchers stated that proprioception has great importance in avoiding unphysiologic joint movements such as extreme extension and flexion positions (Haus et al., 1992; Krauspe et al., 1992; O' Connor and McConnoughey, 1978). Therefore, joint proprioception is a kind of injury prophylaxis (O' Connor and McConnoughey, 1978). But proprioception is also very important in coordinating complex movement systems (Hasan and Stuart, 1988; Hufschmidt and Sell, 1990; Prochazka, 1986; Ring et al., 1988; Sainburg et al., 1993).

Anatomical and Physiological of Mechanoreceptors

Scientists have identified mechanoreceptors in both animal and human tissue, and there appears to be a wide distribution throughout the body. Mechanoreceptors have been identified in the shoulder, knee, and ankle joints, as well as in their musculotendinous attachments and the overlying cutaneous layer (Lephart, 1993). They are located in skeletal muscles, joint capsule, tendons, and ligaments and skin (Grigg, 1994) (Fig 2.2) derives proprioceptive sensation peripherally. They are stimulated by mechanical deformation of the receptors themselves or of tissues adjacent to them. Then transform this mechanical deformation into neural signals.

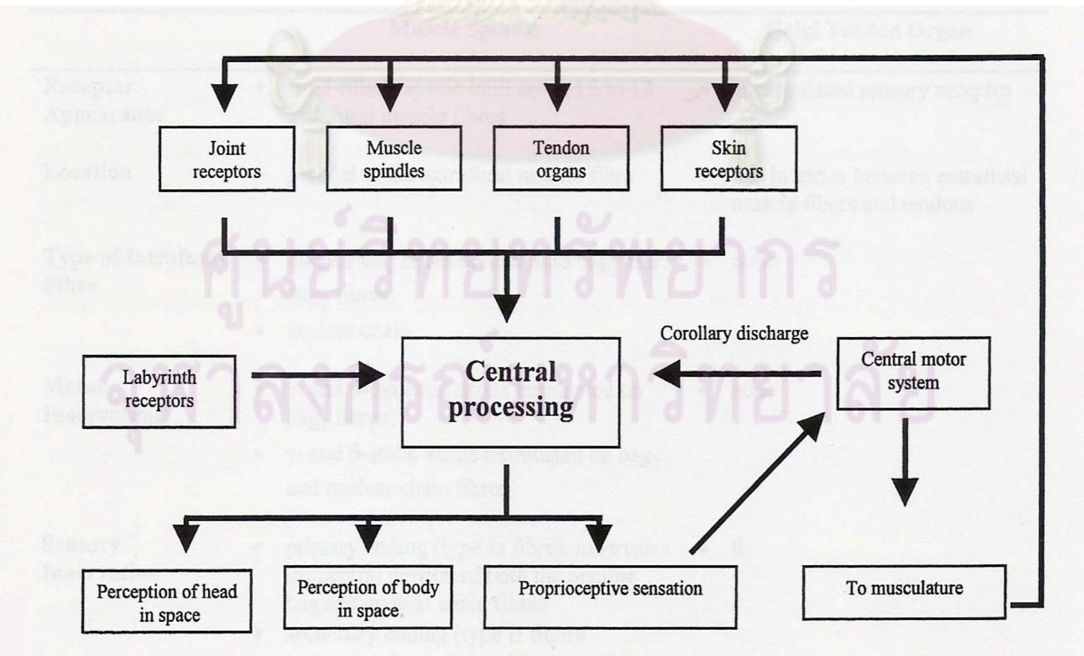


Fig 2.2 Diagram of the origin of proprioceptive sensation (modified from Schmidt 1986)

Proprioceptive information, also called “corollary discharge” (Gandevia, 1996), is a part of the command signals, destined for the muscles and gives feedback into the perceptual regions in the brain (Sperry, 1950).

Skeletal Muscle Mechanoreceptors

Voluntary muscles can be divided into two main kinds of muscle mechanoreceptors. First, the muscle spindles are typically found in skeletal muscles (Barker, 1974; Carpenter, 1990). Second, Golgi Tendon Organs (GTOs) or neurotendinous spindles are mostly situated at the musculo-tendinous or musculo-aponeurotic junctions of extrafusal muscle fibres with the rest in the tendon itself (Barker, 1974; Moore, 1984). The number, density and location of the muscle spindles and GTOs vary extensively among and within muscles (Gandevia, 1996). Anatomical characteristics and actions of the muscle spindles and GTOs are summarized in Table 2.1.

Table 2.1 Anatomical characteristics and actions of the muscle spindles and GTO (Carpenter, 1990; Gregory and Proske, 1990; Guyton and Halls, 1996)

	Muscle Spindle	Golgi Tendon Organ
Receptor Appearance	• fluid-filled capsule built around 3 to 12 intrafusal muscle fibres	• encapsulated sensory receptor
Location	• parallel to the extrafusal muscle fibre	• lies in series between extrafusal muscle fibres and tendons
Type of Intrafusal Fibre	• nuclear bag fibres divided into bag_1 and bag_2 fibres • nuclear chain	• none
Motor Innervation	• γ- and β-dynamic axons terminated on bag_1 fibres • γ- and β-static axons terminated on bag_2 and nuclear chain fibres	• none
Sensory Innervation	• primary ending (type Ia fibre): innervates the central portion of both the nuclear bag and nuclear chain fibres • secondary ending (type II fibre): innervates the peripheral portion of the nuclear chain fibres	• Ib
Ending Characteristics	• Ia: annulospiral ending • II: annulospiral and flower-spray endings	• none
Adapting Rate	• Ia: rapidly adapting • II: slowly adapting	• slowly adapting
Receptor Area	• central portion of the intrafusal muscle fibres	• tendon organ itself
Activation	• lengthening of the whole muscle • contraction of the end portions of the spindle's intrafusal fibres innervated by γ motor nerve fibres	• tension produced by contraction of extrafusal muscle fibres or by external force during passive movement

As the GTOs are only slowly adapting receptors, the muscle spindles, on the other hand, consist of both slowly and rapidly adapting receptor components. Slowly adapting receptors generate impulses and transmit them to the CNS as long as at the time, they are stimulated. However, rapidly adapting receptors are the receptors that generate impulses during the movement, and then stop after approaching the new position cease within the first few seconds. Thus, slowly and rapidly adapting receptors are expected to signal joint position and movement, respectively (Clark and Horch, 1986; Lephart et al., 1998b). They can relay information about joint position. Even when a brief subtle muscle contraction activates at an insufficient level to produce noticeable joint movement. Transient signals plus a good memory of joint position may serve well to provide information about position of a joint (Clark and Horch, 1986).

Contribution of Skeletal Muscle Mechanoreceptors

Muscle spindles are complex receptors that are located in the belly of skeletal muscles. They are fusiform in shape and their average length varies between 2-4 mm (Kandel, 2000). Muscle spindles are attached to extrafusal fibers in parallel and function as stretch receptors. They detect length as well as rate of change of length of the muscle fibers (Guyton, 1991). Muscle spindles are highly sensitive receptors that produce receptor potentials in response to as low as 100 micrometers change in the length of muscle (Kandel, 2000). However, whether this change in length is perceived consciously or not is unclear.

Morphologically, spindles are specialized encapsulated intrafusal muscle fibers innervated by sensory and motor nerve endings (Gray, 1980). The central or equatorial region of the spindle is supplied by group Ia afferent fibers. These are concerned with position or static stretch as well as velocity and acceleration responses of a rapidly adapting dynamic or phasic nature. Group II afferent fibers supply the part of spindle adjacent to the equatorial portion. They are associated with static or maintained stretch producing a continuous tonic response (Gray, 1980; Kandel, 2000). The efferent fibers for muscle spindles originate from gamma motor neurons. These neurons regulate the dynamic and static sensitivity of muscle spindles (Dewalde, 1987). As a result of their neurophysiological properties, the muscle spindles are believed to be suitable candidates to signal both position and movement sense.

The GTOs also have both static and dynamic responses. Increasing in the tension of tendon fibres during muscle contraction help the GTOs be stimulated more effectively than slow passive stretching (Gandevia, 1996; Moore, 1984; Stephens et al., 1975; Stuart et al., 1970). In other word, the GTOs are sensitive to changes in contractile force (Jami, 1992). Accordingly, the GTOs are believed to have a predominant role in signaling the sense of force or load, particularly that produced by contractile elements (Clark and Horch, 1986; Gandevia, 1996; Matthews, 1988; Proske et al., 2000; Rymer and D'Almeida, 1980).

To summarize, there are several experiments that support the importance of muscle mechanoreceptors, especially the muscle spindles, in subserving proprioceptive information, both position and movement sense. First, stimulation of muscle mechanoreceptors by mechanical pull, vibration or electrical stimulation induced the illusion of joint position and movement. Second, proprioceptive acuity is reduced after the elimination of the contribution from muscles receptors by nerve block. Third, tightening the muscle acting on the joint improves proprioceptive acuity. Last but not least, the awareness of joint position and movement still remains after the elimination of inputs from articular and cutaneous mechanoreceptors. The CNS relies on proprioceptive information from the lengthening or antagonistic muscles in order to detect joint position and movement (Janwantanakul, 2001).

Articular Mechanoreceptors

Mechanoreceptors located in the capsule of joint, ligament and any intra-articular structures also produce proprioceptive signals (Schutte and Happel, 1990). Four types of articular mechanoreceptors are identified: Ruffini corpuscle, Pacinian corpuscle and GTO-like corpuscle are considered “true” articular mechanoreceptors while free nerve endings are considered “pain receptors” (Newton, 1982). Table 2.2 summarizes the general anatomical characteristics and actions of each type of articular mechanoreceptors.

Table 2.2 The general anatomical characteristics and actions of each type of articular mechanoreceptors (Grigg and Hoffman, 1982; Newton, 1982; Schaible and Schmidt, 1983; Zimny, 1988)

	Ruffini Corpuscle	Pacinian Corpuscle	Golgi Tendon Organ-like Corpuscle	Free Nerve Ending
Sensory Unit	• myelinated parent axon and 2-6 corpuscles	• myelinated parent axon and 1-5 corpuscles	• myelinated parent axon and 1 corpuscle	• thinly myelinated parent axon and terminal endings
Sensory Innervation	• group I and II	• group II	• group I	• group III and IV
Adapting Rate	• slowly adapting	• rapidly adapting	• slowly adapting	• slowly adapting
Threshold To Activation	• low	• low	• high	• high
Activation	• stretch	• compression	• transverse compression • stretch	• noxious stimuli • deep pressure

Contribution of Articular Mechanoreceptors

With the identification of these receptor types, and the knowledge of their function, articular mechanoreceptors are excited by tension created in the joint capsule and ligaments. They have the potential to signal proprioceptive information when a joint approaches the limit of movement. It appears that the slowly adapting receptors, which consist of Ruffini corpuscles and GTO like corpuscle have the potential to convey information about joint position. The rapidly adapting receptors, the awareness of joint movement, are Pacinian corpuscles. Articular mechanoreceptors are presumed to be able to provide information about joint position and movement to the CNS. As a result, this combination of both muscle and joint receptors forms an integral component of a complex sensorimotor system that plays a role in the proprioceptive mechanism with transmitting any stress on the capsule-ligament structures as a joint reaches its extremes of movement (Guanche et al., 2000; Lephart, 1993).

Nonetheless, the contribution of joint mechanoreceptors to proprioception, both position and movement sense is not entirely clear, largely due to the inability to isolate articular from cutaneous afferent inputs. However, it is shown the combination of articular and cutaneous afferent inputs can provide information about joint position, especially near the extremes of movement. In addition, there is evidence suggesting that articular afferent inputs alone can signal movement sense (Janwantanakul, 2001).

Cutaneous Mechanoreceptors

Various mechanoreceptors are present in the skin. Merkel's discs and Meissner's corpuscles are highly developed encapsulated receptors commonly found in glaborous skin (Latash, 1998). Pacinian corpuscles are large encapsulated fast adapting receptors that are activated by deep pressure and quick stretch of the tissue (Eldred, 1967). These are abundant in the soles of the feet and may influence posture, position and ambulation (Quilliam and Ridley, 1971). Increased discharge from cutaneous receptors was observed at the limit of the physiological range of movement of interphalangeal and metacarpophalangeal joints of the hand and due to mechanical deformation of skin around these joints in six healthy young adults (Burke et al., 1988). Birmingham et al. (2000) demonstrated significant improvement in proprioception ($p < 0.05$) at the knee joint following the application of neoprene sleeve. Similarly, a dramatic increase in proprioception ($p < 0.001$) due to the use of an elastic knee bandage observed by Barrett et al. (1991) may have resulted from augmented cutaneous input.

Contribution of Cutaneous Mechanoreceptors

It has been long known that cutaneous mechanoreceptors have an exteroceptive role (touch, light touch, pressure-touch, pain and temperature). The skin is stretched on one side of the joint, and compressed or folded on the other, when a joint is moved. This may lead to stimulation of mechanoreceptors lying in cutaneous tissue (Carpenter, 1990; Clark and Horch, 1986; Grigg, 1994; Schmidt, 1986).

Janwantanakul (2001) proposed that cutaneous mechanoreceptors play an important role in signaling proprioception. During movements some particularly slowly adapting receptors most cutaneous mechanoreceptors are activated and response to static joint positioning. Recently, the perception of joint position and movement are produce by electrical or mechanical stimulation of the skin around and over the finger joints. Proprioceptive acuity is improved by the application of type or brace, which is believed to be the result of enhanced cutaneous afferent inputs from an excessive skin stretching and/or compression.

Assessment of Proprioceptive System Functions

Objective assessment of proprioception is important due to its functional implications as well as its role in detecting neurological and musculoskeletal pathologies. Nevertheless, there is currently very little information available regarding the measurement of ankle joint position sense. No left-right comparisons or test-retest measurements have been reported (Lephart, 2000).

Assessment of motor pathways

Assessment of joint proprioception is divided into 2 components: kinaesthesia and joint position sensibility. Kinaesthesia is assessed by measuring the threshold to detection of passive motion, while joint position sense is assessed by measuring the reproduction of passive positioning and the reproduction of active positioning (Lephart, 1996; Skinner, 1984; Smith, 1989). In order to minimize the contribution of musculotendinous mechanoreceptors (muscle spindles and Golgi tendon organs) in providing the CNS with information regarding limb position and movement, the threshold to detection of passive movement and reproduction of passive positioning are conducted at a slow angular velocity (0.5 to 2 degrees per second) (Lephart, 1996). The passive nature of this assessment procedure is thought to selectively stimulate Ruffini or Golgi type mechanoreceptors in the joint.

Assessment of the ability to perceive joint position

Measuring joint position sense requires the subject to match a set of index angles set by investigator, and this requires a precise method and accurate registration of limb motion (Lephart, 2000). However, there are essentially no standard protocols for measuring joint position sense or for joint replication tests, and so many measurement, starting reference angle, active or passive reproduction, and open chain (seated) versus closed chain (standing) (Friden et al., 2001). Bernier and Perrin (1998) conclude that assessment of proprioception in a manner would combine the use of joint, skin, and muscle mechanoreceptors rather than selectively assessing each. Further to this they recommend that joint position sense may be measured at clinically relevant velocities in weight bearing. Lattanzio and associates (Lattanzio et al., 1997) and Marks and Quinney (1993) used closed chain weight-bearing joint replications and reported high degree of accuracy. Their results may be due to the fact that there is greater proprioceptive input in the standing weight-bearing position in which multiple joints are being loaded (Ellenbecker and Bleacher, 2004).

The assessment of the ability to perceive joint position is a test that quantitatively examines the ability of an individual to replicate a predetermined (target) joint position that has been previously demonstrated, termed the “repositioning test”. The repositioning test is generally used to evaluate position sense at various joints, such as the shoulder, elbow, wrist, hip, knee and ankle joints (Beynnon et al., 2000; Borsa et al., 1994; Friden et al., 1996; Gandevia, 1996; Hogervorst and Brand, 1998; Jerosch and Prymka, 1996; Lephart et al., 1997; McCloskey, 1978). The testing procedure involves two separate steps. First, an examiner presents a target position to a subject. Second, a subject indicates the joint position perceived (Clark and Horch, 1986). The difference between the actual and replicated angle can be calculated as either an absolute or a real angular error. With absolute error only the magnitude of the error is used and whether the subject over- or underestimates the reference angle (Beynnon et al., 2002).

Active/passive movement

Active/passive movement refers to the manner by which the limb or body part is moved to the target and perceived joint positions. For “passive positioning” to a target position, a limb is usually secured and supported by an apparatus. The relaxed limb is moved passively from a starting position to a target position either by an examiner or apparatus at a constant speed. For “active positioning” to a target position, a subject, instead of an examiner or apparatus, actively moves their limb or body part from a starting position to a target position at either a controlled or uncontrolled speed. A subject moves the limb until either told to stop or a mechanical stop is reached.

In “passive repositioning” technique, after reaching the target position, a subject is asked to remember the position while the limb is sustained in the position for a period of time. After that, the limb is moved away either actively or passively from the target position to the either starting position or a random position. To indicate a perceive position, the limb is passively moved toward the target position. A subject is then instrumented to inform an examiner or manipulate a switch to stop a mechanical arm when they feel the limb has regained the target position. For “active repositioning” technique, a subject actively moves the limb back to the target position (Janwantanakul, 2001).

Andrew et al. (2004) reported that testing for joint position sense involves passive movement of the extremity, as well as Lephart et al. (1997) claimed that the repositioning test with passive movement maximally evaluates the contribution of joint mechanoreceptors to proprioceptive acuity . Similar to Janwantanakul’s statement deduced that testing with passive movement would maximally evaluate the proprioceptive contribution of joint receptors should be viewed with caution (Janwantanakul, 2001). While the repositioning test with active movement provides a more functional assessment of proprioceptive acuity. Functional activities are normally performed with active movement or muscle contraction. Therefore, testing with active movement may be more functionally relevant (Andrew et al., 2004).

Factors Effecting Joint Proprioception

Table 2.3		
Factors Effecting Joint Proprioception		
1. Joint hypermobility	4. Ethnicity	7. Muscle fatigue
2. Age	5. Gender	8. Articular injury
3. Hand dominance	6. Exercise	9. Peripheral neuropathy

1. Joint hypermobility

General ligamentous laxity resulting in an increased ROM is called "joint hypermobility" or "laxity" (Mallik et al., 1994). Joint hypermobility is associated with hereditary connective tissue syndromes such as Ehlers-Danlos syndrome, familial articular hypermobility syndromes, Marfan's syndrome, osteogenesis imperfecta, Larsen syndrome, Desbuquois' syndrome, skeletal dysplasia with predominant joint laxity, and dwarfing dysplasia with variable joint laxity (Beighton et al., 1989). The Beighton scoring system is the most common scoring system, ROM, using in evaluating the joint hypermobility (Beighton et al., 1973).

Joint hypermobility has been demonstrated to affect proprioception at various joints (Barrack et al., 1983a; Hall et al., 1995; Mallik et al., 1994). Two hypotheses have been proposed for decreased proprioceptive acuity in a hypermobile joint. First, a hypermobile joint may possess defects in the capsule-ligamentous structures and a decrease in muscle tone leading to a disruption of proprioceptive signals into the CNS (Allegrucci et al., 1995; Hall et al., 1995; Mallik et al., 1994). Second, in proprioceptive testing, hypermobile joints have more reduce tissue tension and, consequently, a decrease in proprioceptive signal than those of non-hypermobile joint at the end ROM (Allegrucci et al., 1995; Blasier et al., 1994; Mallik et al., 1994).

2. Age

On proprioceptive acuity, they are two stages of the effect of age. To begin with, before reaching maturity, there is an ongoing development of the nervous system. Therefore, proprioceptive acuity, which is mediated through the nervous system, could be hypothesized to change with progressive development. Ashton-Miller et al. (1992) investigated trunk proprioception in subjects with ages ranging from 7-18 years using the repositioning test. They found that with increasing age and were fully matured by age 15-16 years, trunk proprioception improved progressively. A similar result has been recently reported by Visser and Geuze (2000) has recently a similar result about upper limb proprioceptive acuity in boys aged between 5-14 years.

After reaching maturity, sensory impairment such as diminished vision, hearing, olfaction and taste occurs commonly with aging, which also affects the somatosensory system. Advancing age has the potential to affect the function of mechanoreceptors situated in neural tissues, muscles, skin and joint structures, thereby altering proprioceptive acuity. Indeed, a decline in proprioception with increasing age has been shown in various joints (Attfield et al., 1996; Ashton-Miller, 2000; Barrack et al., 1983c; Barrett et al., 1991; Ferrell et al., 1992; Hearn et al., 1989; Hurley et al., 1998; Kaplan et al., 1985; Lord and Ward, 1994; Pai et al., 1997; Petrella et al., 1997; Skinner et al., 1984).

There is a research supporting the effect of aging on proprioception, showed proprioceptive deterioration in osteoarthritic (OA) joints, a condition which occurs commonly in the elderly (Barrack et al., 1983c; Barrett et al., 1991; Garsden and Bullock-Saxton, 1999; Hurley et al., 1997; Koralewicz and Engh, 2000; Marks et al., 1993; Sharma et al., 1997). To explain proprioceptive impairment in the OA joint, several hypotheses have been proposed. proprioceptive deficit in the OA joint may be a result of destruction of articular receptors in joint structures (Barrack et al., 1983c) or may be due to laxity of the joint capsule and ligaments caused by loss of cartilage and bone height (Barrett et al., 1991).

Another hypothesis has attributed proprioceptive impairment in the OA joint to a decline in muscle spindle sensitivity (Hurley et al., 1997). This hypothesis proposes that abnormal sensory inputs to the CNS which, in turn, inhibit α- and γ-motoneurone activation may come from articular damage, which is result of muscle weakness and poor proprioceptive acuity. This phenomenon would result in muscle weakness and poor proprioceptive acuity, respectively. In summary, previous studies is that aging point out likely to have a significant effect on proprioception.

3. Hand dominance

The right and left sides of the brain stem and spinal cord control physical asymmetry between the right and left hemispheres (Koff et al., 1986). The specialization between the right and left limb may come from asymmetry of the CNS. The right side of the body is controlled from the left hemisphere, which is superior of complex motor operation such as speech, fine temporo-sequential motor activities. The left side of body controlled from the right hemisphere, which is superior for the processing of visuo-spatial-perceptual information (Bradshaw and Nettleton, 1983; Tucker and Williamson, 1984). Shimoyama et al. (1990), Todor and Kyprie (1980), Van Emden (1994) showed the example, performance of a simple motor task such as fast tapping is superior with the right limb than with the left limb.

No difference in proprioceptive acuity between the right and left limbs has been found in the previous studies.

4. Ethnicity

The transmission properties of the nervous system are not affected by difference in ethnic backgrounds. For example, there is no difference has been found in the nerve conduction velocity between black and white subjects (Buschbacher and Koch, 1999). As a result, before a final conclusion regarding the effect of ethnicity, research involving a large sample size is required.

5. Gender

Some controversy remains whether gender affects proprioceptive acuity and evidence for the effect of gender on proprioceptive acuity is far from conclusive. No difference from several previous proprioceptive studies at the knee joint were reported in proprioception between males and females (Barrack et al., 1984; Barrett et al., 1991; Friden et al., 1996; Hall et al., 1995; Jerosch et al., 1996a). Therefore, the effect of gender of proprioception still remains to be elucidated.

6. Exercise

A number of researchers in various groups of athletes have examined the effect of regular exercise on proprioception. Several studies have reported enhancement of knee proprioceptive acuity in athletes or following regular exercises (Euzet and Gahery, 1995; Lephart et al., 1996; Petrella et al., 1997). In Petrella et al. (1997), an improvement in knee proprioception, measured by the repositioning test, in active elderly subjects compared with sedentary controls has been found. Their findings of greater proprioceptive acuity following exercise to a number of factors have been attributed. First, competitive athletes with innate superior proprioception may be selected (Allegrucci et al., 1995; Euzet and Gahery, 1995; Lephart et al., 1996). Second, exercise causes not only short-term adaptations of contraction muscles, which the muscle spindles and GTOs may be more excitable to stretching following exercise (Hutton and Atwater, 1992) but also a long-term, which may allow the development (hypertrophy) of extrafusal as well as intrafusal muscle fibres (Euzet and Gahery, 1995; Maier et al., 1972). Last but not least, neuromuscular may be enhancement exercise. The neuromuscular control via both central and peripheral mechanisms may lead to improvement in neurosensory pathways (Euzet and Gahery, 1995; Lephart et al., 1996; Petrella et al., 1997).

7. Muscle fatigue

Muscle fatigue is a reduction of muscle force or power that occurs with exercise (Taylor et al., 2000). A number of simultaneous mechanisms, causing fatigue include: the CNS drive to motor neurons, neuromuscular propagation, excitation-contraction coupling and the availability of metabolic substrates.

There are investigations of the effect of muscle fatigue on at various joints. Deterioration of proprioceptive acuity following fatiguing contractions have been reported in a number of experiments (Lattanzio et al., 1997; Marks, 1994; Skinner et al., 1986a; Taimela et al., 1999), although some studies have not found such a change (Marks and Quinney, 1993; Sharpe and Miles, 1993). Variation in the findings may partly lead to the difference of proprioceptive tests used, fatigue protocol, joint tasted and sample size.

To explain the effect of muscle fatigue on proprioception, a number of hypotheses have been used forward in an attempt. Not only are the contractile elements of muscles but also intramuscular receptors that lie within the fatigued muscle possibly affected by muscle fatigue. Fatigue has been shown to cause a reduction in muscle spindle discharge and a decline in responsiveness to stretch of GTOs (Hutton and Nelson, 1986; Macefield et al., 1991).

Fatigue may cause the desensitization of intramuscular receptors to muscle tension is another hypothesis for a decrease in discharges from intramuscular receptors after fatigue. Consequently, intramuscular receptors may become less sensitive to the stimuli; this may lead to a decrease in discharges from intramuscular receptors (Lattanzio et al., 1997; Voight et al., 1996).

Fatigue, followed with proprioceptive impairment also may relate to increased joint laxity. Muscle fatigue has been shown to increase joint laxity (Sakai et al., 1992; Skinner et al., 1986b; Weisman et al., 1980). “Central fatigue” or changes within the CNS are also caused by fatigue and defined as a failure of voluntary activation of muscle, thereby decreasing maximal voluntary force or power (Gandevia et al., 1995). Changes within the CNS due to fatigue can occur at multiple levels in the motor pathway, including supraspinal and spinal levels.

8. Articular injury

Freeman et al. (1965) postulated that because the tensile strength of the joint receptors is less than the connective tissues in which they are located, the receptors must be damaged when the ligaments or capsules are stretched or torn. This damage may result in functional instability, faulty joint positioning and diminished postural reflex responses (Gross, 1987). Functional instability is defined as repeated injury and/or a feeling of instability and “giving way” that follows a significant acute sprain of the joint (Bernier and Perrin, 1998; Konradsen and Magnusson, 2000).

Such instability is relatively common following an acute ankle sprain (Glencross and Thornton, 1981; Lentell et al., 1995; Bernier and Perrin, 1998). Lentell et al.

(1995) studied proprioception deficits in 42 subjects with unilateral chronic ankle instability (average age 22 years). The duration of reported instability ranged from 3 months to 16 years with an average of 6 episodes of recurrent injury. The subject placed his/her foot on the movable platform that rotated the subtalar joint into inversion from the neutral position (0°) at a rate 0.3°/sec. In this single blind study, threshold to detect passive movement at the subtalar joint was measured bilaterally with the subjects in a sitting position. The injured joint required a significantly greater excursion (4.3±3.1°) than uninvolved side (3.2±1.8°) before the motion was sensed. Konradsen and Magnusson (2000) observed significant differences ($p < 0.05$) in the error between the injured and uninvolved joint of twenty-the young adults for passive to active reproduction of the subtalar joint position. Measurement of proprioception in anterior crutiate ligament deficient knees also demonstrated deterioration of proprioception and impaired function (Barrack et al., 1989).

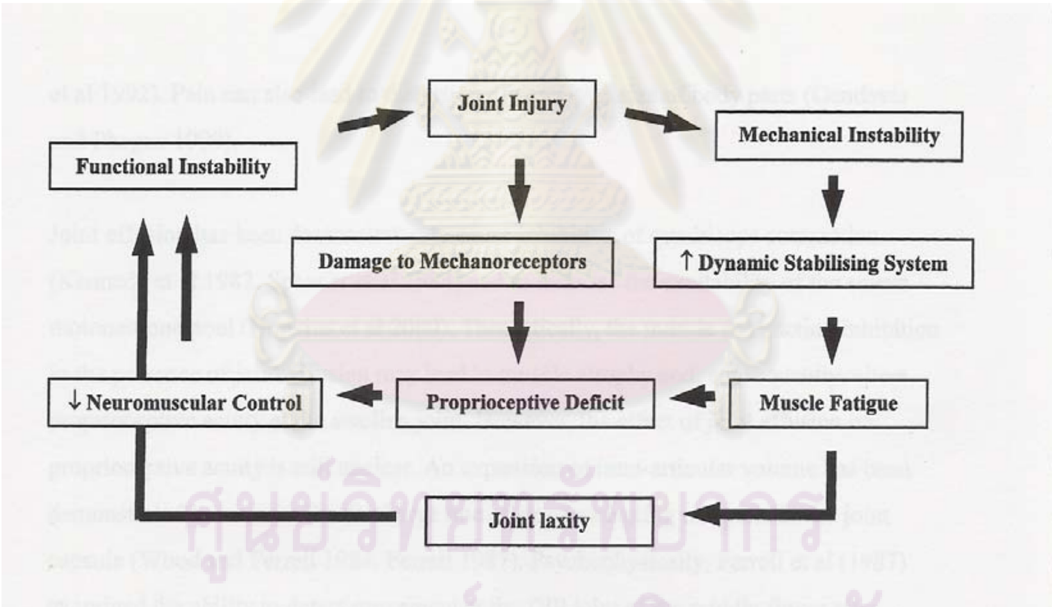


Fig 2.3 Paradigm depicting the relationship of instability and proprioceptive impairment (modifier from Lephart and Henry, 1992)

9. Peripheral neuropathy

There is a large body of literature addressing deterioration of proprioception in people with diabetic sensory neuropathy (Simoneau et al., 1996; van Deursen et al., 1998; van Deursen and Simoneau, 1999). Simoneau et al. (1996) assessed ankle proprioception in a weight-bearing position using the test protocol of threshold to detect passive movement. Subjects with peripheral neuropathy required significantly greater average displacement in the sagittal plane at both 0.25°/sec and 0.75°/sec in order to detect the movement (4.6° and 3.9° respectively) whereas the control group needed 1.7° and 1.4° of displacement respectively. There was no attempt made to eliminate input from cutaneous receptors.

Van Deursen et al. (1998) applied the same protocol but attempted to eliminate plantar cutaneous receptor input by applying a foot clamping device that was fixed on the dorso-lateral aspect of the foot to passively control the movement of the ankle at a velocity of 0.75°/sec. A total of 61 subjects were divided into 4 group s as follows: severe diabetic neuropathy, mild diabetic neuropathy, no diabetes and diabetes without neuropathy. The average threshold required for perception of movement was 1° for the non-diabetic group, 2.5° for the diabetic group with no neuropathy, 3° for the mild diabetic neuropathy group, and 5.8° for the severe diabetic neuropathy group. The differences between the groups were significant ($p < 0.05$) and consistent with the findings of Simoneau et al. (1996), Richardson and Ashton-Miller (1996) used the same protocol to test perception of inversion and eversion movements of the ankle in a weight-bearing position. This study demonstrated a loss of proprioception in older subjects with non-diabetic neuropathy.

Falling

The somatosensory system and, specifically, the proprioceptive system, are critically involved in the sensory control of balance (Ribeiro and Oliveira, 2007). Colledge et al. (1994) studied the relative contributions of vision, proprioception, and vestibular system to the balance in different age groups. They found that all age groups were more dependent on proprioception than on vision for the maintenance of balance. Thus, impaired proprioception could be a contributing factor to falls.

Falls are among the most common and serious problems facing elderly persons. Falling is associated with considerable mortality, morbidity, reduced functioning and premature nursing home admissions (Brown, 1999; Nevitt, 1997; Robbins et al., 1989; Rubenstein et al., 1994; Tinetti et al., 1986). Falls are generally result from an interaction of multiple and diverse risk factors and situations, many of which can be corrected. This interaction is modified by age, disease, and the presence of hazards environment. Especially, impairments in sensation, strength (force-generating capacity of a muscle), reaction time, vestibular function, and vision occur with aging and are believed to collectively contribute to the increased likelihood of falling (Lord et al., 1999; Lord and Sturnieks, 2005; Lord and Ward, 1994).

Risk factors for falling

1. *Intrinsic factors* that is lower extremity weakness, poor grip strength, balance disorders, functional and cognitive impairment, and visual deficits.

2. *Extrinsic factors* that is polypharmacy (i.e., four or more prescription medications) and environmental factors such as poor lighting, loose carpets, and lack of bathroom safety equipment.

Although investigators have not used consistent classifications, The American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention studies ranked the risk factors and summarized the relative risk of falls for person with each risk factor (Table 2.4). There appears to be both the intrinsic and extrinsic factors as important as risk factors for falling. The factors that primarily considered as fall risk, based on muscle weakness, history of falls, gait deficit and balance deficit with respective range at 1.5-10.3, 1.7-7.0, 1.3-5.6, and 1.6-5.4 times. Other risk factors are becoming fall risk, which included use assistive device, visual deficit, arthritis, impaired ADL, depression, cognitive impairment, and adult over the age of 80 years (American Geriatrics Society, 2001).

Table 2.4 Result of Univariate Analysis of Most Common Risk Factors for Falls Identified in 16 Studies that Examined Risk Factors

Risk Factor	Mean RR-OR*	Range
Muscle weakness	4.4	1.5-10.3
History of falls	3.0	1.7-7.0
Gait deficit	2.9	1.3-5.6
Balance deficit	2.9	1.6-5.4
Use assistive device	2.6	1.2-4.6
Visual deficit	2.5	1.6-3.5
Arthritis	2.4	1.9-2.9
Impaired activities of daily living	2.3	1.5-3.1
Depression	2.2	1.7-2.5
Cognitive impairment	1.8	1.0-2.3
Age > 80 years	1.7	1.1-2.5

* RR = Relative risk ratios, OR = Odds ratios

Aging

Aging is a normal biologic process. All multicellular organisms undergo changes with time. The progression of development, reproductive maturity, and aging has been extensively investigated in the biologic sciences. Most physiologic functions do decline with age but different extents, and there are several theories as to why the aging process occurs.

The physiologic changes of aging

Muscle Spindle: Anatomical and Physiological Aged-Related Change

Aging is associated with functional and structural changes in somatosensory systems (Shaffer and Harrison, 2007). The somatosensory receptors responses to perceive the sensation of joint position and movement (Diener and Dichgnas, 1988; Lephart et al., 1998). At the peripheral level, the construction of proprioception is based on the cumulative neural input from mechanoreceptors (articular, muscular, and cutaneous receptors). Several studies reported that advancing age cause a decline in structural modifications within articular, muscular, and cutaneous receptors (Ribeiro and Oliveira, 2007). Table 2.5 provides a summary of anatomical and clinical changes to proprioceptive somatosensation.

Studies using animals and humans showed anatomical and physiological age-related changes in muscle spindle resulting in muscle spindle decline: a study using rats described an age-related changes structural of muscle spindle which can be seen in decreases in the total number of intrafusal muscle fibers and nuclear chain fibers per spindle, and increases in spindle capsule thickness (Kararizou et al., 2005; Liu et al., 2005; Miwa et al., 1995; Swash and Fox, 1972).

Swash and Fox (1972) reported that aged human muscle spindles exhibited increased spindle capsule thickness and a loss of total intrafusal fibers per spindle. Besides that, these spindle modifications may be the result of denervation, because spherical axonal swellings, expanded motor end plates, and group denervation atrophy can also be observed on skeletal muscle (Swash and Fox, 1972). The findings of a recent study by Kararizou et al. (2005) suggested that muscle spindles exhibited declined in the number of intrafusal fibers in the deltoid muscle with the smallest quantity of fibers seen in an individual who was 82 years of age. In addition, Liu et al. (2005) identified that three myosin heavy chain protein content had modified expression in aged muscle spindles when compared to those from young subjects.

The conclusions from these studies suggest that proprioception decreases with aging is in the part because of changes in muscle spindle function. In addition to that, advancing age leads to deficits in the processing of sensory input (myelin abnormalities, axonal atrophy, and declined nerve conduction velocity) and neuromuscular performance decline (Behse et al., 1971; Hashizume and Kanda, 1995; Sharma et al., 1980; Verdu et al., 2000). However, no study was found that examined age-related changes in the Golgi tendon organ (Ribeiro and Oliveira, 2007; Shaffer and Harrison, 2007).

Table 2.5

Proprioceptive Somatosensation: Age-Related Anatomical, Physiological, and Clinical Changes

Model	Muscle Spindle Changes	Articular Receptor Changes	Clinical Proprioception
Human	Increased capsular thickness ↓ number of intrafusal fibers ↓ spindle diameter in deltoid and extensor digitorum brevis muscles; no changes in quadriceps femoris or biceps muscles ↓ number of total intrafusal fibers and chain fibers in biceps muscle; no changes in the number of bag fibers Modifications in myosin heavy chain content Alterations in distal sensory axons	↓ in all joint receptor types in coracoacromioclavicular ligaments in patients undergoing shoulder arthroscopy	↓ JPS in the great toe ↓ JPS ankle in weight bearing and non-weight bearing ↓ JPS in the knee in partial weight bearing but not full weight bearing ↓ JPS in older adults with knee osteoarthritis No changes in hip JPS

*JPS = joint position sense

Articular Receptors: Anatomical and Physiological Aged-Related Change

Only 2 studies were found that have critically analyzed the relationship between the aging process and structural modifications within articular receptors. The studies reported a decline in the numbers of Ruffini's, pacinian, and golgi tendon like ligament receptors across age groups (Morisawa, 1998; Aydog et al., 2006).

Cutaneous Receptors: Anatomical and Physiological Aged-Related Change

Consistent with the anatomical findings of declining cutaneous receptors with age, multiple studies (Perry, 2006; Verrillo, 1979; Verillo et al., 2002; Bouche et al., 1993; Inglis et al., 2002; Wells et al., 2003) have demonstrated that older adults lose vibratory sensation with age and that vibratory testing should be considered when screening for distal sensory impairments in older adults (Table 2.6). Additionally, a degradation of tactile acuity in aging may be clinically meaningful in that a recent study identified that the loss of 2-point sensation in the plantar aspect of the toe was significantly greater in “fallers” than in “nonfallers” (Melzer et al., 2004).

Table 2.6

Cutaneous Somatosensation: Age-Related Anatomical, Physiological, and Clinical Changes

Model	Pacinian Corpuscle	Meissner's Corpuscle	Clinical Cutaneous Testing
Human	↓ number with increasing age ↓ Vibration perception thresholds and perceived magnitude of vibration at frequencies that activate pacinian channels	↓ concentration with increasing age ↓ size and number with increasing age ↓ number in the finger and impaired touch thresholds	Diminished vibration perception threshold testing Diminished monofilament testing Diminished 2-point discrimination testing

Evidence of Proprioception Deterioration with Aging

The actual knowledge about age effects on proprioception is based on cross-sectional studies comparing proprioception in different age groups. Those studies assessed proprioception by measuring JPS and/or the sense of movement, but the methodology used was different between studies. It is important to note that, although using different methodologies, the sense of results led to similar conclusions.

Proprioception involves central and peripheral components. At the peripheral level, the construction is based on cumulative neural input from mechanoreceptors. The central component involves internal feedback loops that transmit information between and within sensory and motors area. The relative contribution of the central and peripheral level is not established, but it is reasonable to expect that the declines in proprioception found in old age subjects could be related to both central and peripheral changes (Ribeiro and Oliveira, 2007). Consequently, the term “peripheral components” is suitable for the purpose of this study.

The studies regarding the effects of aging on proprioception were conducted by Barrack et al. (1984), who investigated the knee joint, concluded that young members of a professional ballet company had significantly better threshold of perception of joint motion than healthy, active age-matched control group. Skinner et al. (1984) investigated the effect on knee proprioception under passive movement (threshold of detection of joint motion and the ability to reproduce passive knee positioning) and observed that older subjects had poorer proprioception in both tests compared to younger subjects.

In the same way, Kaplan et al. (1985) assessed the age-related changes in proprioception using two techniques that required active movement (ipsilateral and contra-lateral active repositioning) and found that older subjects had reduced proprioception compared to younger subjects.

The current literature involving aging and lower-extremity proprioception also provides evidence that proximal joints may not be affected to the same extent as distal joints. Verschueren et al. (2002) examined dynamic JPS for passive ankle plantar flexion tested at various velocities (15°, 20°, 25°, 30°/s). A total of 102 older (mean age = 62.5 years) and 24 young (mean age = 21.7 years) men completed the proprioceptively controlled task reached the prescribed target angle. The oldest category of adults (70 years of age) exhibited significantly greater ($p < 0.05$) deviation from the specific target angle and variability in performance when compared with younger adults. Adults aged 60 to 70 years also demonstrated increased variance in performance, but were no different from younger adults in their ability to reach the prescribed target angle. Sixty-five of the older adults and 15 of the younger adults were retested while also having vibration (60 Hz) applied to the tibialis anterior tendon. Vibration resulted in a marked increase in positioning errors for older adults, but not young adults, suggesting that the age-related decline in dynamic JPS was a combination of reduced cutaneous and spindle function. Finally, the authors analyzed the effects of knowledge of results practice and determined that both younger and older adults significantly improved ($p < 0.05$) following practice trials. These findings demonstrate that dynamic JPS may improve in older adults who undergo focused practice.

The studies regarding the effects of aging on dynamic position sense were conducted by Madhavan and Shields (2005), who expanded on this testing protocol by testing velocities from 10° to 90°/s. The investigators also included measures of balance (single-leg stance time), electromyographic (EMG) muscle activity, and self-report of function

(36-Item Short-Form Health Survey questionnaire [SF-36]). Older adults had decreased dynamic ankle JPS, and proprioceptive decline was strongly associated (R^2=.92) with single-leg stance time (eye closed). Furthermore, elderly participants had co-contraction of the plantar flexors and dorsiflexors throughout the passive proprioceptive positioning task. Increased EMG activity was not seen in younger adults, and the authors hypothesized that older adults' inability to relax may have been a mechanism to increase sensitivity or "gain" in the muscle spindle. These findings are consistent with previous research showing that co-contractions about the ankle serve as a compensatory strategy for elderly people to maintain postural control (Benjuya et al., 2004).

Throughout Ribeiro and Oliveira's review (Ribeiro and Oliveira, 2007), for ankle position sense Robbins et al. (1995) described an age-related decrease of about 3° (angular error of estimation increased from 3.418° in the young adults to 6.548° in the elderly). Similarly, You (2005) found differences of 47.5% in the joint ankle reposition between young (median age: 22.2 years) and aged (median age; 73.1 years) subjects. Barrack et al. (1993) estimated this reduction in about 6.54°. Yan and Hui-Chan (2000) showed that the joint detection threshold was 50% higher in older subjects (aged 57-77 years) than in younger subjects (aged 25-35 years) for both knee extension and flexion movements.

There is evidence that the amount of weight bearing may influence the level of age-related proprioceptive decline for the knee. In a study by Bullock-Saxton et al. (2001), for example, errors in knee JPS during full weight bearing did not differ between young (20-35 years), middle-aged (40-55 years), and older (60-75 years) participants with normal lower-extremity function. The lack of a change with age may reflect that weight bearing maximizes afferent input from multiple joints and all types of proprioceptors (joint receptors, muscle spindle, GTO, and cutaneous input). When subjects were tested in partial weight bearing (30% of full weight bearing), there were differences (p < 0.05) between older adults and participants in the middle-aged and young groups, implying that accuracy of knee JPS is weight dependent. Interestingly, multiplanar weight-bearing JPS at the ankle in older adults (n=46, mean age = 73.12 years) exhibited a significant reduction from young control subjects (n=10, mean age = 22.20 years). However, JPS at the ankle was not able to discriminate between older adults who had not fallen and those with a history of a fall within the past year (n=22, mean age = 73.12 years) (You, 2005), possibly due to the complexity of issues contributing to falls risk (Boulgarides et al., 2003).

Ribeiro and Oliveira (2007) reported that several studies showed a relationship between aging and decline in several aspects of proprioceptive sensitivity, namely a decrease in joint position sense and an increase in movement detection threshold. The lower limb, knee joint position sense, and ankle joint position sense are negatively affected by aging. Similarly, in the upper limb, a decline in elbow and finger joint position sense was observed. Movement detection thresholds increased with advancing age, as shown by the results conducted in the knee (Barrack et al., 1983; Skinner et al., 1984; Yan and Hui-Chun, 2000), ankle (Gilsing et al., 1995; Thelen et al., 1998), and metacarpophalangeal and metatarsophalangeal joints (Kokmen et al., 1978). The hypothesis of a distal-to-proximal loss of proprioception also is supported by these studies involving knee and ankle JPS, in addition to research showing that perception of joint motion at the first metatarsophalangeal joint was significantly different between young and old adults (Kokmen et al., 1978).

The Role of Physical Activity in Proprioception Preservation during Aging

Recent, there has been widely reported that proprioception declines during aging process. Few studies have been conducted to examine the effects of regular physical activity on proprioception preservation during aging (Ribeiro and Oliveira, 2007).

It is interesting to note that Pickard et al. (2003) compared hip JPS in 30 sedentary young subjects (mean age = 21.7 years) and 29 healthy elderly subjects (mean age = 75 years) that practiced physical activity 10 (range 3 to 20) hours per week. Both active and passive hip abduction and adduction JPS were tested, and the results demonstrated that there were no significant group differences. The authors justified the lack of differences between subjects because the aged group was physically active. However, the authors did not compare sedentary aged subjects with active aged subjects, it is impossible to affirm that the lack of significant changes between young and aged subjects is because of the increased physical activity.

Proprioception may be influenced by the level of regular physical activity. Based on this, Petrella et al. (1997) designed a study to investigate knee joint proprioception among young volunteers and active and sedentary elderly volunteers. Knee joint proprioception was measured through reproduction of static knee angles using an electrogoniometer. Sixteen young subjects (age range, 19-27 years) and 24 elderly subjects (age range, 60-86 years) participated in the study. The elderly group was separated into active and sedentary subgroups based on their level of activity during the past years. Significant difference in the absolute error for active to active reproduction of the test position at knee joint were observed between young (mean, 2.01±0.46°) and active old (mean, 3.12±1.12°; $p < 0.001$), young and sedentary old (mean, 4.58±1.93°; $p < 0.001$), and active old and sedentary old ($p < 0.03$). The authors concluded that proprioception is diminished with age and that regular activity may attenuate this decline. Hurley et al. (1998) observed similar result in discriminating young (n=20, mean age 23 years), middle-age (n=10, mean age 56 years), and older (n=15, mean age 72 years) subjects demonstrating the sensitivity of this test at the knee joint.

Gauchard et al. (1999) investigated the effects of different types of exercise on postural control and balance of aged individuals. Researchers chose yoga and soft gymnastics as proprioceptive exercise, which consist of slow movements performed sequentially under different postural conditions; they compared the effects of proprioceptive exercise, bioenergetic physical activities (swimming, cycling, or jogging), and no exercise on postural control in the elderly people. The results indicate that muscular strength was significantly increased in the bioenergetics exercise group, but proprioceptive exercise appeared to have the greatest effect on balance control. The authors concluded that the proprioception can be “trained” and that regular exercise of proprioceptive nature might be beneficial to regain balance. These findings were corroborated by Tsang and Hui-Chan (2003). The authors demonstrated that long-term (mean Tai Chi experience 10.1±9.5 years)

Tai Chi, a Chinese mind-body exercise that puts a great emphasis on the exact joint position and direction, practitioners had improved knee joint proprioception.

Similarly, Xu et al. (2004) designed a study to investigate the proprioception of ankle and knee joints in 21 elderly long term tai chi practitioners (mean age: 66.1 years), 20 long term swimmer/runners (mean age: 65.4 years), and 27 elderly sedentary controls (mean age: 65.6 years). Ankle and knee joints were measured by detecting the threshold of passive movement (Kinaesthesis technique). This study showed that long term tai chi practitioners have better ankle and knee joint kinaesthesis than sedentary controls ,and also their ankle joint kinaesthesis is better than regular swimmer/runners. The authors concluded that the large benefits of tai chi exercise on proprioception may result in the maintenance of balance control in older people. Namely the decline in proprioception with age may be an important contributing factor to falls in the elderly, and this may be influenced by regular physical activity.

Tsang and Hui-Chan (2004) examined whether experienced golfers had attained similar improvement when compared with the tai chi practitioners, as well as healthy elderly subjects and young university students. Researchers using passive knee joint repositioning test to assess joint proprioceptive acuity and limits of stability test to assess ability to voluntarily weight shift within base of support. The result demonstrate that both experienced tai chi practitioners and golfers had improved knee joint proprioception and limits of stability, when compared with those of elderly control subjects similar in age, gender (male), and physical activity level. Such improved outcome measures were comparable to those of young male subjects. These findings suggest that experienced tai chi practitioners and golfers had improved joint proprioceptive acuity and dynamic standing balance control, despite the known aging effects in these specific sensorimotor functions.

Theoretically, older adulthood is accompanied by declines in muscular strength, coordination, function, and increased risk of falling. Interestingly, the strength gains obtained from resistance training are the result of both muscular and neural adaptations (Moritani and DeVries, 1979; Brooks et al., 1996). Based on this, Thompson et al. (2003) designed a study to evaluate the effect of resistance training on proprioception, community dwelling older women completed a three-month exercise study. A resistance training (RT) group (n=19) underwent supervised weight training three times per week while a non-strength trained control (NSTC) group (n=19) performed range of motion activities that mimicked the movements of the RT group without the benefit of muscle loading. Subjects were evaluated at baseline, 6, and 12 weeks for strength and proprioception. Muscular strength was assessed by measuring the subject's one repetition maximum performance on four different exercises. Static proprioception was measured by the subject's ability to reproduce a target knee joint angle while dynamic proprioception was measured by the subject's ability to detect passive knee motion. The RT group made significant strength improvements compared to the NSTC group. Proprioception significantly improved in both groups by 6 weeks. The authors suggested that improvements in proprioception can be obtained via regular activity that is independent of heavy muscle loading. This finding supports the growing consensus that a physically active lifestyle can play a role in preventing the physical deterioration associated with aging and a sedentary lifestyle.

It is interesting to note that Westlake et al. (2007) examined the effects of balance exercises on proprioception (the duration and frequency of this training program was held 1 hour, 3 times per week, over 8 weeks) and identified that short-term improvements in velocity discrimination (velocity sense) were found in the balance exercise group when compared with values at baseline and in the falls prevention education group, may be achieved following a balance exercise intervention. However, improvements were not maintained at the 8 week follow-up. These findings were corroborated by Westlake and Culham (2007). The authors demonstrated that exercise protocol, which emphasizes static and dynamic balance exercises with transitions between different sensory conditions, the ability of older adults to reintegrate proprioceptive inputs is augmented following sensory-specific training in short-term. This effect is likely to be attributable to the possibility of an increase in the discharge of proprioceptive receptors and more probable explanation for this result is an increase during the training intervention in the attention allocated to proprioceptive cues. The direct beneficial consequences of these tasks were reflected in ability of the participants to regain stability, likely by taking advantage of the restored proprioceptive information and integrating it with vestibular inputs and other sensorimotor (Westlake and Culham, 2007).

Additionally, Waddington and Adams (2004) examined the effects of wobble-board training on ability to discriminate between different extents of ankle inversion movements in a group of older subjects. The accuracy with which subjects could identify a set of ankle inversion movements of different extents was measured by the active movement extent discrimination apparatus (AMEDA), with testing conducted in an upright, weight bearing stand. Twenty community-dwelling subjects aged 65 to 85 participated in this study. Each subject was then randomly allocated to a 5-weeks training program (five times a day) using a wobble board or control group. Greater improvement in ankle movement discrimination capability was made in subjects who underwent wobble board training than in subjects who did not train. This study showed improvements in the ankle motor control processes that occur below the level of conscious attention with wobble board training.

Indeed, peripheral level improvements in proprioception were linked to alterations in muscle spindle. There is no evidence that training changes the number of mechanoreceptors (Ashton-Millers et al., 2001), but there is evidence that training induces morphological adaptations in the major mechanoreceptor involved in proprioception, the muscle spindle. Training can induce muscle spindle adaptations at a microlevel, the intrafusal muscle fibers may show some metabolic changes, and at a more macro level, the latency of the stretch reflex response decreases and the amplitude increases (Hutton and Atwater, 1992). Physical activity improving muscle strength can also improve proprioception. The improvement in muscle strength with exercise might yield better control of movement, which, as a consequence, could enhance joint proprioception under weight bearing conditions (Petrella et al., 1997).

Recommendations for Guidelines: *Exercise and Proprioception*

A theory currently being evaluated is that changes in proprioception result in changes in joint function that may lead to degenerative joint disease. These changes correlate with changes in muscle fiber types (Bostrom, 2002) and directly affect the performance of both the activities of daily living and sports (Starkey and Johnson, 2006).

To enhance proprioceptive-mediated neuromuscular controls, rehabilitation and conditioning programs should be structured to address all three levels of central nervous system motor activation: the higher brain centre, brainstem, and spinal cord levels (Lephart et al., 1998).

The levels of motor control

The higher brain

Higher brain centre-promoting activities are initiated on the cognitive level, such as consciously performing end range joint positioning activities, and through repetitive executive stimulate the conversion of conscious to unconscious motor programming. This transition from conscious to unconscious motor programming is performed in the lower extremity trough dynamic balance rehabilitation activities. Initially, patients concentrate on the rehabilitation task being performed in order to facilitate and maximize sensory input. As the patient progresses, the activities incorporate cognitive or psychomotor aspects, which ultimately aid in converting conscious joint stabilization and control to unconscious motor programming (Lephart et al., 1995; Voight, 1996).

The brainstem

To enhance motor function at the brain stem level, balance and postural maintenance activities should be employed. These equilibrium-promoting activities should be performed both with and without visual system input, be implemented following a standardized progression, and be specific to the type of activities and skills the patient will require. The initiation of balance activities assumes the patient is able to bear weight on the lower extremity. Once implemented, these activities should follow the progression from static balance activities to dynamic skill activities. For static balance activities, patients should progress from bilateral to unilateral activities, from activities with the eyes open to those with the eyes closed and from those performed on a stable surface to those performed on unstable surface (Lephart et al., 1995; Guskiewicz and Perrin, 1996; Voight, 1996).

The spinal cord

To address the spinal level of motor control, rehabilitation activities which produce sudden changes in joint position should be included to promote unconscious reflex joint stabilization. Activities such as training on unstable platforms and plyometric exercises encourage joint muscular co-contractions and reactive dynamic muscular stabilization and therefore address neuromuscular training at the spinal level of motor control (Nyland et al., 1994; Voight, 1996).

The influence of proprioception in mediating neuromuscular control has been demonstrated to have profound effects in the injured and surgically repaired joint. Although there is not yet a consensus regarding the role of proprioceptively mediated rehabilitation activities in regaining neuromuscular control, preliminary evidence suggests that such activities may influence the return to participation for the injured athlete (Lephart et al., 1998).

CHAPTER III
RESEARCH METHODOLOGY

Research design

This study is an analytical descriptive research design which examined effects of difference types of exercise on ankle joint position sense by passive reproduction joint position sense test. The questionnaire was used for data collection. Data were characteristic of subjects, exercise profile, and history of fall. Additionally, the physical fitness testing, assessment of balance and risk of fall, as well as assessment of proprioceptive system functions (passive joint position testing) were included.

Study population

In this study, the target population was healthy Thai elderly men and women, who engaged in regular exercise as either walking, tai chi, or jogging and having no exercise, ranging in age from 60 to 70 years old. The study samples were recruited according to the following inclusion criteria and consent to participate in the study.

Screening

Subjects were qualified for the study if they were aged 60 to 70 years and had no documented diseases or conditions lists in the exclusion criteria. All volunteers were initially contacted by telephone to determine their qualification before the study. Of the 181 volunteers who passed the initial screening, 149 individuals completed the study.

<u>Inclusion criteria</u>

Control group

1. Being Thai people, who have no regular exercise, aged from 60 to 70 years old (level of physical activity were recruited according to the following insufficient physical activity criterion; an initiative of the Premier's Physical Activity Taskforce, 2003).

2. Volunteers signed the consent form to become subjects.

Exercise group

1. Thai people aged from 60 to 70 years old and participate in regular exercise as either walking, tai chi, or jogging at least 1 year without taking a break continuously for 3 weeks (level of physical activity were recruited according to the sufficient physical activity criterion; an initiative of the Premier's Physical Activity Taskforce, 2003).

2. Volunteers signed the consent form to become subjects.

Exclusion criteria

1. The participants were sick or injured.

2. Admitted in the hospital for 3 days or more in the past 12 months.

3. History of fall that affect gait and balance.

4. Presence of any trouble gait and neurological or muscular pathologies at lower extremities from a congenital disease such as peripheral neuropathy, stroke, chronic arthritis, poorly control hypertension, lower spondylosis/listhesis with rediculopathy, spinal deformity, parkinson's disease and meniere's disease.

5. A history of symptomatic cardiovascular disease class C or D of American Heart Association (AHA).

6. Regularly participate in more than one type of exercise.

Sample

Sampling technique

This study used purposive sampling technique and voluntariness for recruiting subjects.

Sample size determination

In this study, sample size determination was calculated from Roscoe's simple rule of thumb (Roscoe, 1975). He suggested sample size should be at least ten times larger than the number of variables being considered. Variables for the study are difference types of exercise (walking, tai chi, and jogging) and non exercise, totally 4 variables. The calculation of sample size is then

$$n = 10 \times f$$

n = sample size

f = number of factors (variables) for this study = 4

$$n = 10 \times 4$$

$$n = 40$$

n for sample was 40 persons. To account for 4 groups such as exercise group (walking, tai chi, and jogging) and control group (non exercise), as a consequence, total subjects were 160 persons for this study.

Instruments

1. A model of ankle movement extent discrimination apparatus; AMEDA (Waddington et al., 1999)
2. BalanceCheck force platform (BalanceCheck™ Screener and Trainer 3.2.2 by Bertec, Ohio, USA)
3. A body composition analysis device (InBody 230, Biospace®, Korea)
4. A biopac MP100 system with EMG100C transducer module with an acqKnowLedge Software Version 3.7.3 (Biopac Systems Inc.,Canada)
5. Height measuring board
6. An armchair (46 centimeters height)
7. Step bench (12 inches height)
8. Dumbbell 5 lbs (2.3 Kg.) and 8 lbs. (3.6 Kg.)
9. Sphygmomanometer (ES-H55, Terumo Corporation, Tokyo, Japan)
10. Lange skinfold caliper (Beta Technology Inc., Maryland)
11. Touch-Test™ sensory evaluators (4.31(2.0-grams) Nylon monofilament, North Coast Medical Inc., U/K)
12. Tape measurement (Hoechstmass, West-Germany)
13. A plastic box

14. Stopwatch (JS-609, FBT® ,China)
15. Counter (Hope®, Japan)
16. Angle finder (ED-20SSMB Super Slant, Japan)
17. Magnetic torpedo level (Miley, USA)
18. EMG electrodes (Ambu® Blue Sensor SP, Denmark)
19. Headphones for eliminating auditory stimuli from the testing apparatus
20. A blindfold for eliminating visual feedback
21. Case record form

Procedure

Subject preparation

Prior to each test session, all subjects were asked to refrain from consuming alcohol, caffeine, or food for 2 hours. In addition, vigorous physical activity was not allowed 24 hours (Hermione et al., 2006) prior to the first test session. Comfortable clothing for test sessions should be worn. Upon arrival to the laboratory, the participant was instructed to remove the shoes for all test sessions. Weight, height, body mass index, resting heart rate, and resting blood pressure were recorded.

Standard measurements

Measurements of height, weight, resting heart rate, and resting blood pressure provide a baseline characteristic of the subjects. The following procedures were performed and baseline characteristics of the subjects were recorded.

Standing height: The participant was standing barefoot with the heels together, then stretching upward to the fullest extent. Heels, buttocks, and upper back were touching a wall. The chin was not lifted. Measurement was recorded in centimeter.

Weight: Weight was recorded with the individual wearing comfortable clothes without shoes. Weight was recorded in kilogram.

Body mass index: The BMI, is used to assess weight relative to height and is calculated by dividing body weight in kilograms by height in meters squared ($kg \bullet m^{-2}$) (ACSM's guidelines, 2006). The use specific BMI values to predict health risk is according to the criteria of International Obesity Task Force (IOTF).

Resting heart rate: The participant was sitting and had an adequate rest period of at least 5 minutes prior to the measurement. Adequate rest was indicated when the heart rate had stabilized at a low rate. The resting heart rate was measured with sphygmomanometer (ES-H55, Terumo Corporation, Tokyo, Japan).

Resting blood pressure: The participant was sitting upright in a straight backed chair. Both feet were flat on the floor, and the left arm was resting on the table with the elbow flexed. Subject was relaxed for a few minutes in this position. Conversation was discouraged. The blood pressure was measured with sphygmomanometer (ES-H55, Terumo Corporation, Tokyo, Japan). The phase systolic pressure and diastolic pressure were recorded in millimeters of mercury (mmHg) as indicated on the sphygmomanometer scale.

Methods

The process of research was divided into 2 sections as follows;

1. Measurements of physical and functional performance.
2. Measurements of balance and joint position sense.

The section one was measured in 5 respective tests: measurements of body composition, sensory of foot, upper and lower body strength, functional performance, and cardiorespiratory fitness as follows;

1. Physical and functional performance testing

1.1 Body Composition Assessment

A. **Skinfold measurements** (ACSM's guidelines, 2006)

Using 3 site skinfold measurements.

- Male (Chest, abdomen, and thigh)
- Women (Triceps, suprailiac, and thigh)

1. Measurements on the right side of the body with the subject standing upright.
2. Placed the caliper at 1 to 2 cm away from the thumb and finger.
    a. Perpendicular to the skin fold.
    b. Halfway between the crest and the base of the fold.
3. Release the caliper lever so its spring tension is exerted on the skinfold.
4. Maintained pinch while reading caliper.
5. Read dial on caliper.
    a. Between 1 to 2 seconds after lever has been released.
6. Take duplicate measures at each site.
    - ACSM
    a. If within 1 or 2 mm take average.
    b. If not within 1 or 2 mm take 3 rd measurements.
    c. If still no match, then take average of 2 closes measurements.
7. Rotate through measurement sites or allow time for skin and underlying fat to regain normal texture and thickness.
8. An average of measurements was used for further analysis. The percentage body fat is predicted according to the ACSM's guidelines (2006).

B. **Bioelectrical impedance analysis (BIA)**

Direct segmental multi-frequency bioelectrical impedance analysis method is used to measure percentage body fat, a body composition analysis device (InBody 230, Biospace®, Korea) that uses an 8-point tactile electrode method applied to right arm, left arm, trunk, right leg, left leg. Ten impedance measurements by using 2 different frequencies (20 kHz, and 100 kHz) with an excitation current of 330 μA is applied at the source electrode on each 5 segments (right arm, left arm, trunk, right leg, left leg). The percentage body fat is predicted according to the ACSM's guidelines (2006).


(a) (b)

Fig 3.1 (a) A body composition analysis device and (b) Measurement of body composition

1.2 <u>Sensory Foot Exam</u>

Semmes-Weinstein monofilament test (Janchai, 2005; Lee et al., 2003)

1. Place the patient in supine or sitting position with shoes and socks removed.
2. Touch the monofilament wire to patient's skin on arm or hand to demonstrate what the touch feels like.
3. Instruct the patient to respond "yes" each time they feel the pressure of the monofilament on their foot during the exam.
4. Instruct the patient to close their eyes with toes pointing straight up during the exam.
5. Hold the monofilament perpendicular to the patient's foot.
6. Press the monofilament against the foot, increasing the pressure until it bends into a C-shape. Apply the monofilament along the perimeter of and not on an ulcer, callus, scar, or necrotic tissue. Do not slide monofilament over the skin (Fig 3.2).
7. Hold in place for about 1-2 second. Randomize the sequence of applying the

filament throughout the examination. Repeat the area(s) about 1-2 times where the patient did not indicate feeling the monofilament.

8. Locations for testing:
    - dorsal midfoot
    - plantar aspect of foot including pulp of the first, third, and fifth digits
    - the first, third and fifth metatarsal heads
    - the medial and lateral midfoot
    - the calcaneus
9. Record response on foot screening form with “+” for yes and “-“ for no.
10. When the patient is fail to feel the monofilament at more than 4 out of 10 sites, identifies this patients with loss of protective sensation due to peripheral sensory neuropathy (Lee et al., 2003).

Fig 3.2 Semmes-Weinstein monofilament test

1.3 <u>Assessment of Upper and Lower Body Strength</u>

A. **Senior’s arm curl test** (Howley and Franks, 2007; Rikli and Jones, 1999)

1. Ask the subject to sit on chair with dumbbell.
    a. Women: 5 lbs (2.3 kg)
    b. Men: 8 lbs (3.6 kg)
2. The subjects hold weight in a handshake grip with arm fully extended to side of chair.
3. Curl weight by flexing elbow while turning palm of hand toward shoulder.

4. Lower until elbow is straight.

5. Repeat curling until 30 seconds expires.

6. Number of repetitions was counted for further analysis.

The test administrator provides test instructions to subject, keeps time, counts number of repetitions completed in 30 seconds, and announces when time is over.

B. **Senior's chair stand test** (Howley and Franks, 2007; Rikli and Jones, 1999)

1. Ask the subject to sit on chair with both feet separated approximately shoulder width close to chair.

2. The subjects maintain arms across chest.

3. Stand up without pushing off with arms.

4. Repeat standing up until 30 seconds expires.

5. Number of repetitions was counted for further analysis.

The test administrator provides test instructions to subject, keeps time, counts number of repetitions completed in 30 seconds, and announces when time is over.

1.4 <u>Functional Performance Testing</u>

To ensure blinding of participants in trials of functional performance testing. In an attempt to minimize bias, the assistant researcher provides testing to participants.

A. **Functional reach test** (Duncan et al., 1990)

1. Mounting a yardstick on the wall at shoulder height.

2. Ask the subject to position themselves close to, and be able to flex the shoulder to at least 90 degrees but not touching the wall with their arm outstretched and hand fisted.

3. Take note of the starting position by determining what number the MCP joints line up with on the yardstick.

4. Have the subject reach as far forward as possible in a plane parallel with the measuring device. Instruct them to "Reach as far forward as you can without taking a step." The patient is instructed to reach forward along the yardstick without moving the feet. Guard the subject as the task is performed to prevent a fall.

5. Take note of the end position of the MCP joints against the ruler, and record

the difference between the starting and ending position numbers. If they move their feet, that trial must be discarded and the trial repeated.

Criteria to stop the test: The patient's feet lifted up from the floor or they fell forward.

B. **Timed up & Go test; TUG** (Shumway-Cook et al., 2000)

Setting up the test area

- Determine a path free from obstruction.
- Place a standard arm chair (approximate seat height of 46 cm.) at one end of the path.
- Mark off a 3 m. (10 ft.) distance using a marker (a plastic box) clear marking.

Performing assessment tests

1. Begin the test with the subject sitting correctly in a chair with arms, the subject's back should rest on the back of the chair. The chair should be stable and positioned such that it will not move when the subject stands.
2. Instructions: "On the word *GO* you will stand up, walk to the line on the floor, turn around and walk back to the chair and sit down. Walk at your regular pace. Have the subject walk as quick as possible in a 3 m. (10 ft.) distance.
3. Start timing on the word "*GO*" and stop timing when the subject is seated again correctly in the chair with their back resting on the back of the chair.
4. Guard the subject as the task is performed to prevent a fall.

C. **Single Leg Stance** (O'Loughlin et al., 1993; Vellas et al., 1997; Bohannon et al., 1984; Chullanan, 2005)

- *Single leg stance with eyes open*

1. Stand on plain floor with the shoes off.
2. Place arms across chest with hands touching shoulders.
3. Look straight ahead with eyes open and focus on an object about 3 feet forward.
4. Stand on one leg and do not let legs touch each other.

5. The test will be timed when subjects stand on one leg with the hip extended and knee flexed at 90°.

6. Subjects will attempt to balance themselves within a defined area on a single limb. The maximum amount of time will be calculated.

7. A trial will end if the legs touchs each other, the feet moves on the floor, their foot touches down, or the arms moves from their start position.

8. The test will be timed on each limb with three trials on either side.

9. The recorded time for the test was used for further analysis.

- *Single leg stance with eyes closed*

1. Stand on plain floor with the shoes off.
2. Place arms across chest with hands touching shoulders with eyes closed.
3. Stand on one leg and do not let legs touch each other.
4. The test will be timed when subjects stand on one leg with the hip extended. and knee flexed at 90°.
5. Subjects will attempt to balance themselves within a defined area on a single limb. The maximum amount of time will be calculated.
6. A trial will end if the legs touched each other, the feet moved on the floor, their foot touches down, or the arms moved from their start position.
7. The test will be timed on each limb with three trials on either side.
8. The recorded time for the test was used for further analysis.

1.5 Cardiorespiratory Fitness Testing

Three minute step test (ACSM's guidelines, 2006)

1. Lift the first leg onto step bench.
2. Raise the body and the second leg onto the box.
3. Lower the body by stepping down to floor with the first leg.
4. Return the second leg down to the floor.
5. Repeat until 3 minutes expires.
6. Number of repetitions was counted for further analysis and for VO_2 predicted according to the ACSM's guidelines (2006).

Fig 3.3 Step test

The section two was measured in 2 respective tests: measurements of balance and ankle joint proprioception as follows;

2. Balance assessment and joint position testing

2.1 A BalanceCheck Force Platform

The force platform balance test data were obtained using the BalanceCheck™ software (Bertec Corporation, Ohio, USA). The platform is designed for maximum load of 500 lb (220 kg). The overall dimensions of the plate are 20"x20"x2.5". The complete series of balance assessment tests has been designed to evaluate the subject's ability to maintain balance while standing. Four aspects of stability can be tested: the ability to maintain balance on a hard level surface (normal stability) with eyes open or eyes closed, and on a soft surface (perturbed stability) with eyes open or closed. The system registers vertical forces, and was used to calculate the position and the movement of center of pressure (CoP), called sway. Three outcome variables were:

(i) Anterior-posterior CoP excursion: It is an indication of the magnitude of movement of the CoP in sagittal plane. The smaller value was better.

(ii) Lateral CoP excursion: It is an indication of the magnitude of movement of the CoP in lateral plane. The smaller value was better.

(iii) Direction of max instability: The direction in which the subject is less stable, and therefore most likely to fall. It corresponds to the angle between the horizontal axis and the primary direction of movement, expressed in degrees.

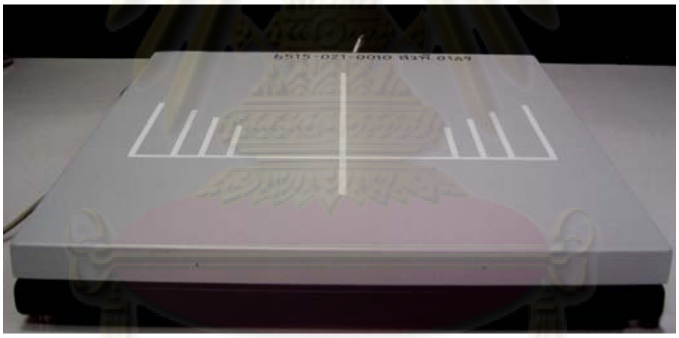


Fig 3.4 Normal stability surface (Hard level surface)

Fig 3.5 Perturbed stability surface (Soft surface)

Performing assessment tests:

1. Being the test with start the BalanceCheck™ software on computer.
2. Enter new participant data. Instruct the participant to remove the shoes.
3. Inform participant of positioning the feet.

- There are white vinyl markings on the balance platform to help with positioning participant's feet. Using these lines as a guide, the feet should be positioned as follows

a. The medial malleolus of both feet should be aligned with the malleolus line on the platform.

b. The feet should be symmetric around the midline and the outside borders should form an imaginary square.

c. The angular alignment of the feet should be such that the participant does not feel uncomfortable.

4. Select the particular test. The digital balance platform is a self-software calibrating device. Therefore, calibration with the BalanceCheck™ software is standard for each participant before data acquisition.

- Normal stability – Eyes open

a. Help the participant step onto BalanceCheck™ platform and position the feet as described as the step 3. *Positioning the feet*.

b. Have the participant stand still in a comfortable position, with weight centered, ***eyes open*** and arms to the sides. The participant should avoid any unnecessary movement, such as talking, gesturing, or turning.

c. Start the test acquisition, which lasts for 10 seconds.

- Normal stability – Eyes closed

a. Have the participant stand still in a comfortable position, with weight centered, ***eyes closed*** and arms to the sides. The participant should avoid any unnecessary movement, such as talking, gesturing, or turning.

b. Start the test acquisition, which lasts for 10 seconds.

- Perturbed stability – Eye open

a. Place the BalanceCheck^{TM} foam on the balance platform with the reference lines facing up.

b. Wait about 3 seconds to make sure that the system calibrates itself to compensate for the weight of the foam.

c. Help the participant step onto BalanceCheck^{TM} platform and position the feet as described as the step 3. *Positioning the feet*.

d. Have the participant stand still in a comfortable position, with weight centered, ***eyes open*** and arms to the sides. The participant should avoid any unnecessary movement, such as talking, gesturing, or turning.

e. Start the test acquisition, which lasts for 10 seconds.

- Perturbed stability – Eye closed

a. Have the participant stand still in a comfortable position, with weight centered, ***eyes closed*** and arms to the sides. The participant should avoid any unnecessary movement, such as talking, gesturing, or turning.

b. Start the test acquisition, which lasts for 10 seconds.

5. Results of the balance assessment tests are presented as comprehensive reports.

Fig 3.6 Standing posture as testing

(a) (b)

Fig 3.7 Testing on normal stability surface (a: Front side and b: Back side)

(a) (b)

Fig 3.8 Testing on perturbed stability surface (a: Front side and b: Back side)

2.2 <u>Passive to Passive Reproduction of Ankle Joint Position</u>

This study has developed a model for assessing ankle joint position sense that closely models the discrimination of inversion movements (Waddington et al., 1999). A model of ankle movement extent discrimination apparatus (AMEDA) (Fig 3.9) is composed of a singles axis capable of recording a range of angles from 0° to 22°. By adjustment of the uplift of the foot, the device can also equipped with a metal frame, which capable of recording a range of angles from 0° to 19°.

The device is a trestle with a tall hand bar (96.5 cm. height), a foot resting (39.5 x 32 cm.) and a moveable platform (41 x 41 cm.) that rotates a singles axis in one direction. A plane of moveable platform was 59.2 cm. height from the floor. This platform is moved by an electric motor which rotates the foot on an axis at rate of 0.25°/s. The angular displacement achieved by the platform is calculated by 2-shafts rotating via a sensor converter of the LabView 8.0 data acquisition system in computer, with expose capability of .01°. The model of AMEDA was calibrated for each participant through use of an angle finder (ED-20SSMB Super Slant, Japan) (recording capability of 0.5°) and a magnetic torpedo level (Miley, USA) attached on the steely platform.

(a) (b)

Fig 3.9 (a) A model of ankle movement extent discrimination apparatus (AMEDA) and (b) A model of AMEDA and the Biopac MP 100 system with EMG100C transducer module (Biopac Systems Inc., Canada) linked with main computer

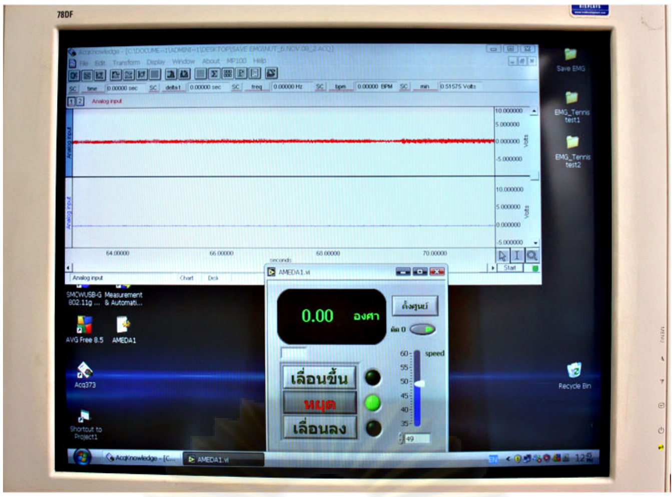


Fig 3.10 Presence of the LabView 8.0 data acquisition system and an acqKnowLedge Software Version 3.7.3 (Biopac Systems Inc.,Canada)

Subject preparation

Prior to the test session, all subjects were asked not to have vigorous physical activity for 24 hours prior to the passive reposition test. Comfortable clothing for the test session should be worn. Upon arrival to the laboratory, the test administrator explains experimental protocol clearly and instructs the participant to remove the shoes before the test.

Procedure

A procedural checklist was followed to ensure a consistent experimental protocol. The model of AMEDA was calibrated for each participant before data acquisition.

Validity and reliability

The method is similar to those used from the previous study (You, 2005) to test the concurrent validity and reliability measurement. The concurrent validity and reliability were determined by comparing the joint angular position data that were concomitantly recorded by the LabView 8.0 system and the angle finder methods. The concurrent angular positions were measured for 15 different positions (range, 0°-20°), randomly chosen.

Intratester reliability

The test-retest reliability of proprioceptive measurement was established by determining an instrument's capability of measuring a variable with consistency (For details, see in Appendix C). All testing conditions were kept as consistent as possible. All the data collection was completed by one tester (the principle investigator). The procedures and the subject's instructions were consistent. The reliability data for the second test session were collected at the similar time of day as of the first session, for all fifteen subjects (mean age, 40.60±12.98 years).

Joint position testing (Aydin et al., 2000; Waddington et al., 1999; Westlake et al., 2007)

Experimental were setup for the passive ankle joint repositioning test.

1. The subject was asked to maintain symmetrical weight bearing while standing with one foot on a footstool and the test foot on a hinged platform. Hip and knee joints were fully extended and trunk was upright.

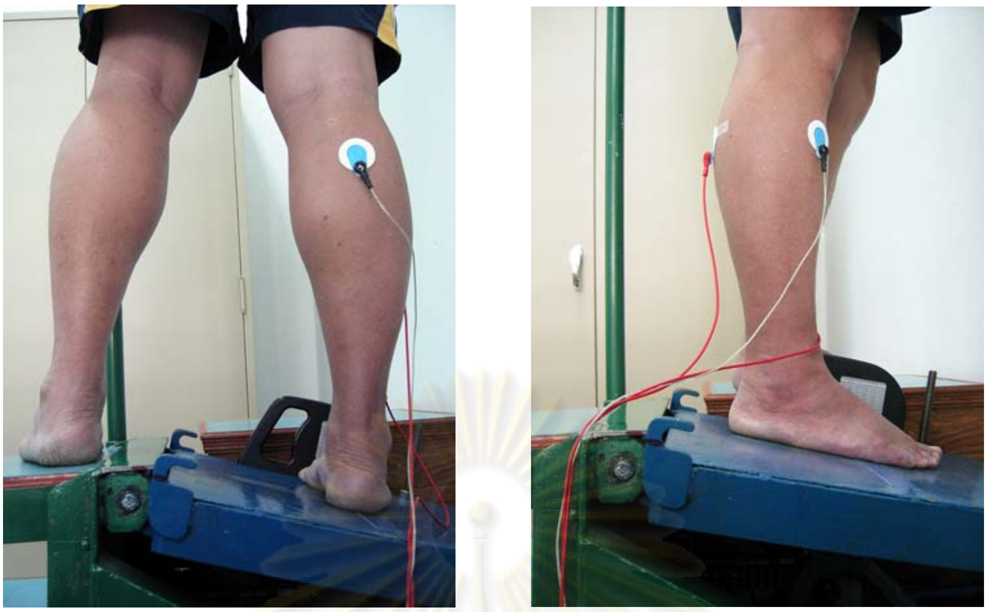
2. The subjects kept their eyes closed and wore headphones with music playing to eliminate visual feedback and auditory stimuli from the testing apparatus.

3. A foot strap was not used because subjects could use additional cutaneous input from the strap. For safety measure, a tall hand bar was placed to provide additional stability.

4. A moveable platform can rotate around a single axis in one direction at a velocity of 0.25°/s through the test positions (a target position) as follow;

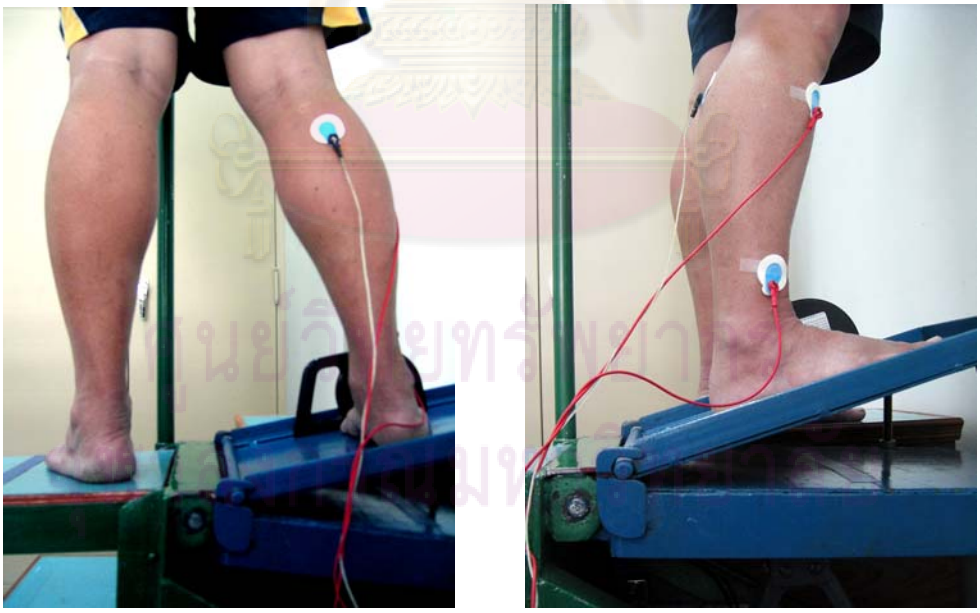
- Frontral plane; 15° inversion, and 10° eversion (Fig 3.11a, Fig 3.12a).
- Sagittal plane; 12° plantarflexion, and 15° dorsiflexion (Fig 3.11b, Fig 3.12b).

* For performing of 10° eversion and 15° dorsiflexion movement of ankle, by adjustment of the foot position, the device can also equipped with a metal frame, which capable of recording a range of angles from 0° to 19°.



(a) (b)

Fig 3.11 (a) Inversion movement at ankle and (b) Plantarflexion movement at ankle



(a) (b)

Fig 3.12 (a) Eversion movement at ankle and (b) Dorsiflexion movement at ankle

5. EMG is used to determine muscle activity, which was recorded using the Biopac MP 100 system with EMG100C transducer module (Biopac Systems Inc., Canada). EMG data were collected by using the acqKnowLedge software version 3.7.3 (Biopac Systems Inc.,Canada). Surface EMG electrodes were applied on the skin parallel to the direction of muscle fibers (on the test leg) to ensure that a better sample of muscle activity is monitored with reducing extraneous electrical activity.

Electrode placement:

a. 15° Inversion movement at ankle, surface EMG electrodes were applied on the skin over the tibialis anterior (TA) and extensor hallucis longus (EHL).

b. 10° eversion movement at ankle, surface EMG electrodes were applied on the skin over the peroneus longus (PL) and peroneus brevis (PB).

c. 12° plantarflexion movement at ankle, surface EMG electrodes were applied on the skin over the soleus and gastrocnemius.

d. 15° dorsiflexion movement at ankle, surface EMG electrodes were applied on the skin over the tibialis anterior (TA) and extensor digitorum longus (EDL).

Performing assessment tests:

1. Randomly predetermined sequence of the 4 respective joint position sense (JPS) tests by the examiner. The sequence of the 4 respective JPS tests was randomized by probability sampling design to eliminate potential bias effect in the repeated measure.

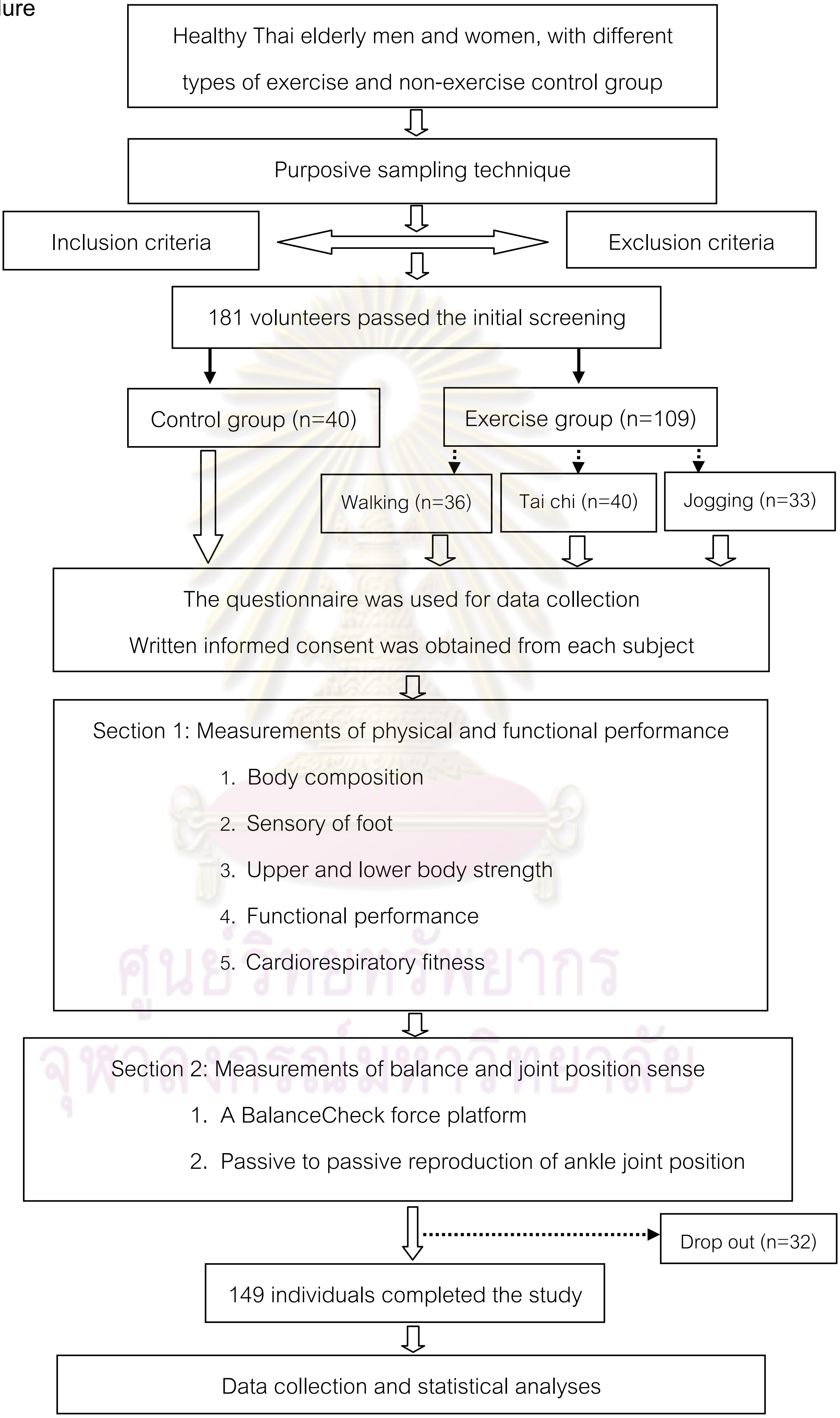
2. The subject began in a starting position (0°) and passively moved the ankle through the test position (a target position) by an apparatus at a constant speed, 0.25°/s. The 2 planes of ankle JPS were independently measured in a random sequence.

3. After reaching the target position, a subject was asked to concentrate on sensation of joint angle while the limb is sustained in the specific position for 15 seconds (Bernier and Perrin,1998), and then the test foot returned to the start position.

4. The examiner then moved the test foot back towards the test position, and the subjects pressed a stop switch once they perceived that the test position had been attained.

5. The difference in the test angle and reproduced angle was calculated as the absolute error. Mean values of two trials in each direction were used for analysis.

Procedure


Healthy Thai elderly men and women, with different types of exercise and non-exercise control group
Purposive sampling technique
Inclusion criteria
Exclusion criteria
181 volunteers passed the initial screening
Control group (n=40)
Exercise group (n=109)
Walking (n=36)
Tai chi (n=40)
Jogging (n=33)
The questionnaire was used for data collection
Written informed consent was obtained from each subject
Section 1: Measurements of physical and functional performance
1. Body composition
2. Sensory of foot
3. Upper and lower body strength
4. Functional performance
5. Cardiorespiratory fitness
Section 2: Measurements of balance and joint position sense
1. A BalanceCheck force platform
2. Passive to passive reproduction of ankle joint position
Drop out (n=32)
149 individuals completed the study
Data collection and statistical analyses

Data analysis

1. Descriptive statistics were used for baseline calculation.
   - Means with standard deviation were used for quantitative data.
   - Numbers with percentages were used for qualitative data.

In the non-normal distribution case, the nonparametric tests (minimum, maximum, and median) were used for quantitative data.

2. The differences on physical and functional performance between two groups were determined by One-way ANOVA; Post Hoc Multiple Comparisons with Scheffe´.

3. The Nonparametric tests with Kruskal-Wallis H were used to detect the differences between four groups on variables of ankle joint position sense (Absolute angular error; AAE), single leg stance, center of pressure (CoP) excursion, and direction of max instability. If there was presence any of a difference on degree of angular error, stance time of single leg stance test (second), excursion (centimeter) and degree of direction of max instability, then Mann-Whitney U was used to investigate the differences on all of these variables between the two groups.

4. Intraclass correlation coefficients (ICC) were used to determine an instrument's capability of measuring a variable with consistency between mean joint angular position data that were concomitantly recorded by the angle finder and the LabView 8.0 system.

An alpha level of 0.05 was used to determine statistical significance. All statistical analyses were performed using Statistic Package for the Social Sciences (SPSS for Windows version 14.0, Chicago, IL, USA).

CHAPTER IV
RESULTS

Characteristics of subjects

A total of 181 older adults were eligible for the study. The complete data were obtained from 149 subjects. Thirty two persons did not complete the study. Two persons out of country, 5 persons had an injury/health problem, 11 persons lost to follow up, and 14 other persons had to take on their own business and family. All subjects were independent in their activities of daily living, and no walking aids were required. By means of a questionnaire with a complementary interview about their physical and sporting activities, subjects were partitioned in four groups: control (sedentary), walking, tai chi, and jogging group.

Table 4.1 provides the baseline characteristics of the subjects (51 men and 98 women) and presents a significant difference observed for baseline % body fat, resting heart rate, and VO_2 estimated across four groups. No significant difference was noted in body mass index, systolic and diastolic blood pressure across the four groups. Additionally, there were 62 subjects with delayed onset muscle soreness after cardiorespiratory fitness testing and 35 subjects with delayed onset muscle soreness after body strength testing.

Table 4.1 Baseline characteristics of the subjects

Characteristics	Group				Total (n=149)
	Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Age (years)	65.6 ± 3.78	63.6 ± 3.52	64.6 ± 4.15	61.5 ± 2.59	63.9 ± 3.86
Gender, n (%)					
• Male	2 (5.00)	15 (41.67)	8 (20.00)	26 (78.79)	51 (34.23)
• Female	38 (95.00)	21 (58.33)	32 (80.00)	7 (21.21)	98 (65.77)
Weight (kg.)	56.91 ± 10.18	60.97 ±10.08	57.97 ± 10.08	63.46 ± 12.25	59.63 ± 10.82
Height (cm.)	153.16 ± 4.84	159.86 ± 8.72	157.86 ± 7.21	162.89 ± 5.75	158.20 ± 7.58
BMI (kg/m^2)	24.19 ± 3.73	23.76 ± 2.77	23.12 ± 2.64	24.08 ± 3.03	23.77 ± 3.08
% Body fat					
• Skinfold	34.78 ± 7.03	28.03 ± 7.33*	31.52 ± 6.34	23.68 ± 6.69*,§	29.81 ± 7.91
• BIA analysis	35.10 ± 6.74	29.42 ± 7.54*	31.51 ± 6.41	24.99 ± 6.82*,§	30.52 ± 7.70
Resting HR (bpm)	72.23 ± 9.40	73.81 ± 12.60	72.71 ± 11.71	64.36 ± 10.40*,†,§	71.00 ± 11.55
Systolic BP (mmHg)	127.35±16.28	132.36±20.81	128.20±17.64	128.00±14.60	128.93±17.45
Diastolic BP (mmHg)	74.35 ± 10.88	76.39 ± 10.32	73.95 ± 11.48	76.21 ± 9.35	75.15 ± 10.54
VO_2 estimated with step test (ml/kg/min)	19.34 ± 3.16	22.20 ± 4.36*	21.80 ± 4.41	25.85 ± 3.74*,†,§	22.13 ± 4.53
Sensory of foot, n (%)					
• No Loss of sensation	40 (100.00)	36 (100.00)	40 (100.00)	33 (100.00)	149 (100.00)
Duration of practice (years)	-	4.64 ± 5.02	6.73 ± 5.11	12.91 ± 7.14	6.66 ± 6.42

Values are mean ± S.D.

Significant difference by using Post Hoc Multiple Comparisons with Scheffe´

* $p < 0.05$ compared with Control group

† $p < 0.05$ compared with Walking group

§ $p < 0.05$ compared with Tai chi group

Falls and fall-related injuries

Participants' fall history data were collected in face-to-face interviews with a questionnaire covering such number of falls in the past 12 months baseline assessment, a cause of fall, fall-related injuries, balance control and gait pattern. Table 4.2 and Figure 4.1 revealed the number of the faller in the previous year, and rate of fall and injuries in each group.

Table 4.2 History of falls

History of falls	Group				Total (n=149)
	Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Fell in last year, n (%)					
• 0 fall	28 (70.00)	27 (75.00)	31 (77.50)	25 (75.76)	111 (74.50)
• 1 fall	7 (17.50)	3 (8.30)	8 (20.00)	6 (18.18)	24 (16.11)
• 2 falls or more	5 (12.50)	6 (16.70)	1 (2.50)	2 (6.10)	14 (9.40)
Rate of falls, n (%)	12 (30.00)	9 (25.00)	9 (22.50)	8 (24.24)	38 (25.50)
Rate of injuries, n (%)	7 (58.33)	7 (77.78)	7 (77.78)	6 (75.00)	27 (71.05)
Injuries, n (%)					
• Abrasion, contusion, or ankle sprain	6 (50.00)	7 (77.78)	5 (55.56)	6 (75.00)	24 (63.16)
• Cortical fracture	1 (8.33)	0 (0.00)	2 (22.22)	0 (0.00)	3 (7.89)

As shown in Table 4.2, a total of 149 subjects, there were 60 falls of the total 38 fallers. Subjects in each group reported having fallen in the last year before baseline assessment, it has been represented 30%, 25%, 22.5%, and 24.24% with respective in control, walking, tai chi and jogging group (Fig 4.1). No significant difference was noted in number of fall, rate of fall and injuries across four group studies and between non-exercise and exercise groups. Comparing rate of falls in non-exercise and exercise group, the rate revealed that non-exercise group is prone to fall more than exercise group 1.26 times (Fig 4.1).

In spite of having more fallers in non-exercise group, fall incidents and the ensuing injury process are most occurred in exercise group (Table 4.2). However, active older adults spend less time in the hospital. Most injuries (63.16% of the total fallers) were abrasion, contusion, and ankle sprain. The main cause of falling were slippery surface, tripping, badly visible steps, poor lighting, loose carpets, lack of bathroom safety equipment, a phase of suddenly stopping bus, and single leg standing during daily activities such as wearing trousers.

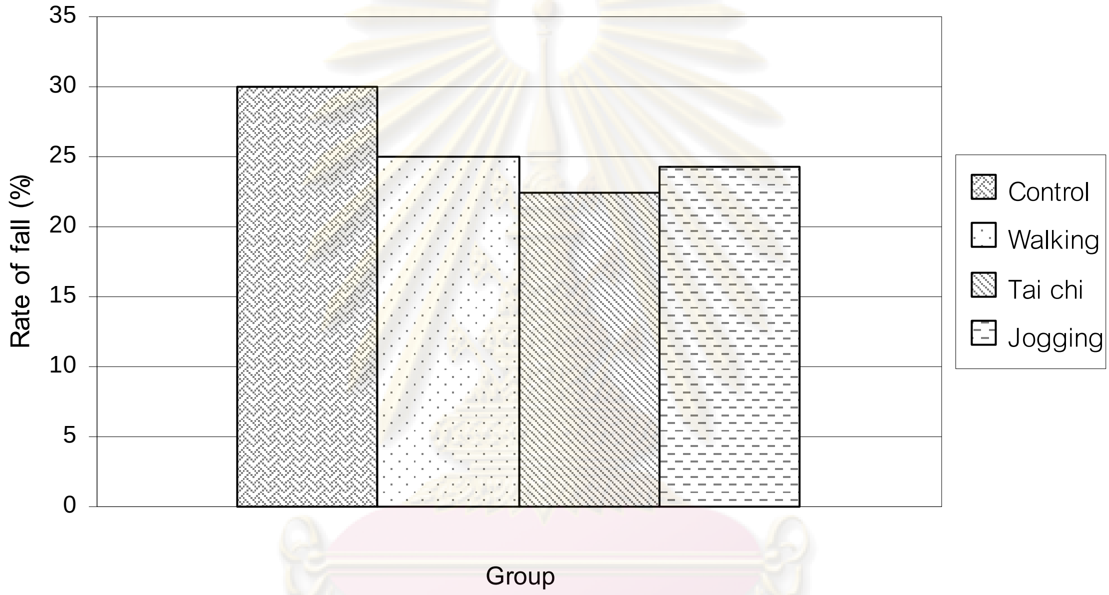


Fig 4.1 Rate of fall (% of the total subjects in each group)

Passive to Passive Reproduction of Ankle Joint Position

Validity and reliability of the measurement for angular position by a model of ankle movement extent discrimination apparatus (AMEDA) via the LabView 8.0 data acquisition system

<u>Validity and reliability</u>

The concurrent validity and reliability of the system's measurement for angular position were determined by comparing the joint angular position data that were concomitantly recorded by the LabView 8.0 system and the angle finder methods. Correlation between the LabView 8.0 system and the angle finder measures was excellent on 15 different angular positions measures (ICC = .99). Figure 4.2 depicts the linearity between the 2 measures, indicating that the measurement of the system (LabView 8.0 system) for joint angular position was valid and reliable.

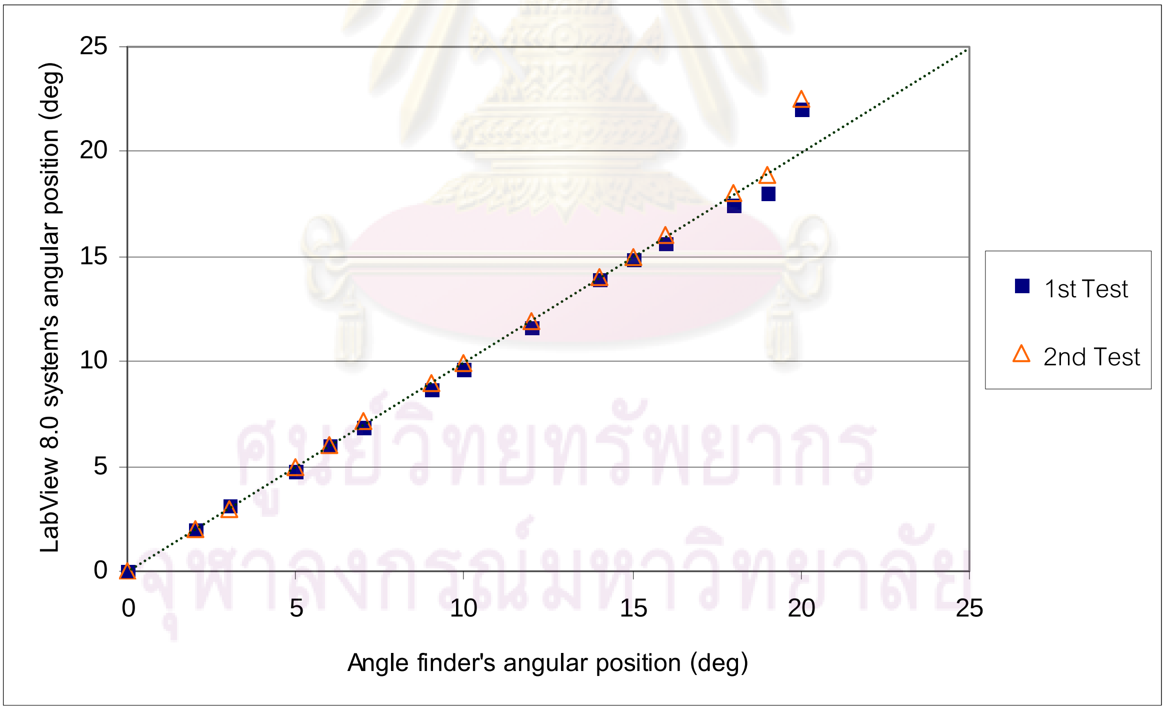


Fig 4.2 The linearity in joint angular position measure between the LabView 8.0 system and the angle finder methods

<u>Intratester reliability</u>

Table 4.3 shows results of the test-retest reliability of examiner's repeated measures by using the LabView 8.0 system. The ICC was calculated for 4 respective position sense tests. Correlations between the repeated measures with ICC were ranging from .50 to .90.

Table 4.3 ICC for the 4 ankle JPS tests (N=15)

Ankle Positions	IV	EV	PF	DF
ICC	.50	.60	.90	.60
P	.026*	.013*	.000*	.017*

*Significant at $P < 0.05$

Absolute angular error

The main outcome of this evaluation was absolute angular error. The study measured the following 4 movement of ankle: 1) 15° Inversion (IV), 2) 10° eversion (EV), 3) 12° plantarflexion (PF), and 4) 15° dorsiflexion (DF) in dominance foot. There were 147 subjects with right foot dominance (only 2 subjects with left foot dominance). The descriptive statistic data of absolute angular error by using nonparametric test was summarized in Table 1 (See in Appendix A). In both inversion and dorsiflexion movement of ankle, tai chi group had a slightly greater median of absolute angular error than other groups (2.04° in inversion and 2.27° in plantarflexion movement). On the other hand, the less median of absolute angular error (1.73° in eversion and 1.89° in dorsiflexion movement) was observed in walking group. Additionally, this analysis offers statistics of minimum and maximum that subjects in each group had performed the tests.

The overall median of absolute angular error received in elderly sedentary control, walking, tai chi, and jogging group were shown in figure 4.3. For all of test positions (IV, EV, PF, and DF), median of absolute angular error had tended to slightly greater in walking and tai chi groups when compared with control and jogging group. The result noted that the walking group had a smaller median of absolute angular error than other groups for eversion (1.73°) and dorsiflexion (1.89°). While, the tai chi group had a mild median of absolute angular error than other groups for inversion (2.04°) and plantarflexion (2.27°).

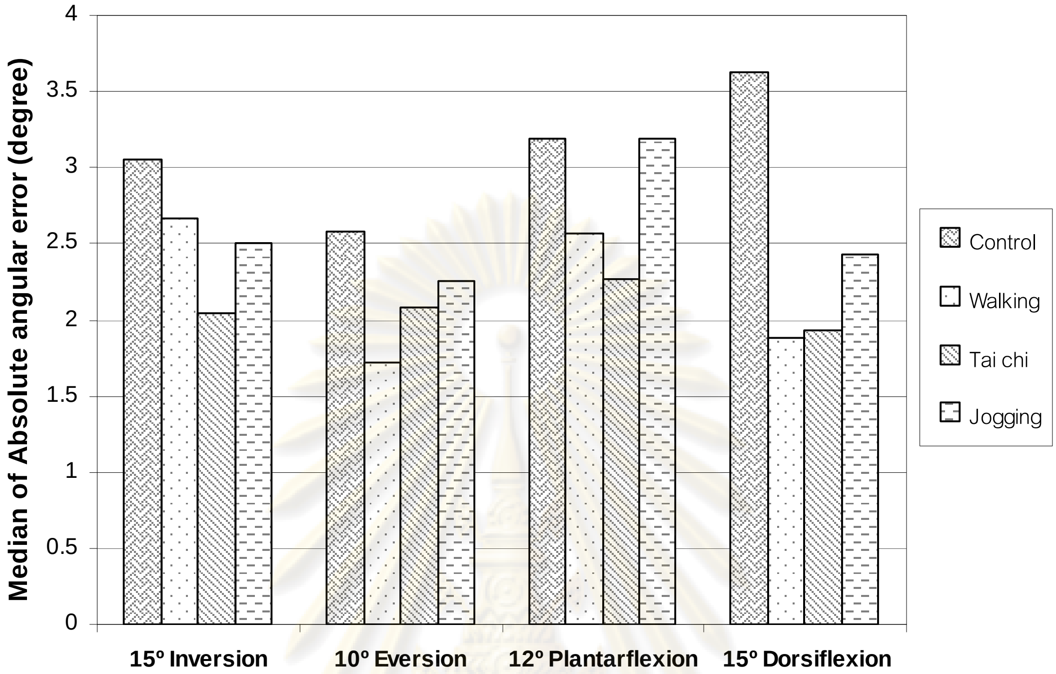


Fig 4.3 Median of absolute angular error received in passive reproduction of ankle joint position test in elderly sedentary control, walking, tai chi, and jogging group

Due to the non-normal distribution case, Kruskal-Wallis H method was used to detect the differences across four groups on median of absolute angular error. Significant difference at median of absolute angular error in three test positions, EV (p = 0.009), PF (p = 0.001) and DF (p = 0.000), were observed across four group studies. After that, Mann-Whitney U test was used to investigate the differences on these variables between any two groups (Table 4.4).

Table 4.4 Median of absolute angular error in the sedentary control, walking, tai chi, and jogging group

Test	Median of Absolute angular error (degree)			
	Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
15^{o} Inversion	3.050	2.670	2.040	2.500
10^{o} Eversion	2.585	1.725*	2.080*	2.250*
12^{o} Plantarflexion	3.195	2.565*	2.265*	3.190§
15^{o} Dorsiflexion	3.630	1.885*	1.935*	2.430*,§

Values are median.

Significant difference by nonparametric test with Mann-Whitney U

* $p < 0.05$ compared with Control group

§ $p < 0.05$ compared with Tai chi group

Mann-Whitney U test showed significant lower absolute angular error of eversion and dorsiflexion in all exercise groups when compared to control group. Different median of absolute angular error in plantarflexion movement of ankle was only significant between walking and control group ($p = 0.016$), and tai chi and control group ($p = 0.000$). In addition, median of absolute angular error in plantarflexion/dorsiflexion was significant differences between tai chi and jogging group ($p = 0.013$ and $p = 0.027$).

Validity and reliability of the measurement for angular position by a model of ankle movement extent discrimination apparatus (AMEDA) via the LabView 8.0 data acquisition system

Validity and reliability

The concurrent validity and reliability of the system's measurement for angular position were determined by comparing the joint angular position data that were concomitantly recorded by the LabView 8.0 system and the angle finder methods. Correlation between the LabView 8.0 system and the angle finder measures was excellent on 15 different angular positions measures (ICC = .99).

Intratester reliability

Intraclass correlation coefficients (ICC) were used to estimate agreement of the same examiner for determines angular position by using the LabView 8.0 system.

The test-retest reliability of the protocol for proprioceptive measurement was evaluated on 15 subjects (mean age, 40.60±12.98 years). The ICC was calculated for 4 respective test positions and the angular position was taken by the same observer, the ICC were ranging from .50 to .90 for intratester reliability of measurement by the LabView 8.0 system.

The ICC revealed that the LabView 8.0 system for determine angular position was highly reliable between the same observer.

Physical and functional performance

Physical performance

A. Cardiorespiratory fitness

The VO_2 estimated with three-minute step test in jogging group was greater than those of other three groups, while that of control group was slightly greater than that of all exercise groups (Table 4.5).

Table 4.5 VO_2 estimated of the subjects

Characteristics	Group			
	Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
VO_2 estimated with step test (ml/kg/min)	19.34 ± 3.16	22.20 ± 4.36*	21.80 ± 4.41	25.85 ± 3.74*,†,§

Values are mean ± S.D.

Significant difference by using Post Hoc Multiple Comparisons with Scheffe´

* $p < 0.05$ compared with Control group

† $p < 0.05$ compared with Walking group

§ $p < 0.05$ compared with Tai chi group

B. Body strength

The study measured the following 2 sections of body strength: 1) upper body strength and 2) lower body strength. ANOVA showed a significant difference only in upper body strength across the four groups ($p < 0.05$) as shown in Table 4.6.

Maximum numbers of repetitions for the upper body strength testing were respectively received in jogging, walking, tai chi, and control group. Although no significant difference was noted in the lower body strength, the number of repetitions for the lower body strength testing showed similar to the results of upper body strength test. The repetition for lower body in jogging group was greater than other three groups, while control group was lower than all exercise groups (Fig 4.4).

Table 4.6 Body strength of the subjects

Test	Group							
	Control (n=40)		Walking (n=36)		Tai chi (n=40)		Jogging (n=33)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Upper body strength (Number of repetitions)	16.18	2.75	19.33*	4.82	18.27	4.82	22.19*,§	6.51
Lower body strength (Number of repetitions)	15.35	3.75	16.94	4.71	16.70	5.03	18.06	4.02

Values are Mean ± S.D.

Significant difference by using Post Hoc Multiple Comparisons with Scheffe´

* $p < 0.05$ compared with Control group

§ $p < 0.05$ compared with Tai chi group

Post Hoc Multiple Comparisons with Scheffe´ revealed a significant difference in upper body strength between control and walking group ($p = 0.047$), and between control and jogging group ($p = 0.000$). Further analysis showed that the jogging had a significantly higher mean number of repetitions of upper body strength test than subjects in the tai chi exercise group ($p = 0.009$).

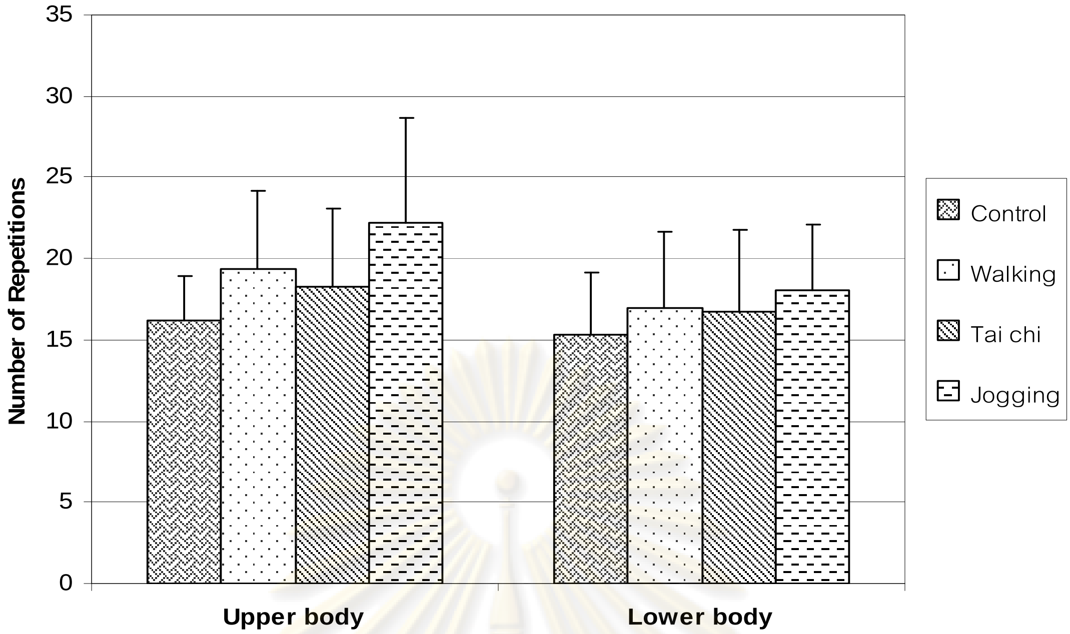


Fig 4.4 Upper and lower body strength outcome measures in elderly sedentary control, walking, tai chi, and jogging group

Functional performance

This study used 2 measurements of functional performance to describe the balance control: functional reach test and Timed up & Go test (TUG). ANOVA showed that both functional reach and TUG test were differed significantly across the four groups ($p < 0.05$) (Table 4.7).

Table 4.7 Functional performance of the subjects

Test	Group							
	Control (n=40)		Walking (n=36)		Tai chi (n=40)		Jogging (n=33)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Functional reach test (cm.)	28.37	4.32	32.82*	3.73	34.52*	3.48	34.23*	4.12
Timed Up & Go test (sec.)	7.64	1.15	6.87*	.82	6.78*	1.03	6.50*	.78

Values are Mean ± S.D.

Significant difference with Post Hoc Multiple Comparisons with Scheffe´

* $p < 0.05$ compared with Control group

Functional reach test revealed significant difference across four groups ($p = 0.000$) (Table 4.7). Distances of 34.52, 34.23, 32.82, and 28.37 centimeters were respectively received in the tai chi, jogging, walking, and sedentary control group (Fig 4.5).

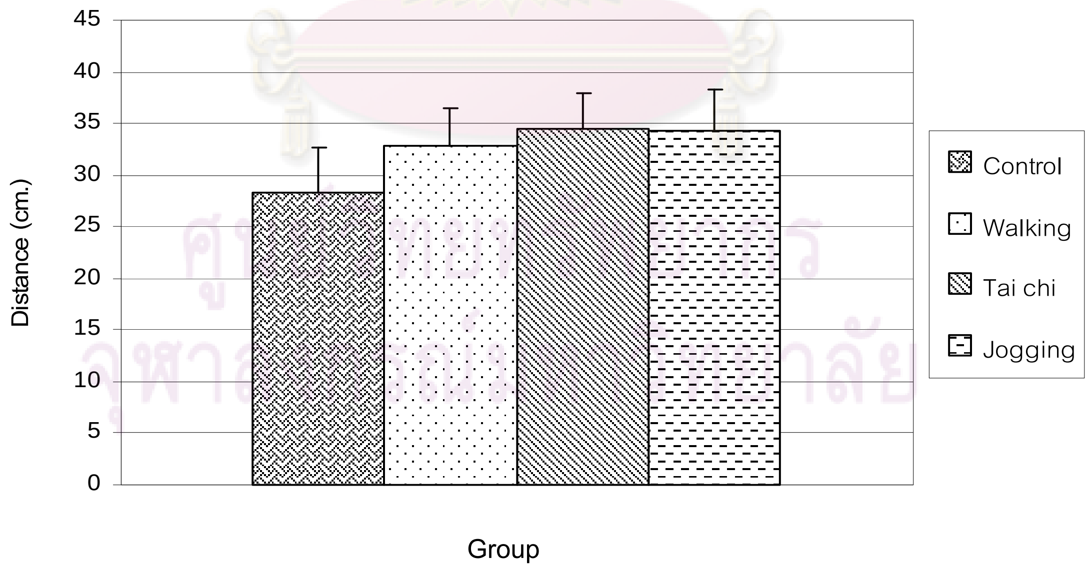


Fig 4.5 Outcome measures of functional reach test in elderly sedentary control, walking, tai chi, and jogging group

The Post Hoc test showed that the sedentary control group could reach a significantly smaller amount of distance than the walking, tai chi, and jogging group (exercise group) ($p = 0.000$), while no significant difference was found among three exercise groups ($p = 0.122$) by using Post Hoc Multiple Comparisons with Scheffe´.

To arrange the time recorded that obtained from Timed up & Go test (TUG), the arrange amount of time were 6.50 seconds in jogging, 6.78 seconds in tai chi, 6.87 seconds in walking, and 7.64 seconds in sedentary control group respectively (Fig 4.6).

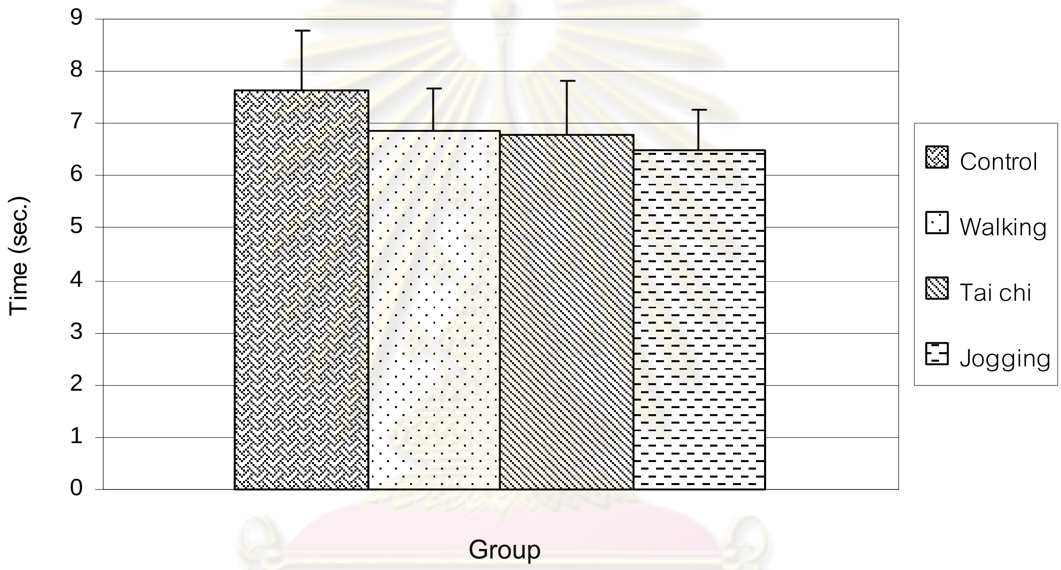


Fig 4.6 Time achieved by TUG test in elderly sedentary control, walking, tai chi, and jogging group

Significant difference in the time recorded of TUG test were observed between sedentary control group and all three exercise groups (jogging, tai chi, and walking group) (Table 4.7), No significant differences was found among the three exercise groups ($p = 0.195$) by using Post Hoc Multiple Comparisons with Scheffe´.

Single Leg Stance

An assessment test has been designed to evaluate the subject's ability to maintain balance while standing. Four aspects of single leg stance (SLT) can be tested: the ability to maintain balance on a right and left leg with eyes open (EO), and on a right and left with eyes closed (EC).

The nonparametric tests showed that jogging group has greater median of stance time after standing on one leg than other three groups in SLT-EO with left leg (31.78 seconds), SLT-EC with right (7.59 seconds) and left (6.66 seconds) leg. For SLT-EO with right leg, the most median of stance time was 31.22 seconds in tai chi group (Table 2, see in Appendix A). Additionally, this analysis offers statistics of minimum and maximum that subjects in each group had performed the tests.

The median of stance time after standing on one leg was summarized in figure 4.7. In both single leg stance-eyes open with right and left leg, the lowest median of stance time were observed in control subjects (7.72, and 7.53 seconds respectively). Furthermore, a reduction median of stance time occurs in all groups after single leg stance with eyes closed testing. Again, the lowest value was recorded on eyes closed condition (SLT-EC with right leg, median = 3.22 seconds; SLT-EC with left leg, median = 3.05 seconds) for the control group.

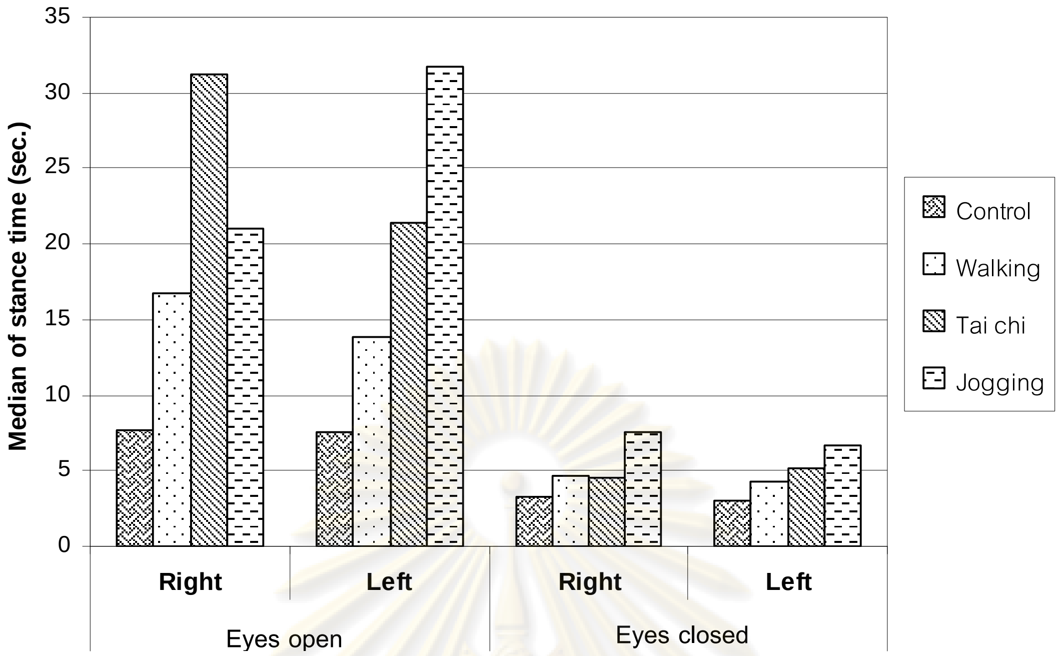


Fig 4.7 Median of stance time received in single leg stance with eyes open and closed in elderly sedentary control, walking, tai chi, and jogging group

Kruskal-Wallis H test was used to detect the differences across four groups on median of stance time. Significant difference at median of stance time in four tests, SLT-EO with right leg (p = 0.000), SLT-EO with left leg (p = 0.000), SLT-EC with right leg (p = 0.003) and SLT-EC with left leg (p = 0.000), were observed across four group studies (Table 4.8). For this condition, Mann-Whitney U test was used to investigate the differences on these variables between the two groups.

Table 4.8 Median of stance time in the sedentary control, walking, tai chi, and jogging group

Test		Median of stance time (sec.)			
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
SLT with eye open	Right	7.72	16.70*	31.22*,†	20.99*
	Left	7.53	13.88*	21.39*,†	31.78*
SLT with eye closed	Right	3.22	4.64*	4.56*	7.59*
	Left	3.05	4.24*	5.20*	6.66*

Values are median.

Significant difference by nonparametric test with Mann-Whitney U

* $p < 0.05$ compared with Control group

† $p < 0.05$ compared with Walking group

Subsequent analysis using Mann-Whitney U test, the result showed that single leg stance-eyes open with right and left leg and single leg stance-eyes closed with right and left leg tests were observed at a significantly greater median of stance time in three exercise groups more than control group (significant difference by using nonparametric test with Mann-Whitney U). In addition, the tai chi group demonstrated a great median of stance time more than walking group after stance-eyes open with right and left leg tests (p = .004 and p = 0.031 respectively).

Center of pressure (CoP)

The complete series of balance assessment tests has been designed to evaluate the subject's ability to maintain balance while standing. Four aspects of stability can be tested: the ability to maintain balance on a hard level surface (normal stability) with eyes open (NS-EO) or eyes closed (NS-EC), and on a soft surface (perturbed stability) with eyes open (PS-EO) or closed (PS-EC). The system registers vertical forces, and was used to calculate the position and the movement of center of pressure (CoP), called sway. The results were divided into 3 sections:

1) Anterior-posterior CoP excursion: It is an indication of the magnitude of movement of the CoP in sagittal plane. The smaller value was better.

2) Lateral CoP excursion: It is an indication of the magnitude of movement of the CoP in lateral plane. The smaller value was better.

3) Direction of max instability: The direction in which the subject is less stable, and therefore most likely to fall. It corresponds to the angle between the horizontal axis and the primary direction of movement, expressed in degrees.

(1) Anterior-Posterior CoP excursion

In the non-normal distribution case, the nonparametric tests (minimum, maximum, and median) were used for quantitative data. It is interesting to note that subjects in tai chi group could maintain balance in which two aspects of the tests (PS-EO, and PS-EC) with having a slightly greater median of A-P excursion (0.8, and 1.2 cm respectively) than other three group studies. Also, a small median of excursion which received by NS-EC testing in tai chi group was same to jogging group (0.7 cm). For NS-EO testing, the control group had a greatly median of excursion (0.7 cm) when compared to the exercise groups (walking, tai chi, and jogging), while an identical median value (0.6 cm) was observed in three groups exercise (Table 3, see in Appendix A). Additionally, this analysis offers statistics of minimum and maximum that subjects in each group had performed the tests.

The median of anterior-posterior CoP excursion was summarized in figure 4.8. In both normal stability with eyes open (NS-EO) and eyes closed (NS-EC), the great median A-P excursion were observed in control subjects (0.7, and 0.9 cm respectively). Furthermore, an increase median of anterior-posterior CoP excursion occurs in all groups after perturbed stability with eyes open (PS-EO) or closed (PS-EC) testing. However, the median was the lowest value (PS-EO, median = 0.8 cm; PS-EC, median = 1.2 cm) for the tai chi group.

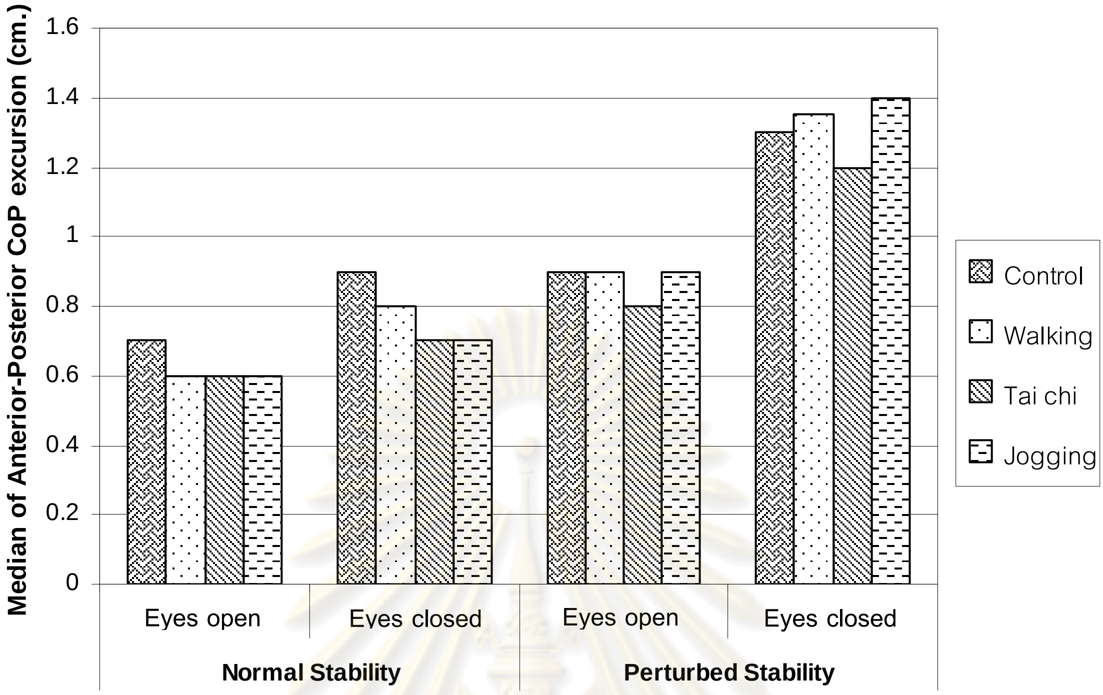


Fig 4.8 Median of anterior-posterior CoP excursion achieved by maintain balance on a normal stability and a perturbed stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group

Due to the non-normal distribution case, Kruskal-Wallis H method was used to detect the differences across four groups on median of anterior-posterior CoP excursion. This result showed that median of A-P CoP excursion in all tests (NS-EO, NS-EC, PS-EO, and PS-EC) were not significant differences across four group studies (Table 4.9)

Table 4.9 Comparison of median of anterior-posterior CoP excursion in the subjects

Test		Median of Anterior-Posterior CoP excursion (cm.)			
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability	Eyes open	.700	.600	.600	.600
	Eyes closed	.900	.800	.700	.700
Perturbed Stability	Eyes open	.900	.900	.800	.900
	Eyes closed	1.300	1.350	1.200	1.400

(2) Lateral CoP excursion

The nonparametric tests showed that tai chi group demonstrated rather mild median of lateral CoP excursion than other three groups in NS-EC (0.2 cm), PS-EO (0.4 cm), and PS-EC (0.4 cm) tests. For NS-EO testing, the median of excursion was 0.2 centimeters in all group studies (Table 4, see in Appendix A). Additionally, this analysis offers statistics of minimum and maximum that subjects in each group had performed the tests.

Figure 4.9 represented the overall median of lateral CoP excursion in four aspects of stability test. In perturbed stability test, median of excursion had tended to increase in all group studies. The tai chi group had a smaller median of lateral CoP excursion than other groups for NS-EC (0.2 cm), PS-EO (0.4 cm), and PS-EC (0.4 cm) test, except in NS-EO testing that all groups demonstrated an identical of median excursion (0.2 cm).

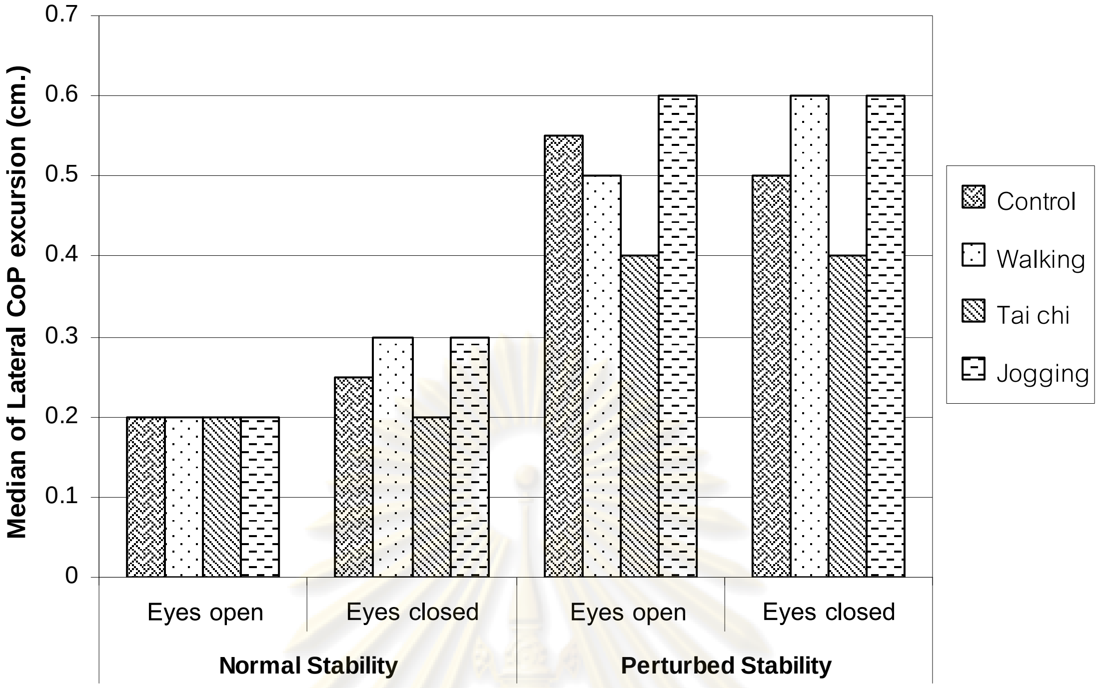


Fig 4.9 Median of lateral CoP excursion achieved by maintain balance on a normal stability and a perturbed stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group

Kruskal-Wallis H method was used to detect the differences across four groups on median of lateral CoP excursion. Significant difference at median of lateral CoP excursion in two tests, NS-EC (p = 0.006) and PS-EC (p = 0.010), were observed across four group studies (Table 4.10). For this condition, Mann-Whitney U test was used to investigate the differences on these variables between two groups.

Table 4.10 Median of lateral CoP excursion in the sedentary control, walking, tai chi, and jogging group

Test		Median of Lateral CoP excursion (cm.)			
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability	Eyes open	.200	.200	.200	.200
	Eyes closed	.250	.300	$.200^{*,\dagger}$	$.300^{\S}$
Perturbed Stability	Eyes open	.550	.500	.400	.600
	Eyes closed	.500	.600	$.400^{*,\dagger}$	$.600^{\S}$

Values are median.

Significant difference by nonparametric test with Mann-Whitney U

* $p < 0.05$ compared with Control group

† $p < 0.05$ compared with Walking group

§ $p < 0.05$ compared with Tai chi group

Subsequent analysis using Mann-Whitney U test, the result showed that both normal stability with eyes closed (NS-EC) and perturbed with eyes closed (PS-EC) tests were observed at a significantly small median of lateral CoP excursion in tai chi group, which less than control, walking, and jogging group.

(3) Direction of max instability

This variable describes the direction in which the subject is less stable, and therefore most likely to fall. It corresponds to the angle between the horizontal axis and the primary direction of movement, expressed in degrees. The subject presents a direction (right or left) while standing and maintain stability in four aspects of stability test: normal stability with eyes open (NS-EO) or eyes closed (NS-EC), and perturbed stability with eyes open (PS-EO) or closed (PS-EC). The main outcome of this evaluation were normal and perturbed stability with eyes open right and left, and with eyes closed right and left.

The descriptive statistic data of direction of max instability in normal stability test by using nonparametric test was summarized in Table 5 (see in Appendix A). In NS-EO test, there were 83 subjects (55.7%) and 66 subjects (44.3%) that shifted their bodies to either right or left direction. In both direction of max instability, control group had a slightly greater median of degree than other groups (3° in right and 6° in left direction). On the other hand, there were 88 subjects (59.06%) and 61 subjects (40.94%) shifted their bodies to either right or left direction in NS-EC test. For right direction, the little median of degree (2°) was observed in jogging group, while the control group demonstrated lower degree (4°) than other three groups in left direction. Additionally, this analysis offers statistics of minimum and maximum that subjects in each group had performed the tests.

Figure 4.10 represented the overall median of direction of max instability received in a normal stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group. The control group had a smaller median of direction of max instability than other groups for NS-EO; right (3°), left (6°), and NS-EC; left (4°), except in NS-EC; right direction that jogging group showed the lowest degrees (2°). Additionally, there were two groups, especially tai chi and jogging group, which their median of degree had decreased in NS-EC test with right direction. Also in NS-EC with left direction, a reduction in median of degree from data of NS-EO with left direction was observed in all groups.

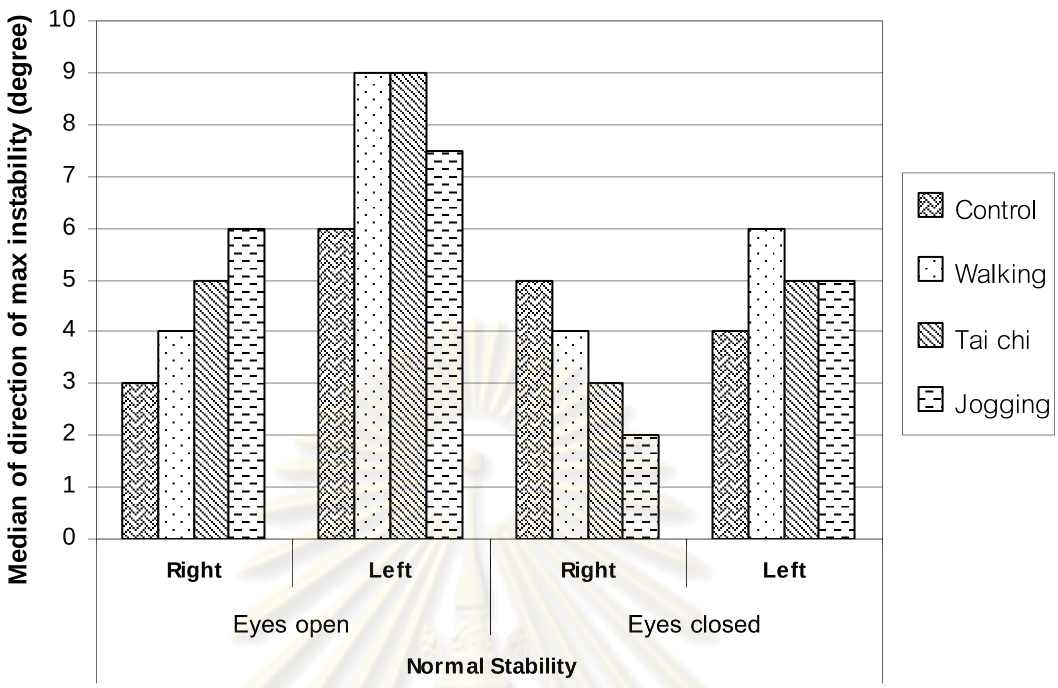


Fig 4.10 Median of direction of max instability received in a normal stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group

For perturbed stability test, there were 93 subjects (62.42%) and 56 subjects (37.58%) that shifted their bodies to either right or left direction when subjects performed eye open. Otherwise, there were 85 subjects (57.05%) and 64 subjects (42.95%) shifted their bodies to either right or left direction in PS-EC test. The median of degree from PS-EO with right direction (9.5°) and PS-EC with left direction (4°) were lowest in control group. Mild degrees in PS-EO with left (14°) and PS-EC with right (4°) were respectively received in walking and tai chi group. Further analysis offers statistics of minimum and maximum that subjects in each group had performed the tests (Table 6, see in Appendix A).

The overall median of direction of max instability received in a perturbed stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group were shown in figure 4.11. In PS-EO with left, median of degree had tended to increase in all group studies when compared PS-EO with right especially control and jogging group. It is interesting to note that median of degree of PS-EC in both right and left direction were lower than PS-EO condition. The tai chi and control group had a smaller median of degree than other groups for PS-EC with right (4°), and left (4°) respectively.

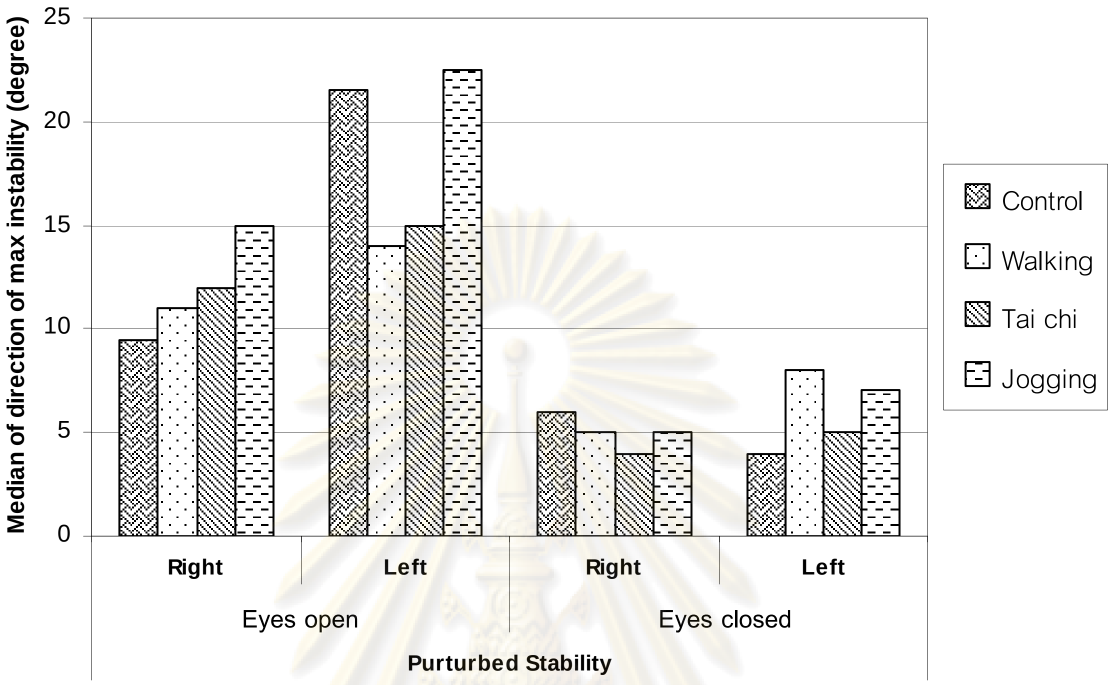


Fig 4.11 Median of direction of max instability received in a perturbed stability surface with eyes open or closed in elderly sedentary control, walking, tai chi, and jogging group

Kruskal-Wallis H test was used to detect the differences between four groups on median of direction of max instability. This result showed that median of direction of max instability in all conditions (NS-EO, NS-EC, PS-EO, and PS-EC with right and left direction) were not significant differences across four group studies (Table 7, see in Appendix A).

CHAPTER V
DISCUSSION AND CONCLUSION

Ankle joint position sense

This study represents the first investigation of proprioception on four test positions at the ankle in older adults who regularly engaged in difference types of exercise and older adults who have no exercise under passive reproduction joint position sense test. A total of 181 older adults were eligible for the study, all of their feet sensations are normal. There were 147 subjects with right foot dominance (only 2 subjects with left foot dominance). The complete data were obtained from 149 subjects. Thirty two persons did not complete the study. Two persons out of country, 5 persons had an injury/health problem, 11 persons lost to follow up, and 14 other persons had to take on their own business and family. Additionally, there were 62 subjects with delayed onset muscle soreness after cardiorespiratory fitness testing and 35 subjects with delayed onset muscle soreness after body strength testing.

The ankle proprioception protocol in the present study is passive reproduction joint position sense which is performed on four test positions: inversion, eversion, plantarflexion, and dorsiflexion movement at the ankle joint in Thai elderly men and women aged 60-70 years old. This test measured the subject's ability to reproduce a target ankle joint angle in the standing position. The difference in the test angle and reproduced angle was calculated as the absolute angular error (AAE). The protocol was set up for performing 15° inversion, 10° eversion, 12° plantarflexion, and 15° dorsiflexion with an angular velocity of 0.25°/s.

Training effects

The results of this study indicate that subjects in exercise groups had better ankle proprioceptive ability than control group, especially when performing eversion, plantarflexion, and dorsiflexion movement at the ankle joint. It is interesting to note that the AAE had tended to be better in walking and tai chi group when compared to control and jogging group (Table 4.4). When investigated the differences on AAE between two groups, Mann-Whitney U test showed significant better AAE of eversion and dorsiflexion than control group in all exercise groups. While different AAE in plantarflexion movement of ankle was only significant between walking and control group (p=.016), and tai chi and control group (p=.000). In addition, AAE in plantarflexion and dorsiflexion was significant difference between tai chi and jogging group (p=.013 and p=.027) (Table 4.4).

The results of primary variable included two important findings. At first, the comparison of ankle joint position sense (ankle JPS) ability between sedentary control and exercise groups, we hypothesized, and the results supported that subjects in exercise groups had markedly better their ability to reproduce passive position of ankle angles in comparison with the control subjects. The second important finding was that the difference in ankle JPS ability were observed in group exercises interaction, specifically between tai chi and jogging, involved in senses of plantarflexion and dorsiflexion motion.

Regarding improvements in proprioception at first issue, demonstrated by enhanced joint position sense, suggest that any exercises had elicited proprioception training based on the fact that deformation of the joint mechanoreceptors providing sensory input to improve neural mechanism (Ellenbecker and Bleacher, 2004). Indeed, at the peripheral level, the construction of proprioception is based on the cumulative neural input from mechanoreceptors (articular, muscular, and cutaneous receptors) (Ribeiro and Oliveira, 2007). Muscle spindle, a type of muscle receptors, is the major mechanoreceptors which provide a necessary complementary neural contribution in addition to the information of joint sensibility from the articular receptors (Lephart et al., 1998; Ribeiro and Oliveira, 2007). Regular physical activity can induce morphological adaptations in the muscle spindle involved in proprioception (Ribeiro and Oliveira, 2007), this study indicate that regular physical activity has influence on ankle proprioception.

This is the only report of ankle joint position sense ability at four test positions: inversion (IV), eversion (EV), plantarflexion (PF), and dorsiflexion (DF) during weight-bearing in older adults. Although, little evidence currently exists regarding the effect of exercises on ankle proprioception at different ankle positions, other one has studied the effect of athletic training on ankle proprioception with contradictory participant group. Aydin et al. (2000) evaluated passive joint position of ankle joint in gymnasts. They found that trained gymnastic group significantly improved joint position sense for both inversion and plantarflexion. Our study revealed that active elderly, tai chi and walking, subjects showed significantly better joint position sense for three test positions (EV, PF, and DF) when compared to the control group (Table 4.4). Additionally, the jogging subjects also demonstrated well AAE than the control subjects in EV and DF motions. One reason for these improvements may be the decision criterion necessary for tests of passive repositioning test (Aydin et al., 2000). Regular physical activity is sufficient to stimulate cutaneous nerve tissue and/or mechanoreceptors in the muscle ligaments, and joint capsule of the ankle joint. Stimulation of these mechanoreceptors may result in earlier and enhanced muscular contractions, thus protecting and stabilizing the joint (Heit et al., 1996; Lephart et al., 1996). Focusing on the joint receptors, they are excited by tension created in joint capsule and ligaments and may have the dominant role in signaling joint position sense (Lephart, 1993; Guanche et al., 2000; Aydin et al., 2000). If regular exercises are best suited to senses changes involved in the perception of joint position, joint receptors may be more valuable in fine judgments of joint position, this would explain why the AAE for passive judgments of JPS in active elderly subjects were significantly better than sedentary control subjects.

Furthermore, several other studies (Petrella et al., 1997; Xu et al., 2004; Thompson et al., 2003; Tsang and Hui-Chan, 2003; Tsang and Hui-Chan, 2004) have been conducted to examine the effects of regular activity or training on joint proprioception in older adult. These studies examined joint proprioception by using various methods. All of the studies consistently revealed an improvement at joint proprioception. Four of these studies (Petrella, Thompson, and 2 studies of Tsang) used passive/active joint repositioning test and kinaesthesia technique to examine knee joint proprioception in active elderly; whereas other one (Xu) used kinaesthesia technique to investigate the proprioception of ankle and knee joints in active elderly. It should also be noted that several of the studies were conducted to investigate the proprioception under different kinds of exercise: aerobic exercise program with or without additional strength training, tai chi, strength training, and golf. Although there were different methods in examining the lower limbs proprioception, the results also showed better in joint proprioception in exercise groups that was supported by this study.

Measures of JPS on inversion movement at the ankle demonstrated no significant across 4 group studies. However, tai chi had better their inversion movement than other kinds of exercise (Table 4.4). Contrary to the lack of improvement in particular movement pattern in the present study, Li et al. (2008) noted that no significant improvement was found for ankle kinaesthesia (motion sense) between plantarflexion (PF), and dorsiflexion (DF) in tai chi group. They thought that the 16-week tai chi intervention might be not longer enough. However, not only did in tai chi group, but also included walking and jogging group in our study which showed no significant in ankle IV movement by group interaction. Indicating that the training effect of these exercises on IV pattern was not obvious. One possibility to explain why group exercises did not show any significant in ankle IV movement is, lacking of correspondence during their training task on the IV motion. Because the most common mechanism of ankle injury is an inward turning (IV pattern) of the sole and the front of the foot (Peterson and Renstrom, 2002). According to the mechanism of injury, any type of exercise in our study may not have dominant role in IV movement pattern. Therefore, to fine judgment of ankle joint position involved in IV movement, these exercise patterns may be less valuable to do this task.

The second important finding was that the difference in ankle JPS ability were observed in group exercises interaction, specifically between tai chi and jogging, involved in senses of PF and DF motion. It could be suggested that tai chi exercisers had markedly better their ability to reproduce passive position of ankle angles in comparison with the other groups. This finding is consistent with the previous studies of Xu et al. (2004) and Li et al. (2008) who studied the effect of tai chi training on ankle proprioception. The authors reported that tai chi exercisers showed better proprioception of ankle joint compared with the untrained group. These studies indicated that the training has some influence on ankle proprioception.

Beneficial effects of exercise on ankle proprioception

Tai chi exercise is a series of individual graceful improvements in a slow, continuous, circular pattern. Tai chi exercise demands precise joint movement, stability, and balance. Performing tai chi depends on either double stance weight-bearing or single weight-bearing manoeuvres, which further require the pivoting of the whole body (Wong et al., 2001). The movements of tai chi are gracefully fluent and consummately precise because specificity of joint angles and body position is critical importance in accurately and correctly performing each form (Jacobson et al., 1997). Furthermore, the continuous transformation of different postures and steps cause more changes in ankle joint movements. These movements help to retain the sensitivity of proprioceptors located in the joint capsules, ligaments, tendons, and muscles. Acute awareness of body position and movement is demanded by the nature of the activity (Xu et al., 2004). Hain et al. (1999) noted that the progressive nature of balance training is similar to process of learning tai chi form.

Further Wilkerson and Nitz (1994) indicated that exercises designed to enhance balance may improve one's awareness of the location of the center of gravity and increase the responsiveness and sensitivity of mechanoreceptors, thereby increasing proprioceptive input to CNS. The possibility Tsang and Hui-Chan (2003) raise is that the improvement of joint proprioception by tai chi could be through increased output of the muscle spindles through the gamma route during voluntary movement (Ashton-Miller et al., 2001; Granit, 1970). In this connection, repeated practice of a motor skill is thought to increase muscle spindles output, which could increased strength of synaptic connections and/or structural changes in the organization and numbers of connections among neurons (Shumway-Cook and Woollacott, 2001). Thus, the theoretical possibility is supported by the results of our study.

Considering to walking and jogging exercise, two of the most common exercises practiced by elderly people; they are form of aerobic exercise, cyclic repetitive actions, and provide good training stimuli for cardiorespiratory fitness and muscle strength (Xu et al., 2004; Overstall, 2003). In performing walking, it is likely that this approximately 65% of the gait cycle is weight-bearing (closed kinetic chain) and 35% is non-weight-bearing (open kinetic chain). Interestingly, during running or jogging, the percentages of closed and open kinetic chain motions essentially reverse (Ellenbecker and Davies, 2001). Bunton et al. (1993) reported that the goal of closed kinetic chain is to improve proprioceptive sensation, and to establish the stability of lower limbs when unexpected change of direction or speed of movement occurs in these limbs. This might partly explain why walking group displayed improvement ankle JPS similar to the tai chi group.

Muscle strength

The results from this study indicated that the great number of repetitions for the upper body strength testing was respectively received in jogging, walking, tai chi, and control group. Additionally, the result showed no significant difference was noted in the lower body strength. The repetition for lower body strength testing in jogging group was greater than other three groups, while control group was lower than all exercise groups (Table 4.6).

Aging is associated with a decreased muscular strength that affects the major postural functions (Whipple et al., 1987). Several studies have shown that training allowings to counteract age-related balance impairment (Campbell et al., 1997) and may improve postural control by acting on balance sensors (Hu and Woollacott, 1994; Perrin et al., 1999) or on the motor response through an increase of muscular strength (Wolfson et al., 1996). Postural control may rely upon the proper use and function of sensory afferences, but could also depend on the muscular strength of lower limb (Gauchard et al., 1999). The paper by Dieen and Pijnappels (2007) further addressed leg muscle strength is a determinant of capability to recover balance. The issue of lower body strength through exercises in this study has shown that repetition of testing is great in jogging group, but no significant improvement as a function of the exercise training (Table 4.6). Although walking (Hagberg et al., 1989; Cononie et al., 1991; Overstall, 2003), tai chi (Li et al., 2001[a]; Li et al., 2001[b]) and jogging (Xu et al., 2004; Xu et al., 2005) produced a positive impact on lower body strength, jogging group has been shown better repetition of testing. Despite having a positive impact to muscular strength, it was felt that the gender imbalance (26 males and only 7 females participated in the jogging) might have bias the summary data.

Interestingly, impairment in lower extremity strength is primary factor which collectively contribute to increased likelihood of falling (Lord and Ward, 1994; Lord et al., 1999; American Geriatrics Society, 2001; Lord and Sturnieks, 2005). The exercise training might partly promote leg muscle strength according to the theory. Consequently, there is a decrease in rate of falling in exercise groups. Not only did the measurement of lower body strength, but performance also based measurement of upper body strength with arm curl test. Improvement in arm muscle strength was observed in walking and jogging group. It is possible that someone in both groups may engaged in activities designed to strengthen the upper extremities during their common exercise for period of one year or more. However, no evidence considers upper limb (arm) strength is the principle segment concerning postural control.

Balance

Functional reach and timed up and go test

Functional reach and the timed up and go (TUG) test are typical examples of performance based measurements of balance and gait impairment. The result suggested that all three exercise groups can produce improvement in functional reach and timed up and go test. Our results have shown that tai chi and jogging have best functional reach and TUG test respectively. However, no significant was observed across exercise groups (Table 4.7). These improvements may reduce the risk of falling in older adults.

Several different exercise modes and modalities designed to improve balance have been studied. Brook-Wavell et al. (1998) found something as simple as brisk walking can improve postural stability in healthy women aged 61-71 years. Kreb et al. (1998) have suggested that six month of moderate intensity lower limb strength training, using elastic band resistance exercises three times a week in functionally limited adults with mean age of 75 years will also improve gait stability. Lan et al. (1996) found that long term tai chi practitioners showed better scores in stand and reach test. Likewise, Brandt et al. (1996) reported that a training program based on the manipulation of sensory inputs significantly improve postural stability. Tanaka et al. (1996) found that a training program designed to improve both sensory and motor function is effective in the improvement of balance among older adults. A study in Japan recruited active, independent older women aged 72-87 years to a three-month dance-based aerobic exercise program. Classes lasted 60 minutes and were held three times a week. There were significant improvement in balance (Single-leg balance with eye closed and functional reach) and mobility/agility (Shigematsu et al., 2002).

Theoretically, exercises are individualized and focus on improving postural alignment and orientation and muscular system, developing strategies for recovery balance, improving anticipatory postural adjustments before voluntary movements, gait stability, and improving balance during every task (Overstall, 2003; Dieen and Pijnappels, 2007). In this study, an increase tendency of elderly with effective functional reach is respectively tai chi, jogging, walking, and control group and with effective TUG respectively is jogging, tai chi, walking, and control group (Table 4.7). It possible that these exercise training which manipulates muscular and/or balance system may be the most effective means to improve balance and gait in older adults.

Single leg stance

Single stance time is one of the most challenging gauges of stability while standing on a narrow area support. It has been the frequently use measured of balance in physical training studies involving older adults (Whipples, 1996). The single leg stance test is a test of static balance, which includes balancing on one leg for a specified amount of time with eyes open or closed (Guskiewicz and Perrin, 1996). Our results have shown that participating regular exercise could improve balance control as their seemed to be a tai chi, jogging, and walking hierarchy (Table 4.8). The present study found that the stance time of the tai chi group were better than that of the others group, consistent with the review of Wu (2002) who reported that participating in tai chi on a regular basis improves the ability to stand on one leg.

Cross sectional studies have provided positive evidence that tai chi has beneficial effects on balance. Tse and Bailey (1992) reported that tai chi practitioners were significantly better at performing right and left single leg stances with their eyes open than non-practitioners. However, this was not the case for single leg stances with eyes closed.

Hong et al. (2000) found a significant difference between tai chi practitioners and non-practitioners in single leg stance time with eyes closed. Besides the cross sectional studies, a number of tai chi intervention studies of balance capacity in elderly people have been conducted. Schaller (1996) found that a 10 week course of an easy to learn westernized form of tai chi resulted in significant improvements to the scores of single leg stances with eyes open, but not in those with eyes closed.

In fact, classical tai chi needs to be performed continuous and slowly, with knee flexion and weight shifting, straight and extended head and trunk, as well as unilateral weight bearing with constant shifting. All of these are associated with the use of internal feedback to control the center of mass, thus benefiting balance ability regardless of whether eyes are open or closed (Hong et al., 2000). This fact may indicate that tai chi exercise produces more benefit for balance control and thus for postural control of older persons.

Center of pressure excursion (CoP excursion)

Balance is the ability to maintain the body's position over its base of support. The center of gravity of the body shifts continuously even during quiet upright standing. Postural sway is the corrective body movement resulting from the control of body position and is determined by measuring the location and amount of change that occurs in the position of vertical force vector projected onto a horizontal plane. Traditionally, postural stability has been measured by determining the excursion or degree of motion of the CoP at the surface of the support through force platform technology (Nashner, 1993; Tanaka et al., 1996; Overstall, 2003). Postural sway is usually measured during quiet, upright standing, and thus reflects the body's effort to maintain balance in that posture, with increased sway indicating greater effort and thus poorer balance (Rogers et al., 2001).

Our study found no significant difference between active healthy subjects and sedentary subjects on anterior-posterior (A-P) CoP excursion (Table 4.7) and direction of max instability (Table 6 in Appendix A) with eyes open and closed, for both the normal and perturbed stability surface. In fact, physical and sporting activities increasing the ankle's muscular force and/or tactile sensitivity and proprioception (Nardone et al., 1990).

Proprioception and sensory input from the plantar surface of the feet have been reported to be the important sensorial system for maintaining balance under normal conditions (Lord et al., 1991). Physical activities, through the increased usage of these seem to allow more efficient postural adaptation (Perrin et al., 1999), hence benefiting balance control regardless of whether normal and perturbed stability conditions. Nonetheless, previous researchers (Horak et al., 1989; You et al., 2002; Stelmach and Sirica, 1986; Levin and Benton, 1973; You, 2005) have suggested that older adults may compensate for deteriorated proprioception (peripheral input) by enhancing sensitivity of the central encoding of sensory sequences (central inputs), therefore sedentary older adults with a history of falls allows for postural control (sway path) for a similar compared with the exercise groups in this case.

However, the tai chi group significantly exhibited reducing in sway path only in the lateral excursion with eyes closed, for both the normal and perturbed stability conditions (Table 4.10). This improvement is related to tai chi movement characteristics. The tai chi forms practiced predominantly demand joint movement, stability, and balance. Jacobson et al. (1997) compared the lateral stability of two healthy older groups who participated in a 12-week tai chi program or no exercise program. The authors reported significant differences between two groups after training, but they did not mention whether the differences were positive or negative.

Additionally, there are many studies that evaluated the effectiveness of tai chi on balance using postural platforms and the study findings are not consistent. In the study by Lin et al. (2000), they conducted a cross-sectional study that included subjects between the ages of 66 and 74. It was found that, the tai chi practitioners (2-35 years of experience) did significantly better in the two most difficult sensory organization conditions (sway-referenced support with eyes closed and sway-referenced vision and support), agreeing with the results of Wong et al. (2001) who suggested that elderly people who regularly practice tai chi showed better postural stability in the more challenging conditions than those who do not (e.g., condition with simultaneous disturbance of vision and porprioception).

Similarly, Forrest (1997) measured the CoP displacement while standing on an unstable support surface that was disturbed by a self-droping load. It was found that the CoP displacement anterior/posterior and lateral directions were significantly reduced after tai chi training. Another study by Wolf et al. (1997) showed negative results. In this study, the authors examined the CoP displacement in the medial-lateral and anterior-posterior directions with and without vision. After a 15-week (twice a week) tai chi program, no significant differences were found, compared with pretraining, in any testing conditions for those subjects who participated in tai chi training.

Overall, the review of Wu (2002) suggested that even with sufficient amount of practice, the testing conditions that present more challenging environments (such as dynamic vs static and disturbance of two sensory systems vs only one) seem more likely to show significant changes.

Falls

Our finding that the sedentary control group have the most fell in the last year with represented 30%, while exercise groups reported having fell in the last year 25%, 22.50%, and 24.24% in walking, tai chi, and jogging group respectively (Table 4.2). It appears that regular physical activity, especially tai chi, is an important preventative activity against falls (Lauritzen et al., 1993; O' Loughlin et al., 1993).

The most landing or falling, which occurs as a result of plantarflexion and inverted ankle, often induces ankle sprains (Nordin and Frankel, 2001; Sekizawa et al., 2001) and may be including the ensuing contusion and/or abrasion. One interesting aspect of this point is that ankle JPS in plantarflexion and inversion motions tended to be markedly better than other kinds of exercise in tai chi practitioners (Table 4.4). Moreover, elderly who regularly practice tai chi also showed greatest balance control in more challenging conditions than those who do not, even their lower body strength was not obvious as well as jogging and walking group. It appears that regular tai chi could against falls. Thus, improvement in ankle proprioception, specifically inversion and plantarflexion movements, is more influential factor which contributes to decrease falls risk in older adults.

If considering to aerobic exercise, jogging and walking, the results demonstrated that walking did better ankle JPS involving eversion (EV), plantarflexion (PF), and dosiflexion (DF) motions (Table 4.4), and has less lower body strength as compared to jogging group (Table 4.6). In other words, jogging does well affect joint position sense in inversion (IV) (Table 4.4) and has more benefit in promote leg muscle strength as compared to walking (Table 4.6). For this reason, there is a decrease in rate of falling in jogging group. However, this result almost was indifference compared with walking group. All in all, improvement in both ankle JPS, especially IV and PF, and muscular strength of lower limb are powerful factor in preventing falls in elderly.

Accumulating evidence indicates that structured exercise help maintain an independent life by maintaining postural stability (balance), strength, endurance, bone density, and functional ability may prevent falls and injuries associated with falls in older age. But some types and pattern of exercise do not seem to improve postural stability, let alone prevent or reduce the risk of falls (Skelton, 2001).

In spite of having more fallers in non-exercise group, fall incidents and the ensuing injury process are most occurred in exercise groups (Table 4.2). On the one hand, a fitter quicker group of elderly people may fall at speed while about their daily activities (Speechley and Tinetti, 1991). However, active older people may spend less time in hospital.

Conclusion

The decline in ankle proprioception with age may be an important contributing factor to falls in the elderly, and this may be influenced by regular exercise. This study showed that, compared with elderly who had common activities over one year experience and elderly who seldom practiced any physical and sporting activities, active elderly who engaged in regularly exercise as either walking, tai chi, or jogging had better ankle proprioceptive ability than inactive elderly. However, tai chi as a balance exercise may have more benefit than walking and jogging exercise in regaining and retaining proprioception of the ankle joint especially inversion and plantarflexion movements, which may be more valuable in maintaining of balance control and reducing falls in the elderly. Therefore, ankle joint position sense in both of inversion and plantarflexion movements should be considered when providing strategies to improve proprioceptive function in older adults.

Additionally, an increase in muscular strength of lower limb involving regular exercise also might partly reduce the risk of falls. Thus, it is suggested that regular participating exercise designed to improve ankle proprioception and muscular strength of lower limb had more effective in lowering falls risk in older people.

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APPENDICES

APPENDIX A

Descriptive statistics

Table 1 Descriptive statistics of absolute angular error in ankle joint position test

Test	Descriptive statistics	Absolute angular error (degree)				Total (n=149)
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
15° Inversion	Mean (S.D)	3.568(2.209)	2.888(1.723)	2.520(1.303)	2.771(1.770)	2.946(1.809)
	Minimum	.750	.000	.480	.560	.000
	Maximum	10.000	7.000	6.450	7.240	10.000
	Median	3.050	2.670	2.040	2.500	2.610
10° Eversion	Mean (S.D)	3.082(1.638)	2.100(.942)	1.992(1.191)	2.230(1.089)	2.363(1.321)
	Minimum	.940	.450	.210	.450	.210
	Maximum	7.720	4.860	4.500	4.500	7.720
	Median	2.585	1.725	2.080	2.250	2.190
12° Plantarflexion	Mean (S.D)	3.730(1.894)	2.736(1.470)	2.114(1.289)	3.025(1.544)	2.899(1.665)
	Minimum	1.110	.750	.110	.340	.110
	Maximum	8.250	6.240	4.500	7.600	8.250
	Median	3.195	2.565	2.265	3.190	2.750
15° Dorsiflexion	Mean (S.D)	3.946(2.161)	2.120(1.396)	1.807(1.143)	2.522(1.270)	2.615(1.761)
	Minimum	.630	.130	.000	.750	.000
	Maximum	12.250	6.700	4.680	7.200	12.250
	Median	3.630	1.885	1.935	2.430	2.400

Table 2 Descriptive statistics of subject's ability to maintain balance in single leg stance test

Test	Descriptive statistics	Group				Total (n=149)
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
SLT with eye open Right (sec.)	Mean (S.D)	9.97(8.24)	26.03(27.77)	49.27(60.91)	39.53(44.36)	30.95(42.84)
	Minimum	2.84	2.13	5.77	2.02	2.02
	Maximum	37.33	99.17	344.49	204.11	344.49
	Median	7.72	16.70	31.22	20.99	16.37
SLT with eye open Left (sec.)	Mean (S.D)	10.15(6.98)	26.81(32.42)	46.33(63.24)	46.71(53.52)	31.99(46.63)
	Minimum	2.08	2.01	4.99	2.14	2.01
	Maximum	29.35	161.57	307.91	229.80	307.91
	Median	7.53	13.88	21.39	31.78	14.32
SLT with eye closed Right (sec.)	Mean (S.D)	4.33(3.27)	8.07(9.48)	6.71(5.08)	9.09(7.12)	6.93(6.71)
	Minimum	1.21	1.45	1.80	1.42	1.21
	Maximum	16.67	41.48	21.94	28.56	41.48
	Median	3.22	4.64	4.56	7.59	4.31
SLT with eye closed Left (sec.)	Mean (S.D)	3.48(2.13)	7.16(7.09)	6.39(5.03)	8.81(9.37)	6.33(6.52)
	Minimum	1.02	1.63	.58	1.24	.58
	Maximum	12.97	31.48	22.94	48.86	48.86
	Median	3.05	4.24	5.20	6.66	4.27

Table 3 Descriptive statistics of anterior-posterior CoP excursion

Test	Descriptive statistics	Anterior-Posterior CoP excursion (cm.)				Total (n=149)
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Normal Stability with eyes open	Mean (S.D)	.655(.231)	.672(.240)	.593(.153)	.597(.185)	.630(.206)
	Minimum	.200	.300	.300	.300	.200
	Maximum	1.300	1.300	1.000	1.100	1.300
	Median	.700	.600	.600	.600	.600
Normal Stability with eyes closed	Mean (S.D)	.855(.327)	.789(.253)	.678(.197)	.769(.314)	.772(.281)
	Minimum	.300	.400	.300	.080	.080
	Maximum	1.500	1.800	1.200	1.700	1.800
	Median	.900	.800	.700	.700	.700
Perturbed Stability with eyes open	Mean (S.D)	.900(.240)	.925(.295)	.808(.259)	.936(.386)	.889(.297)
	Minimum	.400	.400	.400	.300	.300
	Maximum	1.500	1.500	1.500	1.700	1.700
	Median	.900	.900	.800	.900	.800
Perturbed Stability with eyes closed	Mean (S.D)	1.320(.479)	1.336(.401)	1.213(.365)	1.452(.429)	1.324(.425)
	Minimum	.700	.600	.500	.600	.500
	Maximum	3.600	2.400	2.100	2.300	3.600
	Median	1.300	1.350	1.200	1.400	1.300

Table 4 Descriptive statistics of lateral CoP excursion

Test	Descriptive statistics	Lateral CoP excursion (cm.)				Total (n=149)
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Normal Stability with eyes open	Mean (S.D)	.245(.106)	.256(.108)	.240(.103)	.224(.087)	.242(.101)
	Minimum	.100	.100	.100	.100	.100
	Maximum	.500	.500	.500	.400	.500
	Median	.200	.200	.200	.200	.200
Normal Stability with eyes closed	Mean (S.D)	.273(.138)	.264(.099)	.198(.077)	.248(.115)	.245(.112)
	Minimum	.100	.100	.100	.100	.100
	Maximum	.800	.500	.500	.500	.800
	Median	.250	.300	.200	.300	.200
Perturbed Stability with eyes open	Mean (S.D)	.608(.357)	.533(.220)	.483(.202)	.591(.291)	.552(.277)
	Minimum	.200	.200	.200	.200	.200
	Maximum	2.000	1.300	1.100	1.300	2.000
	Median	.550	.500	.400	.600	.500
Perturbed Stability with eyes closed	Mean (S.D)	.595(.310)	.622(.256)	.550(.611)	.638(.346)	.599(.408)
	Minimum	.100	.200	.100	.140	.100
	Maximum	1.500	1.500	4.000	1.500	4.000
	Median	.500	.600	.400	.600	.500

Table 5 Descriptive statistics of direction of max instability in normal stability test

Test	Descriptive statistics	Direction of Max Instability (degree)				Total
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Normal Stability with eyes open Right	Mean (S.D)	5.00(5.35)	5.25(4.60)	9.74(13.70)	7.53(6.28)	6.66(8.16)
	Minimum	0.00	0.00	0.00	0.00	0.00
	Maximum	21.00	19.00	60.00	23.00	60.00
	Median	3.00	4.00	5.00	6.00	4.00
Normal Stability with eyes open Left	Mean (S.D)	8.85(7.63)	9.31(6.69)	12.81(17.54)	6.63(4.75)	9.68(11.25)
	Minimum	1.00	1.00	1.00	1.00	1.00
	Maximum	27.00	25.00	85.00	15.00	85.00
	Median	6.00	9.00	9.00	7.50	8.00
Normal Stability with eyes closed Right	Mean (S.D)	6.74(7.19)	4.62(3.93)	4.52(4.69)	3.42(4.48)	4.89(5.32)
	Minimum	0.00	0.00	0.00	0.00	0.00
	Maximum	32.00	17.00	16.00	18.00	32.00
	Median	5.00	4.00	3.00	2.00	3.50
Normal Stability with eyes closed Left	Mean (S.D)	5.29(4.34)	7.87(5.95)	5.07(3.28)	7.14(5.95)	6.30(4.99)
	Minimum	1.00	1.00	1.00	2.00	1.00
	Maximum	16.00	23.00	13.00	24.00	24.00
	Median	4.00	6.00	5.00	5.00	5.00

Table 6 Descriptive statistics of direction of max instability in perturbed stability test

Test	Descriptive statistics	Direction of Max Instability (degree)				Total
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)	
Perturbed Stability with eyes open Right	Mean (S.D)	17.23(23.31)	19.39(19.68)	17.52(14.63)	19.43(18.08)	18.33(19.07)
	Minimum	0.00	0.00	3.00	0.00	0.00
	Maximum	84.00	73.00	62.00	70.00	84.00
	Median	9.50	11.00	12.00	15.00	11.00
Perturbed Stability with eyes open Left	Mean (S.D)	25.14(21.86)	18.15(17.49)	22.59(22.87)	29.75(25.48)	23.73(21.86)
	Minimum	2.00	6.00	2.00	1.00	1.00
	Maximum	74.00	73.00	86.00	77.00	86.00
	Median	21.50	14.00	15.00	22.50	16.00
Perturbed Stability with eyes closed Right	Mean (S.D)	8.11(9.79)	7.52(11.96)	6.70(7.57)	5.17(4.95)	6.89(8.85)
	Minimum	0.00	0.00	0.00	0.00	0.00
	Maximum	40.00	46.00	28.00	17.00	46.00
	Median	6.00	5.00	4.00	5.00	5.00
Perturbed Stability with eyes closed Left	Mean (S.D)	9.48(16.86)	7.93(4.48)	5.23(2.86)	10.33(13.26)	8.45(11.78)
	Minimum	1.00	1.00	1.00	2.00	1.00
	Maximum	74.00	15.00	10.00	55.00	74.00
	Median	4.00	8.00	5.00	7.00	5.00

Table 7 Median of direction of max instability in the sedentary control, walking, tai chi, and jogging group

Test			Median of Direction of Max Instability (degree)			
			Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability	Eyes open	Right	3.00	4.00	5.00	6.00
		Left	6.00	9.00	9.00	7.50
	Eyes closed	Right	5.00	4.00	3.00	2.00
		Left	4.00	6.00	5.00	5.00
Perturbed Stability	Eyes open	Right	9.50	11.00	12.00	15.00
		Left	21.50	14.00	15.00	22.50
	Eyes closed	Right	6.00	5.00	4.00	5.00
		Left	4.00	8.00	5.00	7.00

APPENDIX B

Median Frequencies

In the non-normal distribution case, the nonparametric test was used for quantitative data. Table 8-12 represented number of subjects in each group who demonstrated result more or less than sum median of the overall subjects.

Passive to Passive Reproduction of Ankle Joint Position

The number of subjects in each group that achieved absolute angular error more or less than sum median of the overall subjects was shown in Table 8. There were 62.5% (inversion), 65% (plantarflexion), and 67.5% (dorsiflexion) of the all tai chi subjects who had less absolute angular error than sum median of absolute angular error when compared the subjects in sedentary control, walking, and jogging group.

Table 8 Number of subjects in each group that achieved absolute angular error more or less than median value of the overall subjects

Test	Median	Frequencies			
		Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
15° Inversion, n (%)	> Median	26 (65.00)	19 (52.78)	15 (37.50)	14 (42.42)
	≤ Median	14 (35.00)	17 (47.22)	25 (62.50)	19 (57.58)
10° Eversion, n (%)	> Median	26 (65.00)	14 (38.89)	17 (42.50)	17 (51.52)
	≤ Median	14 (35.00)	22 (61.11)	23 (57.50)	16 (48.48)
12° Plantarflexion, n (%)	> Median	25 (62.50)	16 (44.44)	14 (35.00)	19 (57.58)
	≤ Median	15 (37.50)	20 (55.56)	26 (65.00)	14 (42.42)
15° Dorsiflexion, n (%)	> Median	30 (75.00)	13 (36.11)	13 (32.50)	18 (54.55)
	≤ Median	10 (25.00)	23 (63.89)	27 (67.50)	15 (45.45)

Single Leg Stance

There were 75% (SLT-EO with right leg), 72.5% (SLT-EO with left leg), and 65% (SLT-EC with left leg) of the all tai chi subjects who had more time standing than sum median of time when compared the subjects in sedentary control, walking, and jogging group.

Table 9 Number of subjects in each group that achieved ability to maintain balance more or less than median value of the overall subjects

Test		Median	Frequencies			
			Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
SLT with eye open , n (%)	Right	> Median	6 (15.00)	19 (52.78)	30 (75.00)	19 (57.58)
		≤ Median	34 (85.00)	17 (47.22)	10 (25.00)	14 (42.42)
	Left	> Median	8 (20.00)	18 (50.00)	29 (72.50)	19 (57.58)
		≤ Median	32 (80.00)	18 (50.00)	11 (27.50)	14 (42.42)
SLT with eye closed , n (%)	Right	> Median	12 (30.00)	19 (52.78)	21 (52.50)	22 (66.67)
		≤ Median	28 (70.00)	17 (47.22)	19 (47.50)	11 (33.33)
	Left	> Median	9 (22.50)	18 (50.00)	26 (65.00)	21 (63.64)
		≤ Median	31 (77.50)	18 (50.00)	14 (35.00)	12 (36.36)

Center of pressure (CoP)

(1) Anterior-Posterior CoP excursion

The result note that the tai chi group demonstrated a greater number of subjects who had anterior-posterior CoP excursion, with NS-EO (70%); NS-EC (67.5%); and PS-EO (65%) tests, less than sum median of A-P excursion when compared the subjects in sedentary control, walking, and jogging group.

Table 10 Number of subjects in each group that achieved anterior-posterior CoP excursion more or less than median value of the overall subjects

Test		Median	Frequencies			
			Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability, n (%)	Eyes open	> Median	21 (52.50)	15 (41.67)	12 (30.00)	11 (33.33)
		≤ Median	19 (47.50)	21 (58.33)	28 (70.00)	22 (66.67)
	Eyes closed	> Median	23 (57.50)	22 (61.11)	13 (32.50)	15 (45.45)
		≤ Median	17 (42.50)	14 (38.89)	27 (67.50)	18 (54.55)
Perturbed Stability, n (%)	Eyes open	> Median	22 (55.00)	19 (52.78)	14 (35.00)	17 (51.52)
		≤ Median	18 (45.00)	17 (47.22)	26 (65.00)	16 (48.48)
	Eyes closed	> Median	14 (35.00)	18 (50.00)	15 (37.50)	20 (60.61)
		≤ Median	26 (65.00)	18 (50.00)	25 (62.50)	13 (39.39)

(2) Lateral CoP excursion

There were 85%, 72.5%, and 77.5% of the all tai chi subjects who had less lateral CoP excursion than sum median of lateral excursion when compared the subjects in sedentary control, walking, and jogging group.

Table 11 Number of subjects in each group that achieved lateral CoP excursion more or less than median value of the overall subjects

Test		Median	Frequencies			
			Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability, n (%)	Eyes open	> Median	15 (37.50)	17 (47.22)	17 (42.50)	11 (33.33)
		≤ Median	25 (62.50)	19 (52.78)	23 (57.50)	22 (66.67)
	Eyes closed	> Median	20 (50.00)	19 (52.78)	6 (15.00)	17 (51.52)
		≤ Median	20 (50.00)	17 (47.22)	34 (85.00)	16 (48.48)
Perturbed Stability, n (%)	Eyes open	> Median	20 (50.00)	17 (47.22)	11 (27.50)	17 (51.52)
		≤ Median	20 (50.00)	19 (52.78)	29 (72.50)	16 (48.48)
	Eyes closed	> Median	16 (40.00)	20 (55.56)	9 (22.50)	18 (54.55)
		≤ Median	24 (60.00)	16 (44.44)	31 (77.50)	15 (45.45)

(3) Direction of max instability

Table 12 revealed the number of subjects in each group that achieved direction of max instability more or less than median value of the total subjects in each section. There were 19.28%, 17.2%, and 21.88% of the control subjects who had less median of degree than sum median in following sections, NS-EO with right; PS-EO with right; and PS-EC with left when compared the subjects in sedentary control, walking, and jogging group. While tai chi group showed numbers of subjects (15.91%, 18.03%, and 18.82%) who give a less median of degree than sum median in following sections, NS-EC with right; NS-EC with left; and PS-EC with right when compared the subjects in other groups.

Table 12 Number of subjects in each group that achieved direction of max instability more or less than median value of the total subjects in each section

Test		Median	Frequencies			
			Control (n=40)	Walking (n=36)	Tai chi (n=40)	Jogging (n=33)
Normal Stability with eyes open, n (%)	Right	> Median	11 (13.25)	9 (10.84)	10 (12.05)	11 (13.25)
		≤ Median	16 (19.28)	11 (13.25)	9 (10.84)	6 (7.23)
	Left	> Median	4 (6.06)	8 (12.12)	11 (16.67)	4 (6.06)
		≤ Median	9 (13.63)	8 (12.12)	10 (15.15)	12 (18.18)
Normal Stability with eyes closed, n (%)	Right	> Median	15 (17.04)	11 (12.50)	11 (12.50)	7 (7.95)
		≤ Median	8 (9.09)	10 (11.36)	14 (15.91)	12 (13.64)
	Left	> Median	7 (11.48)	9 (14.75)	4 (6.56)	6 (9.84)
		≤ Median	10 (16.39)	6 (9.84)	11 (18.03)	8 (13.11)
Perturbed Stability with eyes open, n (%)	Right	> Median	10 (10.75)	11 (11.83)	12 (12.90)	11 (11.83)
		≤ Median	16 (17.20)	12 (12.90)	11 (11.83)	10 (10.75)
	Left	> Median	8 (14.28)	3 (5.36)	8 (14.28)	8 (14.28)
		≤ Median	6 (10.71)	10 (17.86)	9 (16.07)	4 (7.14)
Perturbed Stability with eyes closed, n (%)	Right	> Median	10 (11.76)	7 (8.24)	11 (12.94)	8 (9.41)
		≤ Median	9 (10.59)	14 (16.47)	16 (18.82)	10 (11.76)
	Left	> Median	7 (10.94)	10 (15.62)	5 (7.81)	9 (14.06)
		≤ Median	14 (21.88)	5 (7.81)	8 (12.50)	6 (9.38)

APPENDIX C

Test-retest reliability method

The test-retest reliability of proprioceptive measurement was established by determining an instrument's capability of measuring a variable with consistency. The present study assessed JPS by using the LabView 8.0 system and passive to passive JPS paradigm. Prior to test session, test administrator brief clearly experimental protocol and instruct the participant to remove the shoes before testing. In initial of experimental setting, 1) The subjects kept their eyes closed and wore headphones with music playing to eliminate visual feedback and auditory stimuli from the testing apparatus, 2) a foot strap was not used because subjects could use additional cutaneous input from the strap and 3) a surface EMG biofeedback unit was used to determine muscle activity. Surface EMG electrodes were applied on the skin parallel to the direction of muscle fibers (on the test leg).

For the inversion (IV) test, the participant began in a starting position (0°), and maintains symmetrical weight bearing while standing with one foot on a footstool and the test foot on a hinged platform, hip and knee joints were fully extended and trunk was upright. Then, passively moved the ankle through the test position (a target position, 15°) by an apparatus at a constant speed, 0.25°/s. After reaching the target position, the participant was instructed to concentrate on sensation of joint angle while the limb is sustained in the specific position for 15 seconds and then the test foot returned to the start position. After that, the examiner moved the test foot back towards the test position, and the subjects pressed a stop switch once they perceived that the test position had been attained (passively reproduce the target position). The difference in the test angle and reproduced angle was calculated as the absolute error. Mean values of two trials in each direction were used for analysis. For other JPS tests (10° eversion; EV, 12° plantarflexion; PF, 15° dorsiflexion; DF) used a similar technique to those used in inversion position. Specially, for performing of 10° EV and 15° DF movement of ankle, by adjustment of the foot position, the device can also equipped with a metal frame (See figure 3.10-3.11 in chapter 3).

The intratester reliability study was performed on 2 separate occasions, approximately 24 hours apart. All testing conditions were kept as consistent as possible, including the same tester, procedures (i.e., consistent instruction, calibration, foot position, testing sequence, the same established joint angular positions), time of day and interval, and testing environment (lighting, temperature) were consistent as possible (You, 2005). The same established joint position angles (15°; IV, 10°; EV, 12°; PF, 15°; DF) that were determined by the subjects at the first test were used at the second test as target positions. Reliability data were collected from 15 healthy subjects (mean age, 40.60±12.98 years). The reliability data for the second test session were computed and used for further analysis.

APPENDIX D

Compendium of Physical activity

CODE	METS	SPECFIC ACTIVITY	EXAMPLES
01010	4.0	Bicycling	Bicycling, <10 mph, leisure, to work or for pleasure
01020	6.0	Bicycling	Bicycling, 10-11.9 mph, leisure, slow, light effort
01030	8.0	Bicycling	Bicycling, 12-13.9 mph, leisure, moderate effort
01040	10.0	Bicycling	Bicycling, 14-15.9 mph, racing or leisure, fast, vigorous effort
02030	3.5	Conditioning exercise	Calisthenics, home exercise, light or moderate effort, general (example: back exercises), going up & down from floor
02070	7.0	Conditioning exercise	Rowing, stationary ergometer, general
02100	2.5	Conditioning exercise	Stretching, hatha yoga
02130	3.0	Conditioning exercise	Weight lifting (free, nautilus or universal-type), light or moderate effort, light workout, general
03020	5.0	Dancing	Aerobic, low impact
03031	4.5	Dancing	Ballroom, fast (disco, folk, square), line dancing, Irish step dancing, polka, contra, country

03040	3.0	Dancing	Ballroom, slow (e.g. waltz, foxtrot, slow dancing), samba, tango, 19th C, mambo, chacha
05020	3.0	Home activity	Cleaning, heavy or major (e.g. wash car, wash windows, clean garage), vigorous effort
05025	2.5	Home activity	Multiple household tasks all at once, light effort
05030	3.0	Home activity	Cleaning, house or cabin, general
08050	5.0	Lawn and garden	Digging, spading, filling garden, composting
08095	5.5	Lawn and garden	Mowing lawn, general
08150	4.5	Lawn and garden	Planting trees
08230	1.5	Lawn and garden	Watering lawn or garden, standing or walking
08246	3.0	Lawn and garden	Picking fruit off trees, picking fruits/vegetables, moderate effort
12010	6.0	Running	Jog/walk combination (jogging component of less than 10 minute)
12020	7.0	Running	Jogging, general
12180	10.0	Running	Running, on a track, team practice
15030	4.5	Sports	Badminton, social singles and doubles, general

15100	12.0	Sports	Boxing, in ring, general
15255	4.5	Sports	Golf, general
15660	4.0	Sports	Table tennis, ping pong
15670	4.0	Sports	Tai chi
15675	7.0	Sports	Tennis, general
17152	2.5	Walking	Walking, 2.0 mph, level, slow pace, firm surface
17190	3.3	Walking	Walking, 3.0 mph, Level, moderate pace, Firm surface
17200	3.8	Walking	Walking, 3.5 mph, Level, brisk, Firm surface, walking for exercise
18240	7.0	Water activities	Swimming laps, freestyle, slow, moderate or light effort
21025	3.5	Volunteer activities	Standing – moderate (lifting 50 lbs., assembling at fast rate)

Source: Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR, Schmitz KH, Emplaincourt PO, Jacobs DR and Leon AS. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 2000: s498 - s516.

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