# COMPARISON OF STANDING BALANCE PERFORMANCE, PROPRIOCEPTION AND MUSCLE STRENGTH BETWEEN WOMEN WITH AND WITHOUT SYMPTOMATIC KNEE OSTEOARTHRITIS

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**NARAT PICHAIYONGVONGDEE: COMPARISON OF STANDING BALANCE PERFORMANCE, PROPRIOCEPTION AND MUSCLE STRENGTH BETWEEN WOMEN WITH AND WITHOUT SYMPTOMATIC KNEE OSTEOARTHRITIS. THESIS ADVISORS: CHANUT AKAMANON, B.Sc., M.A., PREECHA RUGPOLMUANG, MD., JITHVAREE KHAMDEJ, B.Sc., M.Sc. (PHYSIOTHERAPY). 178p. ISBN 974-664-726-1.**

Osteoarthritis (OA), a joint disease affecting articular cartilage and soft tissue, is frequently found at the knee joint of Thai adults. It was uncertain whether proprioceptive deficits and weakness of knee muscles coexisted with poor standing balance in OA patients. The purpose of this study was to compare balance control ability as measured by the SMART Balance Master System, knee proprioceptive sense and muscle strength of knee flexor and extensor groups between females with and without symptomatic knee osteoarthritis, aged range 40-60 years. Percentage of maximum stability and sway velocity from Sensory Organization Test (SOT), sway velocity from the center target test, on-axis velocity and directional control from rhythmic weight shift left/right and measured variables from the limits of stability test, error angle from the proprioception test and knee muscle strength values were compared between these two groups. Results of balance test revealed statistically significant differences ($p<0.05$) between these two groups on the percentage of maximum stability on an eyes closed condition and the sway velocity on eyes closed with sway-referenced support surface condition of SOT. For rhythmic weight shift left/right and limits of stability tests, significant differences were found only in the on-axis velocity of the fast speed pacing and reaction time to the right-back target, respectively. Results of proprioceptive and muscle strength tests revealed significant differences ($p<0.05$) on the error angle at 60 degrees of knee flexion, and knee flexor and extensor muscles, respectively. From these results, it was probable that proprioceptive deficits and weakness of knee muscles could lead to poorer balance control in the OA group when compared with the controls. It is recommended that physical therapists should be aware of these impairments and provide appropriate assessment and treatment accordingly.

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**ณรัตน์ พิชัยยงค์วงศ์ดี: เปรียบเทียบความสามารถในการทรงตัวในท่ายืน การรับสัมผัสตำแหน่งและความแข็งแรงของกล้ามเนื้อระหว่างผู้หญิงที่มีและไม่มีอาการข้อเข่าเสื่อม (COMPARISON OF STANDING BALANCE PERFORMANCE, PROPRIOCEPTION AND MUSCLE STRENGTH BETWEEN WOMEN WITH AND WITHOUT SYMPTOMATIC KNEE OSTEOARTHRITIS). คณะกรรมการควบคุมวิทยานิพนธ์: ชนัตถ์ อาคมานนท์, M.A. , ปรีชา รักษ์พลเมือง, พ.บ., จิตวรี ขำเดช, วท.ม. (กายภาพบำบัด). 178 หน้า ISBN 974-664-726-1**

ข้อเสื่อม เป็นโรคของข้อต่อซึ่งจะมีการทำลายของ กระดูกอ่อนที่ผิวข้อ และ เนื้อเยื่อต่างๆ บริเวณ รอบข้อ โดยจะพบได้บ่อยที่ข้อเข่าในคนไทยวัยผู้ใหญ่ ทั้งนี้ไม่มีข้อสรุปที่แน่ชัดว่า การบกพร่องของการรับสัมผัสตำแหน่งและ การอ่อนแรงของกล้ามเนื้อเกิดร่วมกับการทรงตัวที่ลดลงในคนที่มีข้อเข่าเสื่อม ดังนั้นการศึกษานี้ จึงมีวัตถุประสงค์เพื่อ เปรียบเทียบ ความสามารถ ในการทรงตัว โดยวัดจาก เครื่อง SMART Balance Master System การรับสัมผัสตำแหน่งของข้อเข่า และ ความแข็งแรงของกล้ามเนื้อทั้งในกลุ่มงอ และเหยียด ข้อเข่า ระหว่างผู้หญิงที่มี และไม่มี อาการข้อเข่าเสื่อม ที่มีช่วงอายุ 40-60 ปี ค่าตัวแปรที่ใช้ในการศึกษาครั้งนี้คือ % maximum stability และ sway velocity จาก Sensory Organization Test (SOT), sway velocity จาก center target test, on-axis velocity และ directional control จาก rhythmic weight shift left /right test, ตัวแปรต่างๆจาก limits of stability test , ค่าความผิดพลาดของการรับสัมผัสตำแหน่ง และ ค่าความแข็งแรงของกล้ามเนื้อ จะถูกนำมาเปรียบเทียบกันระหว่างทั้งสองกลุ่ม ผลการศึกษาพบว่ามีความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ $p < 0.05$ ระหว่างทั้งสองกลุ่มของ ตัวแปร % maximum stability ขณะ ยืนหลับตา และ ตัวแปร sway velocity ขณะหลับตาและมีการบิดเบือนของพื้นที่ยืนอยู่จากการทดสอบ SOT สำหรับ การทดสอบ rhythmic weight shift left/right และ limits of stability พบว่า มีความแตกต่างอย่างมีนัยสำคัญเพียง ตัวแปร on-axis velocity ขณะเคลื่อนจุดศูนย์ถ่วงของร่างกายด้วยความเร็วที่เร็วมาก และ ตัวแปร reaction time ขณะเคลื่อนจุดศูนย์ถ่วงของร่างกายไปยัง right-back target ตามลำดับ ส่วนค่าความผิดพลาดของการรับสัมผัสตำแหน่งและความแข็งแรงของกล้ามเนื้อ พบว่ามีความแตกต่างอย่างมีนัยสำคัญทางสถิติที่ มุมของการงอเข่า 60 องศาและ กำลังกล้ามเนื้อทั้งในกลุ่มเหยียด และงอเข่า ตามลำดับ จากผลการศึกษาดังกล่าว อาจเป็นไปได้ว่าการสูญเสียการรับสัมผัสตำแหน่งและการอ่อนแรงของกล้ามเนื้อ เป็นเหตุทำให้กลุ่มผู้ป่วยที่มีอาการข้อเข่าเสื่อมมีความสามารถในการทรงตัวลดลงเมื่อเปรียบเทียบกับกลุ่มควบคุม จึงตั้งข้อเสนอแนะว่านักกายภาพบำบัดควรทราบถึงความบกพร่องเหล่านี้ เพื่อทำการตรวจประเมินอย่างเหมาะสม และ ให้การรักษาที่สอดคล้องกับปัญหา

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# LIST OF ABBREVIATION

| | |
|---|---|
| cm. | centmetre (s) |
| deg/sec | degree per second |
| EC | eyes closed condition |
| EO | eyes open condition |
| ECSS | eyes closed with sway-referenced support surface |
| EOSS | eyes open with sway-referenced support surface |
| F/B | front/back |
| kg. | kilogram (s) |
| L/R | left/right |
| SD | standard deviation |
| SOT | Sensory Organization Test |
| SV | sway-referenced vision condition |
| SVSS | sway-referenced vision and support surface |

# CHAPTER I

# INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease that most commonly found in elderly people (1). It is a slowly progressive disease which affects the articular cartilage and soft tissues around the joint (2). The most frequently affected joints are many but those interfere with locomotion are the hip and knee joints. The early stage of osteoarthritis is asymptomatic but later it may contribute to pain, restriction of range of motion, deformity and disability (3). The radiographic characteristics at osteoarthritic joints show anatomical changes such as osteophyte and cyst formation, narrow joint space, loss of cartilage and subchondral sclerosis. Moreover, osteoarthritic patients can develop disability, abnormal gait and loss of stability eventually (2). Pain during weight bearing is a major symptom of osteoarthritis. Furthermore, locking and giving way in weight - bearing joint are consequences of progressive disease (1).

The etiology of osteoarthritis is still not clearly understood, although age, sex, obesity and degree of physical activity have been demonstrated to be contributing factors for development of osteoarthritis (4-8). In Felson's study, the prevalence of symptomatic osteoarthritis was reported to be increased with increasing age and the percent of symptomatic with radiographic changes in elderly was reported to be 31% in women and 21% in men (4). In addition, the knee osteoarthritis was found to be more common than other joints (hand or hip) and found more often in women than men (9).

In Thailand, the prevalence of osteoarthritis has been reported in many studies (10-11). For example, in Songklanakarin Hospital, (10) most patients were reported to develop their symptoms during 40-60 years old but those who came to see the doctor for medical treatment were around 46-65 years old, with the ratio of male to female equaled 1: 4 (10). For Siriraj Hospital, it was found that the patients'characteristics were similar to Songklanakarin Hospital in terms of sex and symptom but majority of the patients who came to see the doctor for medical treatment were between 50-60 years old (11).

Wollacott (12) reviewed the changing of posture and movement in aging. She found that the decline of physiological function in terms of motor, sensory and central processing were related with increasing age. Several studies (13-17) reported the components declining in osteoarthritic patients as related to postural control to be muscle strength, flexibility and proprioceptive sense. Messier et al (17) reported that patients with symptomatic osteoarthritis of the knee were poor in flexibility, gait and strength of the knee muscles than control group. Other studies (13-16) found that osteoarthritic patients demonstrated poorer proprioception than normal subjects. Some investigators perceived that proprioceptive impairment may be the result of aging and that OA may not be the cause of poor proprioception (14-15). Moreover, the conclusion that all patients with OA have proprioceptive impairment remains unclear and it is inconclusive whether this contributes to the loss of balance in osteoarthritic patients or not. Furthermore, other clinical findings such as pain and stiffness can lead to difficulty in performing task that result in inability to live independently (10). The weakness of muscles found in OA may not be caused by the disease itself but may be due to the decrease in physical activity as a result of joint dysfunction. Such impairments in OA may lead to poor balance because both strength and proprioception are important components for controlling balance.

Jones et al in 1995 (18) used a sway meter for investigating postural sway in osteoarthritic patients. The quadriceps strength was evaluated by a spring gauge. They found that patients had reduced quadriceps strength and increased body sway. These results may be associated with an increase in the risk of falling. In another study, Wegener et al in 1997 (19) studied the static and dynamic balance in patients with bilateral osteoarthritic knees by using the Balance System™ (Chattecx Corporation, Chatanooga, TN). The balance was tested under various conditions such as eyes open, eyes closed and platform motions. From this study, they found that osteoarthritic patients had greater postural sway than the control group. This implied that balance control of the osteoarthritic group was worse than normal, however, the mechanism involved has not been clarified. The investigators assumed that the decline in muscle strength, proprioceptive impairment and joint edema might be responsible for the loss of balance in osteoarthritic patients. In another study, Hurley et al in 1997 (20) found that osteoarthritic patients were less stable than controls when measured by a custom made swaymeter. However, the difference between these two groups did not reach a significant level.

The SMART Balance Master System is an instrument for measuring the ability to use sensory and motor components in balance control. The sensory component of balance control can be assessed by using the mode of sensory organization test (SOT). Particularly, SOT is designed to assess the patient 's ability to effectively use visual, vestibular and somatosensory inputs to maintain postural stability and to select the input providing the most functionally appropriate orientation information under a variety of conditions (21). The assessment of the ability to use motor component in balance control is assessed by the test of controlling center target, rhythmic weight shift, and limits of stability tests. Therefore, the SMART Balance Master System can provide more challenging conditions in testing balance control and that not only the ability to use sensory but also the ability to control movement under various testing conditions can be investigated.

The study on balance characteristics of the knee osteoarthritic patients is very limited and two studies (18-19) thus far reported the evidence of balance impairment in this type of patient while one study did not support such findings (20). It is interesting to clarify whether this balance impairment commonly coexists with knee osteoarthritis in most patients. Furthermore, the sensory and motor components contributing to balance control should be investigated in order to elucidate the cause of balance impairment if these can be found in the knee osteoarthritic patients. The testing of sensory and motor contributions to balance can be made possible through the use of the SMART Balance Master System. The present study attempts to investigate not only the balance characteristics but also the proprioceptive sense and muscle strength around the knee joints of the osteoarthritic patients in order to determine if any relationships exist among these measured variables.

## 1.1 Purposes of the Study

### 1.1.1 General Objective

The objective of this study was to compare balance control ability as measured by the SMART Balance Master System, knee proprioceptive sense and muscle strength of knee flexor and extensor groups between females with (OA group or OA patients group) and without (control group) symptomatic knee osteoarthritis. The age range of both groups were between 40 to 60 years.

### 1.1.2 Specific Objective

1.To compare the balance performances obtained from the SOT, center target, rhythmic weight shift, and limits of stability tests between the control group and knee osteoarthritic group.

2.To compare the error angle obtained from the knee proprioception test between the control group and the knee osteoarthritic group.

3. To compare the muscle strength of the knee flexor and extensor groups between the control group and the knee osteoarthritic group.

## 1.2 Parameters of the Study

1.The SOT

- Percentage of maximum stability (% maximum stability or Equilibrium score): the amount of stability or absence, which 100% is most stable and 0% is fall or least stable.

-Sway velocity (degree/second): the average velocity of COG movement in degree per second.

2.Center Target Test

-Sway velocity (degree/second): the mean sway velocity of the center of gravity (COG).

3. Rhythmic Weight Shift: Left- Right and Front-Back.

-On axis velocity (degree/second) is the average velocity of the COG movement along the specified movement direction.

-Directional control (%) is the average velocity of an off- axis COG motion expressed as a percentage of the average on-axis velocity.

4. Limits of stability

-Reaction time (second): the time in seconds between the command (blue circle appears at peripheral target) to move and the point at which the patients first initiates movement.

-Movement velocity (degree/second): the average velocity of COG movement in degree per second measured between the time the patient reaches 5% of the "End Point" distance until 95% of the "End Point" distance is achieved.

-End point excursion (%): the distance traveled by the COG on the primary attempt to reach the target. Distance is expressed as a percentage of the theoretical maximum LOS distance. The first movement is completed when progress towards the target ceases.

-Maximum excursion (%): the furthest distance traveled by the COG during the trial. The maximum excursion may be larger than the End point excursion if the patient makes additional, corrective attempts to reach the target after the primary attempt has fallen short.

-Directional control (%): a comparison of the amount of movement in the intended direction (toward the target) to the amount of extraneous movement (away from the target), calculated by subtracting the off-axis distance from the on-axis distance, and expressing the difference as a percentage of the actual on-axis distance. A Directional control score of 100% indicates a perfect straight line movement from the center to the End point defined above, while lower percentages indicate larger off-axis movement.

5. Muscle strength: Isometric strength of the knee muscle is measured in kilograms.

6. Error angle is the difference between the tested angle and the reproduced angle measured in degrees.

## 1.3 Scope of the Study

This study focused on determining the ability to use sensory and motor components for controlling balance, isometric strength and proprioceptive sense of the knee in females with and without symptomatic knee osteoarthritis who ranged in ages from 40-60 years.

## 1.4 Hypotheses of the Study

1. There would be a significant difference in balance performance between knee osteoarthritic group and control group.

2. There would be a significant difference in error angle obtained from the knee proprioception test between knee osteoarthritic group and control group.

3. There would be a significant difference in muscle strength of the knee between knee osteoarthritic group and control group.

## 1.5 Advantages of the Study

1. The data on balance performance measured by the SMART Balance Master, muscle strength and proprioception in the knee osteoarthritic and normal control groups can be used as a referenced database for Thai people.

2. Objective measurement of balance, muscle strength and proprioception used in this study may help to improve the clinical assessment protocol for osteoarthritic patients.

3. Comprehensive assessment of balance function can be used as guideline for the plan of treatment in knee osteoarthritic patients.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Definition of Osteoarthritis

According to Salter in 1983 (22), the term Osteoarthritis is synonymous with the following terms: degenerative joint disease, osteoarthrosis, degenerative arthritis, senescent arthritis, and hypertrophic arthritis. Later in 1990, Dieppe (2) offered the concise definition of osteoarthritis as " an abnormal state of a synovial joint" (p.262). However, Huch et al (23) cited Goldberg and Kuettner in 1995 and further clarified the pathogenesis of osteoarthritis disease as " a result of both mechanical and biological events that destabilize the normal coupling of degradation and synthesis of articular cartilage chrondrocytes and extracellular matrix, and subchondral bone" (p.667). This degenerative process is believed to be initiated by multiple factors including genetic, developmental, metabolic and traumatic which involved all types of tissues of the diathrodial joint (23). The disease is manifested by the changes in morphology, biochemistry, and biomechanics of both cells and matrix which leads to "a softening, fibrillation, ulceration, loss of articular cartilage, sclerosis and eburnation of subchondral bone, osteophytes, and subchondral cysts" (Huch et al,1997, p.667 ).

Osteoarthritis is characterized clinically as joint pain, tenderness, restriction of joint motion, crepitus, occasional effusion and non-systemic inflammation (23).

According to Creamer and Hochberg (24), the most important clinical symptom of OA is pain, which is caused by the inflammation of synovial membrane, joint capsule distension, periarticular ligaments damage, periarticular muscle spasm, periosteum elevation by osteophytes, and subchondral bone thickness.

Osteoarthritis can be classified into two subgroups as follows (25,26):

1.Primary or idiopathic osteoarthritis which has unknown prior event or disease with relation to the osteoarthritis. Genetic and hormone may produce the symptom.

2. Secondary osteoarthritis is caused by associated condition or disease such as inflammatory joint disease, overuse of the joint, traumatic lesions, metabolic processes weakening the cartilage, and congenital deformities.

## 2.2 Factors Influencing Osteoarthritis

### 2.2.1 Age and gender

Age is one of the predominant factors for development of osteoarthritis. There are several published papers that reported the high incidence of osteoarthritis in elderly people (4,5,6,7). Gender is another risk factor that influence on the prevalence of osteoarthritic symptom (4).

Forman and coworkers in 1983 (5) evaluated the sign and symptoms suggestive of osteoarthritis of the knee in 682 elderly people aged 60 years and older. These elderly were examined about pain, crepitus and instability by the rheumatologist.

The results showed that the symptom of people among 60 years and older did not increase with age.

Limpaphayom and coworkers in 1983 (6) studied the change of the knee joint with increasing age in Thai population in order to report the roentgenographic changes such as joint space and osteophyte. Subjects in this study were divided into two groups. Group 1 included 160 people without previous knee injury or knee pain for the previous 10 years and came to see the physician because of problems besides the lower extremities. Group 2 included 157 patients diagnosed as degenerative joint diseases of the knee. All participants were evaluated by x-ray. The results showed that joint space tended to decrease as the age of patient increased while size of osteophyte became bigger. The osteophyte in group 2 was larger than group 1 in all age groups.

Felson and coworker in 1987 (4) studied the prevalence of osteoarthritis of the knee, medical history, physical examination and anteroposterior radiograph of the knee. Age of subjects were between 63 to 94 years. They found that the prevalence of knee osteoarthritis increased with age among person over 65 years old. Furthermore, they found that women had more symptomatic osteoarthritis than men. In addition, Felson et al in 1995 (27) studied the incidence and natural history of knee osteoarthritis in the elderly by using radiography. They found that incidence rate in women were 1.7 times higher than in men and progression of disease occurred slightly more often in women; however, rates of progression did not vary by age in this sample. Among women, the incident rate of radiographic osteoarthritis was approximately 2% per year, 1% per year developed symptomatic knee osteoarthritis, and about 4% per year experienced progressive osteoarthritis.

Later, Kirkwood in 1997 (7) found the relationship between osteoarthritis and aging. Osteoarthritis is a time-dependent disorder while age raising. Moreover, many risk factors such as genetic also contribute to osteoarthritis.

**2.2.2 Obesity**

Davis et al in 1990 (28) provided the evidence that obesity was associated with osteoarthritic knee. They examined 3,905 adults aged between 45 to 74 years by radiographic examination. In addition, anthropometric measurements of height, weight, triceps skinfold, subscapular skinfold, upper arm girth, bitrochanteric breadth and elbow breadth were collected for analysis. The obesity was defined by measure of body-mass index (BMI). The results of this study showed that women with knee osteoarthritis had significantly larger mean values for anthropometric measures, including BMI, than women without knee osteoarthritis.

Spector and coworkers in 1994 (29) studied the incidence and progression of osteoarthritis in women with unilateral knee disease. Fifty eight women with radiographic diagnosis of knee osteoarthritis aged between 45-64 years were recruited from a general population. After 24 months, all subjects were followed up for examination by x-ray. When comparing the radiographic films before and after 24 months, 34% of women developed the incidence of osteoarthritis in the contralateral knee and 22.4% of women progressed radiologically in the index joint. In addition, 47% of women in the top BMI developed osteoarthritis.

Felson in 1995 (30) reviewed the relation of osteoarthritis and overweight person. Most studies agreed that overweight increased the amount of load across a joint and this could induce cartilage breakdown, which led to OA. Persons who are overweight may have increased the rate of cartilage breakdown and lead to OA. Moreover, adipose tissue may be metabolically active, especially in post-menopausal women, who are at highest risk of OA. Overweight is an important risk factor of OA in the knees, hips and hand. Furthermore, weight loss may prevent OA, especially in the knees.

Hochberg and colleagues (8) examined the association of body weight, body fatness, and body fat distribution with osteoarthritis of the knee. The participants who aged 40 and over were evaluated for OA by x-ray. Three measures; BMI, waist-hip ratio, and percent of body fat were recorded in each subject. The results showed that BMI, waist-hip ratio, and percent of body fat were related to increasing age and the OA knee had highest BMI.

**2.2.3 Physical activity**

Kohastsu and coworker in 1989 (31) evaluated the role of physical activity, obesity and history of significant knee injury on development of severe osteoarthritis of the knee. The osteoarthritic group and control group were compared in the part of

BMI, age, work level and history of knee injury. They found that BMI of osteoarthritic group was higher than control group. Moreover, the level of physical activity at work of osteoarthritic cases was higher than control. The percent of history of knee injury in osteoarthritic group was reported to be higher than control group. Process of wear and tear in osteoarthritis such as obesity, heavy work and prior knee injury were linked to mechanical factors. These factors can lead to the development of osteoarthritic symptom.

**2.2.4 Proprioception in osteoarthritis**

Barrete et al in 1991 (16) measured joint position sense in the knee. Eighty-one normal and forty-five osteoarthritic knees were examined by a new method which used a leg supported splint. Each subject was moved passively to 10 different pre determined positions of flexion and reproduced to the previous angle. The age of patients ranged from 16 to 86 years; 51% were male and 49% were female. The patients were divided in to 3 groups: 1) normal subjects of various ages 2) osteoarthritic patients 3) patients with total knee replacement. The quality of joint position sense was compared among these three groups with and without elastic bandage wearing. Patients with osteoarthritis showed poorer joint position sense than normal group with similar age. The replaced knee group had better joint position sense than osteoarthritic group. An elastic bandage around the knee improved the performance of patients with poor joint position sense.

Sharma and colleagues in 1997 (15) compared the proprioception between unilateral osteoarthritic patients and elderly controls. Twenty-eight knee osteoarthritic patients and control group were assessed on proprioception by an apparatus (consisted of a stepper motor, a transmission, linkage system, seat adjustment components and computer) that passively moved the knee at 0.3 ° per second. Subjects pushed hand-held button after definite detection of knee joint position change. The results showed that unilateral osteoarthritic patients had worse proprioception than the elderly controls. The proprioception of unilateral osteoarthritic patients was not different between knees.

Pai et al in 1997 (13) investigated the relationship between joint protective mechanisms and the progression of knee osteoarthritis. Subjects were 30 patients with bilateral knee osteoarthritis and 29 elderly control. Threshold for detection of knee displacement was an assessing proprioception method. An apparatus consisted of a stepper motor, transmission and linkage system, seating adjustment components and angular displacement and force transducers. Both legs were moved to the starting position of 45° knee flexion at 0.3 degree/second. The relation between age and joint position sense indicated that proprioceptive accuracy decline with age. Moreover, proprioceptive accuracy is decreased in osteoarthritic knee when compared with the knee of age match controls. In addition, the result indicated that patients who had greater disease related function limitation also had worse joint position sense.

Hurley and coworkers (20) studied the component of sensorimotor system that help maintain balance and perform a smooth gait in patients with knee osteoarthritis. The participants were assessed on quadriceps function, postural stability, and functional performance. Comparison with control group, they found that the osteoarthritic patients had weaker quadriceps than control group. Moreover, the mean error of joint position sense was greater than the control subjects. Regarding postural stability for any of stance condition, there was no difference between the patients who could maintain stance condition and the control subjects. When removed the visual field or reduced base of support, the postural stability in both groups were decreased. For functional performance, the patients were slower in all ADL testing than the control subjects. In conclusion, patients with knee osteoarthritis demonstrated quadriceps sensorimotor deficits, some of which related to decreased postural stability and functional performance.

**2.2.5 Muscle strength in osteoarthritis**

Tan et al in 1995 (32) determined the relationships of torque and torque ratio of knee flexor to extensor muscles developed as a result of joint dysfunction and disuse in knee OA. The subjects for this study consisted of two groups of patients (GroupA and GroupB) and one group of 30 healthy subjects (GroupC). The first group (GroupA) was composed of 30 patients with clinical and radiographic finding of knee OA, whereas the second group (GroupB) was composed of 30 patients with knee pain and without radiographic finding of knee OA. The maximum peak torque (MPT) and ratio of hamstrings to quadriceps muscles (H/Q ratio) of isokinetic and isometric were measured by an isokinetic dynamometer. The isokinetic test of knee flexor and extensor were done at right leg dominant and performed at 60°/s and 180°/s. The isometric tests were performed at 30° and 60° of knee flexion. These results revealed isokinetic and isometric MPT loss of knee extensor and flexor in both patients groups. The H/Q ratio of isokinetic and isometric showed significant difference between groups only at 180°/s. This may be related to equal strength loss of knee extensors and flexors in patients with knee OA. This study concluded that the strengthening exercise of hamstring muscles is as important as quadriceps strengthening for OA knee patients.

Slemenda et al in 1997 (33) determined the association between quadriceps weakness and osteoarthritis of the knee. The sample of 462 elderly persons were 65 years and over. Patients were evaluated for osteoarthritis by x-ray and for knee pain and function by the Western Ontario and McMaster Universities Arthritis Index. The strength of each leg was evaluated by isokinetic dynamometer. The test was done 3 trials for flexion and extension at both 60°/s and 120°/s. Women with osteoarthritis, either with pain or no pain, were weaker in left knee extensor muscle than asymptomatic women with normal knee. In conclusion, quadriceps weakness may be present in patients with osteoarthritis and may not result from knee pain or muscle atrophy. The author suggested that the weakness might be the result of muscle dysfunction. The finding that osteoarthritic patient had weaker quadriceps than control groups were also reported by Hurley et al (20) as mentioned in the previous section.

In 1997, Fisher and coworker (34) studied muscle function in patients with osteoarthritis. Forty-five men and 45 women were diagnosed with osteoarthritis and confirmed by x-ray. The control group (41 males and 63 females) did not have symptomatic osteoarthritis or any medical or functional limitations. Maximum isometric strength, endurance and angular velocity of quadriceps and hamstrings muscle were measured for all subjects. It was found that the maximum isometric strength of quadriceps and hamstrings in the OA men was significantly greater than that of the OA women. Moreover, the maximum isometric torque for knee extension in the control group was higher than the OA group. With respect to the average value for quadriceps endurance, the OA group was lower than control group. Regarding walking time, there was no significant difference between men and women in OA group. Concerning the data for hip maximum angular velocity, the OA group was significantly slower than control group. In conclusion, the study revealed that the OA group had reduction in functional capacity and muscle function.

Recently, Hurley in 1999 (35) reviewed the role of muscle weakness in OA. The author hypothesized that motor and sensory dysfunction of muscle may be important factors in the pathogenesis of articular damage and are not a consequence of joint damage. A new paradigm (Figure 2.1) was constructed for describing the relationship between muscle sensorimotor dysfunction, joint damage and disability in OA. The sensorimotor dysfunction of periarticular muscle is evident in the majority of patients with OA and contributes to pain and disability. Muscle dysfunction will not be the most important factor in OA and may only have a minor influence in some condition, but is an important factor in the pathogenesis and progression of OA.

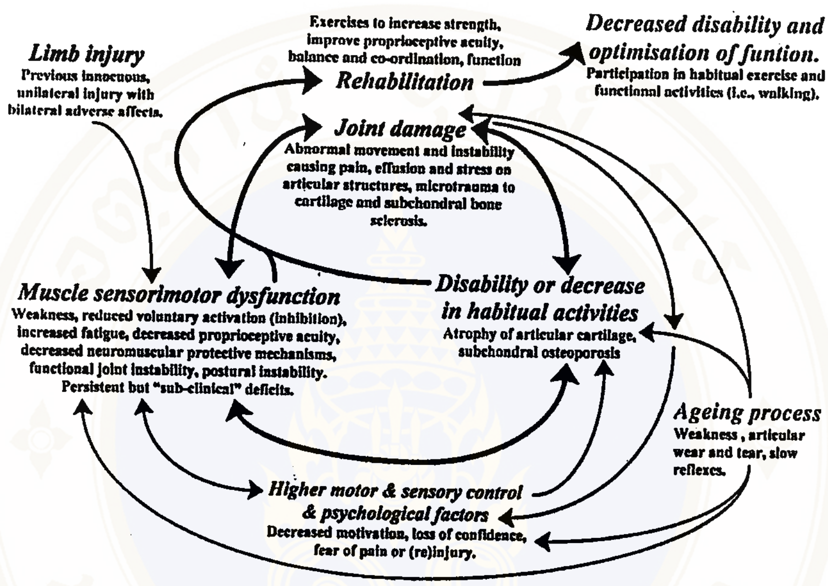



**Figure 2.1** A new paradigm for pathogenesis of OA (source: Hurley MV. The role of muscle weakness in the pathogenesis of osteoarthritis. Rheum Dis Clin North America 1999;25(2):283-98 )

## 2.3 Balance

Balance is closely related to functional status. According to Berg in 1989 (36), functional status of balance included the following: maintenance of posture (standing, sitting); controlled movement of the center of mass such as transfers, turning or reaching and response to destabilizing force such as trips or slips to maintain or return to center of mass to the area over the base of support.

The term "Balance" has been defined differently in the literature. Ragnarsdottir (37) cited Gally and Foster in defining balance as "a state in which the body is in equilibrium". Coogler in 1992 (38) contended that "balance is generally viewed as the ability to maintain the body's center of gravity (COG) over the base of support (BOS)" (p.54). In 1995, Winter (39) maintained that "balance is a generic term to describe the dynamics of body posture to prevent falling. It's related to the initiated forces acting on the body and the characteristics of body segment".

According to Nashner in1994 (21), postural stability was described as the maintenance of stability with the feet in place in which the body's center of gravity (COG) must be positioned vertically over the base of support.

Later, Hageman and colleagues in 1995 (40) used the term postural control and defined that "postural control is the ability to maintain the body's center of gravity over the base of support during quiet standing and movement"(p.961).

### 2.3.1 Static and dynamic balance

In clinical setting, balance can be classified as the static and dynamic balance. Wade and Jones (41) defined static balance as an individual's stationary position in quiet upright stance and dynamic balance as task such as locomoting across a balance beam or walking on a tightrope. On the other hand, Berg in 1989 (36) explained that the definition of static balance widely used at present is incomplete as it ignores the minor automatic adjustments that occur when a body maintains a position. The term dynamic is too general, covering a broad spectrum of situations. In addition, maintenance of a position, postural adjustment to voluntary movements, and reaction to external disturbance were described as functional states of balance maintenance. In 1996, Ragnarsdottir (37) suggested that the term static balance is imprecise because it does not take normal postural sway into account, which is considered as part of standing balance. In addition, the term of dynamic balance has been criticized the same as Berg in 1989.

Wollacott and Tang (42) further delinated the static balance as the base of support (BOS) remains stationary and only the body center of mass (COM) moves. For the dynamic balance, both the BOS and COM are moving and the COM is never kept within the BOS during single-limb support periods.

**2.3.2 Center of gravity**

Balance requires that the position of body's center of gravity must be maintained over the base of support. In natural standing, the center of gravity is located in the midline of the sacral region (36, 38) with its alignment placed above the center of base of support (21). If the movement of COG is beyond the base of support or over the limits of stability, a fall or step occurs (36). The SMART Balance Master Operator's Manual (43) defined the position of COG is approximately 55% of total height and 14% of foot length in front of the medial malleolus bone in the ankle joint. The line of COG is inclined 2.3 degree from the vertical line passing through the ankle joint (Figure 2.2)

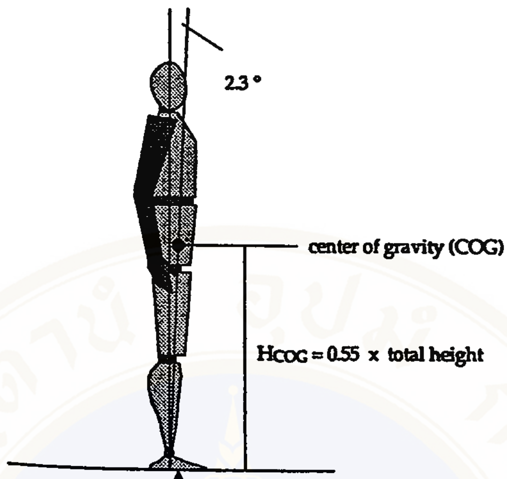



**Figure 2.2** The Center of Gravity Alignment (Source: The introduction of the PRO and SMART Balance Master®. p. B-5)

**2.3.3 Base of support and limits of stability**

The base of support for standing is defined as the area contained within the perimeter of contact between the surface and the two feet. The base of support area is nearly square when the feet placed apart during standing (21). The limits of stability (LOS) is defined as the largest possible COG sway angle as a function of sway direction from the center position without loss of balance. The LOS depends on the distance between feet and base of support (38). The LOS can be described as an ellipse, with an anteroposterior limit to be approximately 12.5 degree (Figure 2.3). The lateral LOS depended on the height of person and the area between feet (38,21). The SMART Balance Master Operator's Manual (43) defined the limits of stability (LOS) as maximum distance a person can lean in a given direction (measured as angular distance from vertical) without losing balance

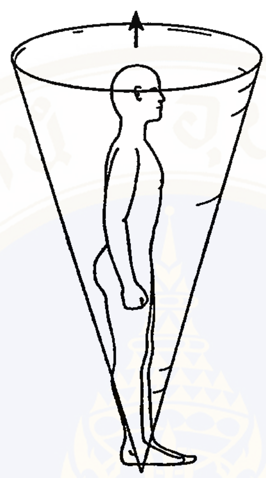


**Figure 2.3** The Limits of Stability (Source: Nashner L. Evaluation of postural stability, movement, and control. In:Hasson SM, editor. Clinical exercise physiology. St.Louis: Mosby-Year Book, 1994;199-11)

**2.3.4 Postural sway**

The SMART Balance Master Operator's Manual in 1994 (43) described postural sway as the ongoing body movements while a person maintains on upright posture. According to Slobounov and coworkers (44), postural sway is defined as the motion of the center of gravity. Hughes et al in 1996 (45) suggested that postural sway could be used as a measure of balance in which an increase in postural sway was shown to be associated with sensorimotor deficits.

**2.3.5 Loss of balance**

Whipple et al in 1993 (46) defined loss of balance as an event in which a subject exceeded the limits of stability and took steps, had to be restrained from falling by the operator, or made hand contact with the walls of the visual surround. Wolfson and coworkers in 1992 (47) observed that loss of balance could occur during the SOT test or Motor Coordination Test (MCT test) when a subject's sway exceeded the limits of stability which required a step and/or support by the examiner.

**2.3.6 Mechanism of balance**

Balance is generally viewed as the ability to maintain the body's center of gravity (COG) over the base of support (BOS). Balance requires the ability to make an appropriate musculoskeletal response within the biomechanical constraints of body and the physical constraints of the environment (38). The limitations of range of motion and muscle strength and endurance can affect the maintenance of the equilibrium position and the available movement strategies for achieving equilibrium (48). The senses that perceive the orientation in relation to gravity, support surface and surrounding objects require the combination of information from the vestibular system of the inner ear, somatosensory system, and vision (38).

The visions rely on the position and motion of the head with respect to the surrounding objects. Visual input is an important source of information for postural control, but sometime the visual information may be misinterpreted by the brain. The visual system has difficulty distinguishing between object motion, refered to as exocentric motion, and self-motion, refered to as egocentric motion (48).

The somatosensory system provides the information about the relationship of the body to the support surface (38). Somatosensory receptors included joint and muscle proprioceptors, cutaneous and pressure receptors (48).

The vestibular input provides a gravitational reference for determining the orientation of the head in space (38). The vestibular system is composed of the semicircular canals that sense angular acceleration of head and are sensitive to fast head movement whereas the otoliths signal linear position and respond to the slow head movements (48).

These three sensory systems require more than simply combination of them since the input from any of the three may be inaccurate for signaling body orientation. The brain must select the accurate inputs and ignore the inaccurate one. This process is called "sensory organization".

**Sensory organization**

The maintenance of the COG over the base of support involves integration of visual, vestibular and somatosensory system inputs. Vision provides information on orientation of the head in relation to surrounding objects, while somatosensory provides the information from the support surface. On the other hand, the vestibular system references the gravitational and orientation of the head in space. In situation with perturbation of sensory inputs, the CNS must select and rely on the orientationally accurate sensory input to maintain balance (49).

The musculoskeletal responses were made appropriated in order to remain in balance. The ability to coordinate and control muscles and joints properly must compromise postural stability. Moreover, these patterns of movement have been described for correction of sway in normal: ankle, hip and stepping strategy. These strategies are selected based on the support surface configuration and the size and speed of the COG change (48).

**Postural movement strategies**

The characteristic patterns of muscle activity for maintaining posture during surface being disturbed is called muscle synergies, which is defined as the functional coupling of groups of muscle and related with postural movement strategies. These patterns are refered as the ankle, hip and stepping strategies (48).

Ankle strategy is the first pattern for controlling balance during small shifts or perturbation of COG (48). The ankle strategy is used when standing on firm, large surface and the COG movement is relatively small and slow (38). The ankle strategy brings the COM (center of mass) back to a position of stability through body movement centered primarily about the ankle joint (48). The movement at ankle joint was completed by contraction of ankle joint muscle to create torque about ankle joint.

Whereas, the thigh and lower trunk muscles contracted for resisting the destabilization of these proximal joints (21).

Hip strategy is a secondary movement pattern for maintaining balance. This strategy is needed when standing on an unstable or small surface and the movements are large and fast (38). This strategy controls the COM to a position of stability through the motion of hip joints. The trunk moving in one direction generates an opposite horizontal (shear) reaction force against the support surface. The knee joint tends to resist for destabilizing by coordination of muscular actions about ankle, knee and hip joints (21).

When a postural perturbation is strong enough to displace the COM outside the base of support, the stepping strategy is used to bring the COM back into base of support (21). The stepping strategy is necessary when neither the ankle nor the hip strategy can retrieve the COG; therefore, new limits must be established by creating a new BOS (38). The stepping strategy is effective for very large and fast perturbations for which the other strategies are insufficient (48).

## 2.4 Factors Influencing Balance

### 2.4.1 Age and gender

Pyykko and coworkers in 1990 (50) evaluated the postural control mechanism of elderly subjects. Thirteen women and four men aged between 85 years and over were included in this study. The 100 control subjects were between 50 to 60 years.

Postural control in each subject was assessed by a force platform with a strain gauge. The postural perturbation was induced by vibration at the calf muscle in each leg. The test was done in four conditions: 1) on a firm surface with visual control 2) on a firm surface without visual control 3) on a foam plastic with visual control 4) on a foam plastic without visual control. This study showed that postural control of the elderly subjects was impaired when they stood on a firm surface without visual control. On the foam surface with and without vision, the elderly subjects demonstrated higher sway velocities than the control. In both groups, men tended to have higher sway velocities than women. Based on the results of this study, visual system was found to be predominant for controlling balance in the elderly subjects.

Hytonen et al in 1993 (51) measured body sway in 212 healthy volunteers aged between 6 to 90 years. The subjects were divided into six groups: 1) 6-15 (n=18) 2) 16-30 (n=45) 3) 31-45 (n=18) 4) 46-60 (n=100) 5) 61-75 (n=16) and 6) 76-90(n=15). Each subject was tested during standing with arms cross over the chest on force platform. The protocol was made with eyes open and eyes closed on both firm and foam plastic surface. During each test, the pressoreceptor system was tested by covering the force platform with foam plastic. The proprioception system was tested by vibration on calf muscle. This study indicated that age between 30 to 60 years was most stable in equilibrium. Visual information is important for controlling balance in upright position in elderly subjects while proprioceptive sense and pressoreceptor were found to be important for postural control in children.

Wolfson and associates in 1994 (52) measured the effect of limited sensory input and support surface movement for detecting gender differences in balance. Subjects aged 60 years and older were recruited for the study. They were tested on a dynamic posturography platform (EquiTest, Clackamas, OR). The protocol consisted of Sensory Organization Test (SOT) and the Motor Coordination Test (MCT). Each condition was repeated three times. The parameters used in this study were Equilibrium Quotient (EQ), Balance Strategy Score (BSS), Loss of Balance (LOB), Latency, and Angular movement. In SOT, EQ of females were worse than male in condition 6. LOB of females were worse than male in conditions 4-6. There was no consistent gender-base pattern of change in BSS among three trials. In MCT, the response latencies of male were longer than female for both forward and backward translation but this gender difference (5-6 milliseconds) is consistent with greater height of males and longer neural transmission path. The Angular Momentum (AM) in male showed large amplitude during forward translation, indicating male to be more quickly in generating force to counterbalance backwards sway momentum. This study suggested that women performed worse on balance than men.

Hageman et al (40) determined the effect of age and gender on functional reach and five Balance Master measures. Men and women within the age ranges of 20 to 35 years and 60 to 75 years participated in the testing. Each age group consisted of 12 females and 12 males. The instrument used for measuring balance was a Balance Master. This system was composed of two forceplates that connected to an IBM 386 computer with a monitor. The data on standing body sway area with eyes open, eyes closed and visual feedback were collected. Then, movement time and path length of the subject's center of gravity were assessed. The functional reach was measured as the maximum distance a subject could reach during fixed base of support in standing. The findings revealed that postural sway increased with age and with eyes closed. The movement time in older adults were found to be slower than the younger adults. Men showed larger values of functional reach than women but gender effect was not significant when the values were normalized to height.

La Pier and associates in 1997 (53) compared postural sway in static and dynamic balance between older men and women. Both groups were ranging in ages from 55 to 69 years. The Balance Master was used for testing. Rhomberg tests with eyes open or closed for 60 seconds were used for screening subjects before inclusion into the study. The static COP (center of pressure) excursion was tested during quiet standing with eyes open and eyes closed. The dynamic COP excursion was tested by throwing a physioball overhead with both hands. A total maximum COG (center of gravity) excursion was calculated as the sum of the maximal AP (anteroposterior) and ML (medial-lateral) excursion. The results showed that there was no significant difference in the absolute maximum COG excursion between men and women during both static and dynamic conditions. The women had greater AP and total maximum COG excursion normalized by height than men during dynamic stance. These results suggested that older women showed relatively greater dynamic postural sway than men.

**2.4.2 Sensory and motor system**

**2.4.2.1 Sensory system**

**Somatosensory system**

In 1993, Duncan et al (54) assessed the relationship between physiological components of balance and mobility in elderly men (70 to 104 years old) who were free from any significant diseases. All subjects were evaluated on mobility and sensory systems such as vision, vibration and proprioception. The results of the study showed a decline in functional mobility in elders. The declining of mobility may be due to the deficits of multiple components of balance control not only one component.

Nardone et al in 1995 (55) studied the response of leg muscle during standing purturbation in 75 subjects. All participants performed standing on a movable hydraulic platform. EMG of soleus and tibialis anterior were recorded during stance with eyes open and eyes closed. The relationship between soleus responses and postural sway with eyes open or closed depended on the contribution of visual and somatosensory inputs in the control of body sway.

**Visual system**

Stones and Kozma (56) evaluated balance in people with visual impairment and blindness. The balance was tested during one leg stance with eyes open and supporting leg alternating between right and left. Subjects with minimal visual impairment were tested during eyes closed. There was no significant difference between subjects with congenital and acquired blindness. However, balance times in minimal sight were longer than fully blind group. The finding supported that visual input was an important source of feedback for balance skills.

In 1993, Whipple (46) compared body sway and loss of balance in elderly person on three different visual inputs (eyes open, eyes closed, and inaccurate) during standing on an unstable surface. A computerized dynamic posturography platform was used for SOT in six conditions. The elderly demonstrated more sway than younger group. SOT condition 5 (sway-surface with eyes closed) and SOT condition 6 (inaccurate vision with sway-surface) showed greatest differences between groups. The effect of vision appeared to differ as a function of whether the support surface was fixed or sway – referenced.

**Vestibular system**

Wolfson et al in1992 (47) used dynamic posturography for testing balance in 234 community-dewelling elderly subjects (mean age 76 ± 5 years). The data showed that older group had greater sway than young controls on conditions five and six of SOT (sway-surface with eyes closed, sway – referenced vison and surface). This implied that the decrements in older persons indicated a diminished capacity to process conflicting sensory input as well as a possible narrowing of the limit of stability. Moreover, these decrements were believed to be the result of biomechanical or central processing changes as opposed to diminished sensory or vestibular input.

Fife and Baloh in 1993 (57) investigated the factors influencing disequilibrium with unknown cause in 26 older people and compared with 26 age-matched controls. The vestibulo-ocular reflex was tested by sinusoidal rotation in a motorized chair at a frequency of 0.05 Hz. The results suggested that loss of vestibular function led to disequilibrium in many older people. It implied that the vestibular function declined with age.

**Motor system**

Lord et al in 1993 (58) studied balance, reaction time and muscle strength between women with and without exercising (aged 57 to 75 years). When compared with 21 nonexercising women, the exercisers performed better in all tests and had lower mass index scores. These results suggested that exercise may lead to improving a number of sensori-motor that contributes to stability and exercise may help to prevent falls in older women.

Wolfson et al in 1995 (59) studied the effects of lower extremity strength as well as gait and balance on the occurrence of falls in nursing home residents. The instrument consisted of the EquiTest balance platform for SOT and Cybex 340 Isokinetic Dynamometer for testing the strength of flexion and extension at ankle, hip, and knee. The occurrence of loss of balance during SOT was correlated with diminished lower extremity strength. These results indicated a strong relationship of lower extremity strength to balance and gait.

**2.4.3 Disease**

Simoneau et al (60) found the evidence that sensory ataxia due to diabetic neuropathy may effect postural control. Fifty-one subjects, divided into three groups (n=17 per group), participated in the study. Group1 consisted of subjects who had diabetes and neuropathy (DM-NP); Group 2, subjects affected with diabetes without neuropathy (DM-nonNP); and Group 3, subjects were free from both diabetes and neuropathy (nonDM). Postural stability was tested in four conditions on a force platform: eyes open/ head straight, eyes open/ head back, eyes close/ head straight, and eyes closed/ head back. The results showed that DM-NP subjects were less stable than DM-nonNP and nonDM subjects. So, the loss of sensory perception could lead to postural instability in diabetic patients.

## 2.5 Balance Performance in Musculoskeletal Disorders

In 1991, Nies and Sinnott (61) investigated balance responses in middle age adults. Twenty subjects with low back pain (LBP) and twenty-five with healthy back (HB) were recruited for the study. The sensory conditions were measured with computerized forceplate stabilometry. Subjects with low back pain showed significantly greater postural sway and center of force shifted to posterior.

Byl and Gray in 1993 (62) measured simple and complex balance responses in 50 subjects with idiopathic scoliosis and 20 controls. The idiopathic scoliosis group had higher mean body sway than controls. Within idiopathic scoliosis group, children with mild scoliosis were better in maintaining balance than children with progressive curves.

These findings suggested that adolescents with idiopathic scoliosis could not maintain balance as good as normal.

Goldie et al in 1994 (63) investigated postural control in unilateral inversion injury of the ankle. Subjects were divided into 2 groups, twenty- four in the balance exercise training group and twenty-four in the untrained group. A force platform was used to investigate balance in one-leg stance with eyes open and closed on the injury and non-injury legs. The results of this study showed that postural control was worse on injury leg than non-injury leg in untrained group when tested with eyes open and closed. There was no decrease in postural control on the injury leg of trained subject when tested with eyes open and closed. Therefore, balance training should be a routine part of rehabilitation following lateral ligament sprain in the ankle.

Lynn and associates (64) studied balance characteristics of women with and without osteoporosis by using a computerized dynamic posturography (CDP). The age of subjects ranged from 52 to 85 years. The subjects were divided into 3 groups: 1) osteoporosis with normal posture 2) osteoporosis with kyphosis 3) normal posture without osteoporosis. Six subtests of the sensory organization test (SOT) involves: 1) eyes open, 2) eyes closed, 3) sway reference of visual surround, 4) sway reference of platform, 5) sway reference of platform with eyes closed, 6) sway reference platform and visual surround. Subset 1 to 3 were performed for one trial. Subset 3 to 6 were performed for 2 trials. This study found that patients with kyphosis had more postural sway and greater use of hip strategies to maintain balance than the other groups. The patients with normal posture had best scores on SOT, however, their balance strategy scores were poorer than the normal group. All groups demonstrated the learning effect in the second trial. In addition, the osteoporosis group showed more reliance on hip strategy to maintain balance.

Potter et al in 1990 (65) studied the effect of knee flexion contractures on standing balance in 15 normal subjects on a Kistler force platform. Postural sway in mediolateral (ML) and anteroposterior (AP) directions and the mean position of COG were determined within 20 seconds in all subjects. The knee flexion contracture was simulated using an adjustable line attached from a belt around the subject's waist to a plastic sheet under the sole of each foot. With 30° unilateral and bilateral contractures, the ML was found to increase. On the other hand, with 15° bilateral contractures, the AP sway increased. In addition, with 30° unilateral contracture, the COP moved toward the unflexed side, but for the 30° bilateral contractures, it moved forward. This study provide insight into how knee-flexion contractures alter standing balance, and underline the importance of preventing and treating this common disorder.

Holder-Powell and Rutherford in 2000(66) assessed balance performances in subjects with unilateral lower limb musculoskeletal injury, ranging in ages between 18 and 78 years. The one-legged standing balance was tested using the Chattanooga Balance System. The testing conditions consists of : 1) the uninjured/dominant leg with eyes open 2) the uninjured/dominant leg with eyes closed 3) the injured/dominant leg with eyes open 4) the injured/dominant leg with eyes closed. The postural sway was recorded for 10 seconds. The results showed that subjects with nondominant injuries performed significantly better than those with dominant injuries.

In another study, the body sway measurement in the frontal plane was assessed in 26 patients with chronic anterior cruciate ligament (ACL) insufficiency (67). The injured and the noninjured legs were receiving a training program and physiotherapy. The follow-up tests were made after 3, 12 and 36 months. The average speed of sway movements differed significantly when compared the patients with normal subjects prior to training. There was no difference in speed of the sway movements between the noninjured and the injured limb. At 3 mouths, the noninjured side improved but the injured side did not. At 12 months, both sides were shown to improve. The improvement of both limbs persisted at 36 months. It can be concluded that standing balance in patients with chronic ACL insufficiency can be improved by training (67).

## 2.6 Balance in Knee Osteoarthritis

Jones et al in 1995 (18) studied postural sway and quadriceps strength in patients with osteoarthritis. They used a sway meter for testing postural instability during standing on foam with eyes open and eyes closed. The horizontal spring gauge was used for measuring isometric contraction of quadriceps muscle. The results showed the decrease in quadriceps strength and greater body sway in subjects with a diagnosis of osteoarthritis which led to increasing tendency to fall.

Wegener et al in 1997 (19) assessed balance function in patients with knee osteoarthritis and compared with normal subjects. The subjects in both groups ranged in ages from 54 to 79 years. The questionnaire, functional assessment scale, and Balance System™ were used in this study. All subjects were assessed on the severity of OA symptom by using a functional assessment scale. Two trials of 6 balance testing conditions were performed as follows: eyes open and eyes closed while platform stable, tilting angular rotation, and linear translation. The results of balance testing, revealed that the arthritic group showed greater body sway than control. The investigators suggested that further study was needed to assess strength, activity level, and proprioception in order to clarify the factors contributing to balance problems in knee osteoarthritic patients.

Hurly et al (20) used a swaymeter to assess the displacement of knee OA patient's center of gravity (COG) and compared with the control group. Postural stability was performed in three conditions; bipedal stance with eyes open and eyes closed, and monopedal stance with eyes open. There was no significant difference between patients who could maintain stability and the controls. The postural stability of both groups decreased when visual was removed or when base of support was reduced.

# CHAPTER III

# MATERIALS AND METHODS

## 3.1 Subjects

Female subjects with knee osteoarthritis (OA group), ranging in ages from 40 to 60 years were recruited from Orthopaedic Surgery Out Patient Clinic and Physical Therapy Clinic at Siriraj Hospital, and Jitsumnukekul Clinic. For the control group, women without symptomatic knee osteoarthritis who had similar age, weight and height with the OA group were recruited from the staff members of Siriraj Hospital. Those who met the inclusion criteria were invited to participate in this study and signed an informed consent (Appendix A). This study was approved by the committee on human rights related to research involving human subjects of the Faculty of Medicine Siriraj Hospital, Mahidol University.

The criteria for including subjects in the study consisted of:

- Able to understand and follow instructions.
- No history of injuries or surgery at hip, knee and ankle joints.
- No sign of inflammation at knee joints.
- Ambulatory without accessory devices.
- No history of neurological disorders.
- No prior experience in being tested using the Smart Balance Master.
- Able to see the symbols on a computer screen positioned at 60 centimeters away.

The subjects were excluded if they had any of the following:

- A severe pain at knee joints that led to an inability to stand for 20 minutes.
- An impaired sensation in lower extremities.
- An abnormal posture that might affect balance such as scoliosis, kyphosis.
- Pain at the other body regions that affected balance such as back, hip, ankle.
- Serious medical condition such as heart disease, respiratory disease, etc.
- History of vertigo.
- Dizziness within 24 hours before testing.
- Alcohol intake within 24 hours.
- Medical intake that affected balance within 24 hours.

In addition, subjects included in the OA group had to meet the following criteria:

- Had symptomatic osteoarthritis of one or both knees as diagnosed by the orthopaedist and confirmed with the results of physical examination based on the criteria recommended by the American College of Rheumatology as follows:

1. Knee pain on most days of previous month.
2. Crepitus on motion.
3. Morning stiffness or stiffness after rest < 30 minutes.
4. Age > 38 years.
5. Bony enlargement.

According to the American College of Rheumatology classification criteria for knee osteoarthritis, the criteria were fulfilled if: 1,2,3&4

1,2&5

1,4&5

## 3.2 Instrumentation

1.For physical examination: an assessment form, a standard goniometer, a ball, a Snellen chart, a vernier caliper, a tape measurement with 1 mm. increment.

2.For testing muscle strength: a Myometer (Penny & Giles D60107 Model 0-60 kg.) consists of (Figure 3.1):

2.1 Myometer head

2.2 Reset button

2.3 Spreader applicator

2.4 Digital readout display

2.5 Connector socket and terminal

2.6 Power ON/OFF switch

2.7 Measuring unit

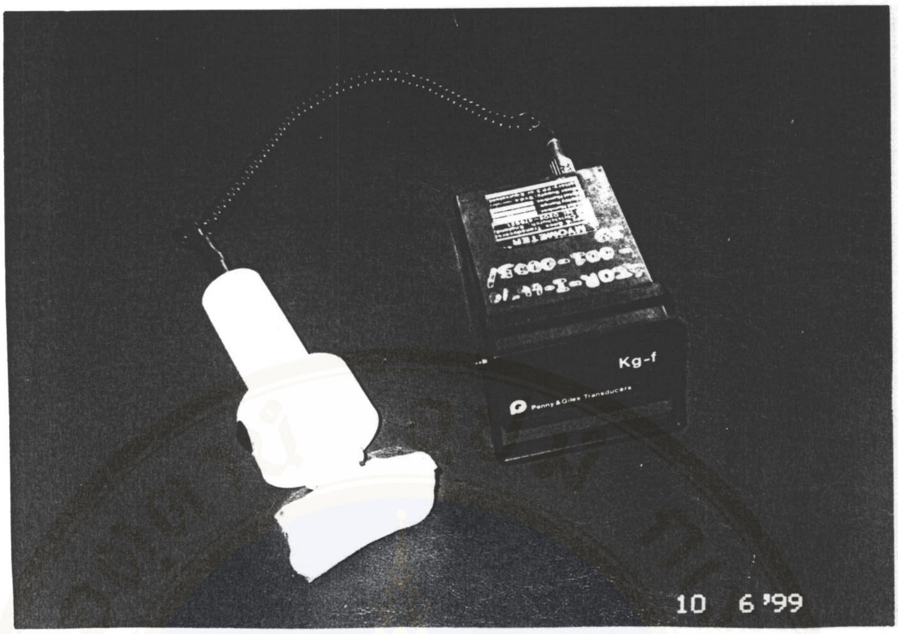



**Figure 3.1** Myometer (Penny & Giles D60107 Model)

3. For testing proprioception: a modified goniometer with adjustable stand. This was constructed by the present investigator for measuring knee angle in sitting position on a high chair during proprioception test (Figure 3.2).

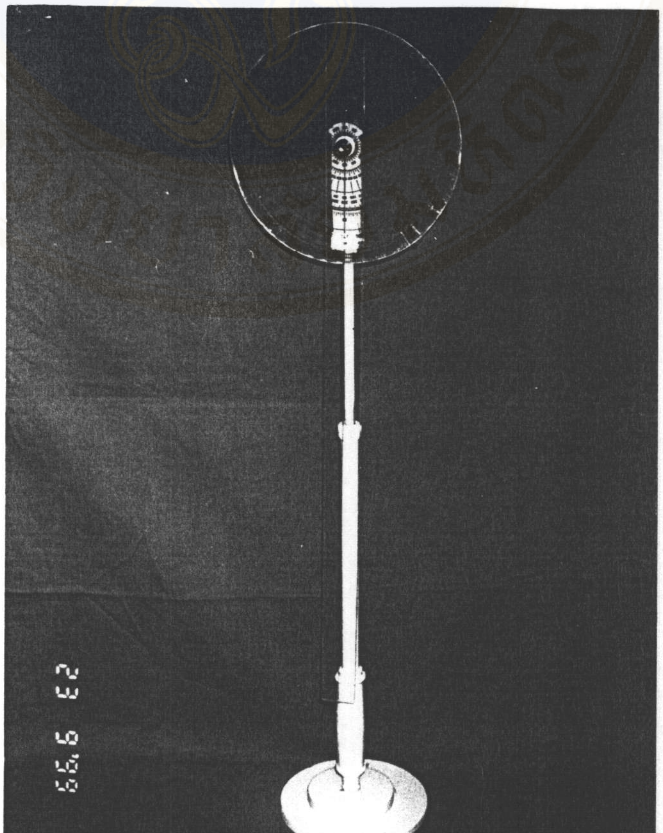


**Figure3.2** A modified goniometer with adjustable stand

4.For testing balance: the SMART Balance Master with software version 5.0. The SMART Balance Master consists of:

4.1 Dual forceplate consists of two 9"×18" (23×46cm.) footplates connected by a pin joint. The two footplates are supported by five transducers. Four transducers detect the vertical force and the other one detects the horizontal (shear) force.

4.2 Overhead bar (safety strap and carabiniers included) and safty harness.

4.3 Operator hand switch or stop switch

4.4 A visual surround

4.5 IBM – compatible PC/AT computer with SMART Balance Master™ software version 5.0. It has an internal calibration system for SMART Balance Master when turns on a switch. The system has two monitors, a keyboard and a printer. One monitor is placed on the visual surround for providing feedback of the location of the subject's center of gravity. Software calculates force outcome from five transducers and the location of center of mass that equal to approximately 55 % of total height. Both center of mass and force outcome are used to calculate sway angle in degree which is angle distance between vertical line from center of foot support and the line from the same point to center of gravity (Figure 3.3).


**Figure 3.3** The SMART Balance Master ™ ; Neurocom® Intrnational, Inc

## 3.3 Procedure

All subjects in both OA and control groups were interviewed about their general health status (Appendix B: 1&2) and those who met the inclusion criteria were invited to participate in this study. They were explained about the testing procedure and signed an informed consent.

The subjects' height and weight were measured while barefoot, followed by visual acuity test using a Snellen chart. All subjects in both groups received proprioception testing of the knee, muscle strength testing of the knee flexor and extensor groups, and a laboratory balance test. Additional assessments were provided for only the OA group, they were a physical examination and an assessment of Index severity of osteoarthritis (ISOA)(68)(Appendix B: 2.6).

### 3.3.1 Proprioception test of the knee (Figure 3.4)

Proprioception test was performed at 50 and 60 degrees of knee flexion, twice for each angle. These angles were chosen because joint reaction force increases as the knee is in more flexed position. Additionally, many activities of daily living are performed with more flexed knee in closed kinematic chain such as stair climbing, rising from low sitting, etc, create greater joint reaction force in the knee. Furthermore, intratester reliability of knee proprioception test yielded better results on these two angles. The method of testing is the following:

1. Subjects sat on a higher chair with both feet hanging above the floor.
2. The thigh of the tested leg was anchored by a strap.
3. The center of goniometer was placed directly over the condyle of the femur.
4. Subjects were instructed to close their eyes during the test.
5. The tester guided the leg to 50°of knee flexion and asked the subject to hold the leg at this position for about 3 seconds before returning the leg to the starting position.
6. Subject was instructed to reproduce the previous angle position.

7. The tester recorded the reproduced angle and repeated the test one more time.

8. The proprioception test of 60° of knee flexion was performed twice using the same procedure (5,6,7).

**Figure 3.4** Proprioception test of the knee

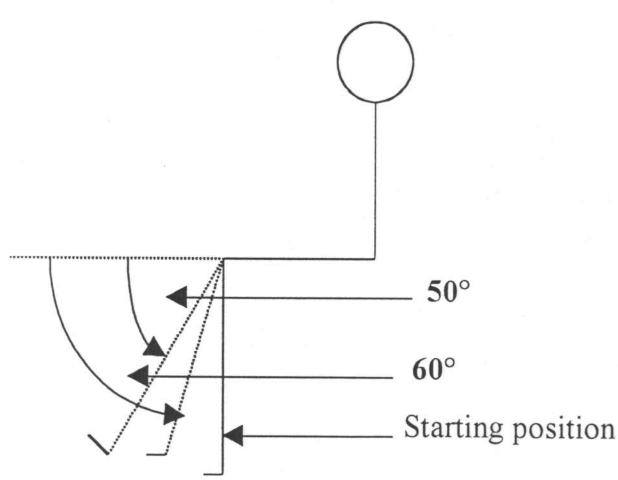



**Figure 3.5** The angle at 50 and 60 degrees of knee flexion

**3.3.2 Muscle strength testing** (Figure 3.6)

1. Subjects sat on a high chair.
2. The strap was applied at the thigh and pelvis to prevent compensatory movement.
3. The applicator of the myometer was placed just proximal to the ankle joint.
4. Subjects were instructed to apply the maximum force of knee extension and flexion to the applicator of myometer for about 3 seconds.
5. Each action was performed twice for the knee flexor and extensor groups of both knees.

**Figure 3.6** Muscle strength testing

### 3.3.3 Laboratory balance test

Before starting the test, each subject wore a safety harness. Then, each subject was instructed to place her feet on a forceplate. The position of the feet was adjusted, depending on the height of each subject, by aligning lateral border of each foot on the line marked on forceplate (S =76 to 140 cm.; M= 141 to 165 cm.; T= 166 to 203 cm.). The medial malleoli were aligned with the transverse line on forceplate and the forefoot was placed in comfortable position. The subjects were instructed not to move the feet and their arms hanged at side of body until the end of testing (Figure3.7). The sequence of balance test is shown in Table 3.1

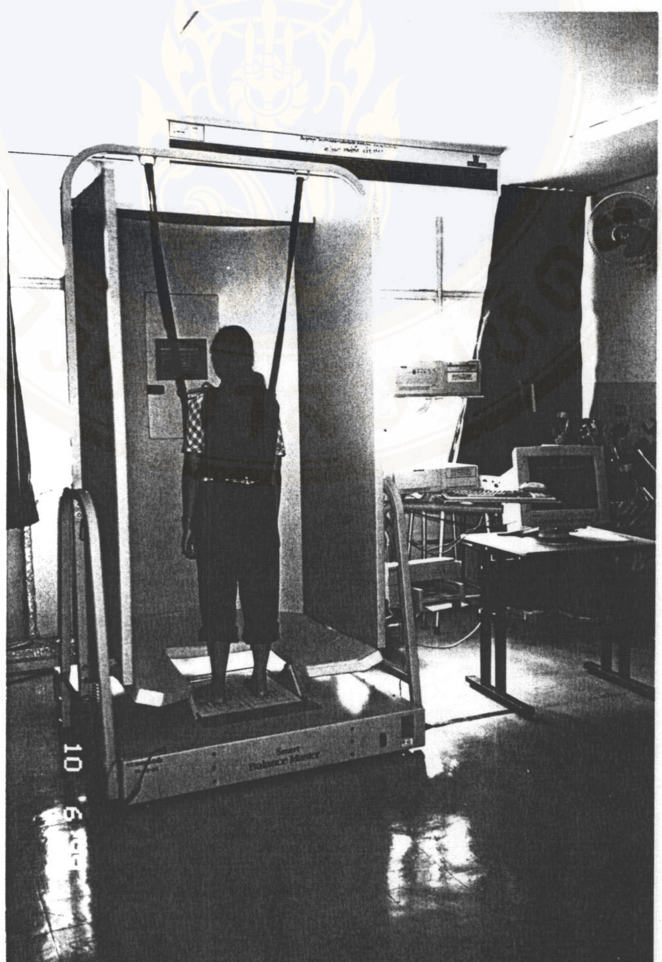


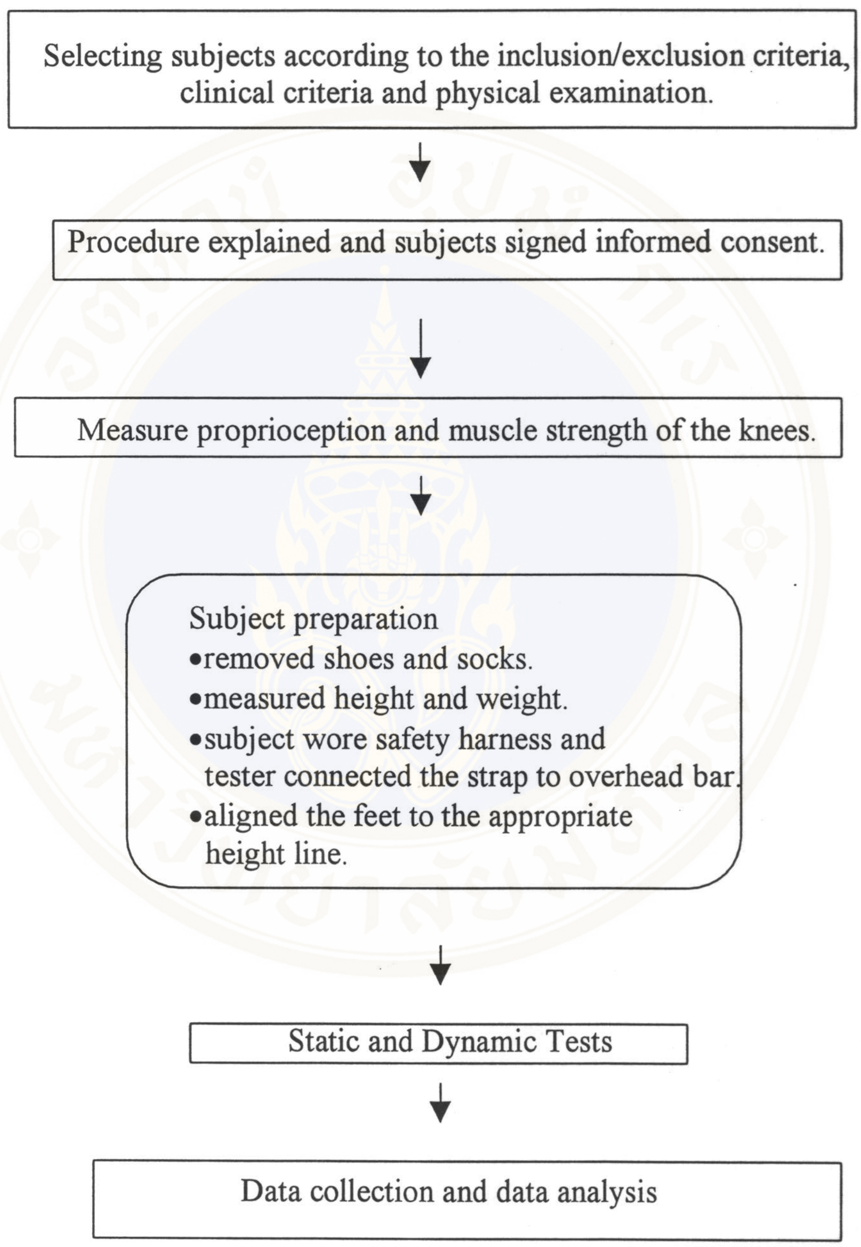
**Figure 3.7** Laboratory balance test

**Table 3.1** The sequence and description of the Static and Dynamic balance tests

| Test order | Test name | Repetition | Protocol Description |
|---|---|---|---|
| 1* | Align, eyes open (EO) | 1 | Look straight ahead while standing as still as possible with eyes open, eyes closed and receiving feedback about position of COG, represented as a cursor on screen. |
| 2* | Align, eyes closed (EC) | 1 | |
| 3** | Center target | 1 | |
| 4** | Rhythmic weight shift –Left/Right | 1 | Rhythmic weight shift follows a ball side to side of 50% of LOS at three different speed pacing. |
| 5** | Limits of Stability (LOS) | 1 | Weight shift from center to 8 outer targets positioned in a ellipse (75% of LOS). The subjects followed the ball to the clockwise highlighted target and held 4 sec. before returning to center target. |
| 6* | Sway-referenced vision (SV) | 1 | Standing as still as possible with fixed support and sway- referenced vision. |
| 7* | Eyes Open, Sway-referenced surface (EOSS) | 1 | Standing as still as possible with sway-referenced surface and normal vision. |
| 8* | Eyes closed, Sway-referenced surface (ECSS) | 1 | Standing as still as possible with sway-referenced surface and eyes closed |
| 9* | Sway -referenced vision and surface (SVSS) | 1 | Standing as still as possible with sway-referenced vision and surface |

*** Static test (Sensory Organization Test)**
****Dynamic test**

## 3.4 Experimental protocol



| Condition | Vision | Support | Patient Instructions |
|---|---|---|---|
| 1 | Normal | Fixed | Stand quietly with your eyes OPEN |
| 2 | Absent | Fixed | Stand quietly with your eyes CLOSED |
| 3 | SwayRef | Fixed | Stand quietly with your eyes OPEN |
| 4 | Normal | SwayRef | Stand quietly with your eyes OPEN |
| 5 | Absent | SwayRef | Stand quietly with your eyes CLOSED |
| 6 | SwayRef | SwayRef | Stand quietly with your eyes OPEN |

**Figure 3.8** The Sensory Organization Test

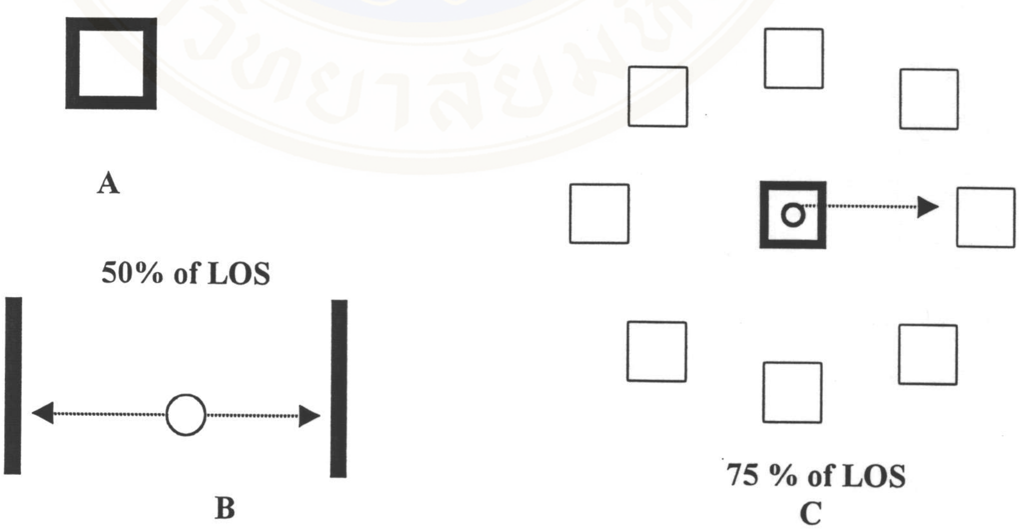



**Figure 3.9** Dynamic balance test; A: Center target test, B: Rhythmic Weight Shift Left/Right test, C: Limits of Stability test

## 3.5 Data analysis

All data were analyzed using the SPSS for Window release 7.5. The normal distributions of all data were determined by Kolmogorov Simirnov goodness of fit test.

With normally distributed data, the Independent t-test was used to determine the statistical difference between osteoarthritic and control groups. Otherwise, the Mann-Whitney U-test was used instead. Statistical significance was set at the $p < 0.05$.

## 3.6 Sample size

The sample size was calculated using the following formula (69,70):

$$N = \frac{2Sp^2 (Z_{(1-\alpha/2)} + Z_{(1-\beta)})^2}{(\mu_1-\mu_2)^2}$$

N = sample size for each group

$$Sp^2 = \text{pooled variance} = \frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{(n_1-1)+(n_2-1)} \quad \text{or} \quad \frac{S_1^2+S_2^2}{2}$$

if $n_1 = n_2$ ;

$n_1$ = sample size of control group in the pilot study.

$n_2$ = sample size of OA group in the pilot study.

$S_1^2$ = variance of control group in the pilot study.

$S_2^2$ = variance of OA group in the pilot study.

$Z_{(1-\alpha/2)}$ = Z-value when set the confident level equal to 95% or significance level at 0.05 ($\alpha$ =0.05) =1.96.

$Z_{(1-\beta)}$ = Z-value when set the power of testing equal to 90% ($\beta$ =0.1) =1.28.

($\mu_1$-$\mu_2$) = the difference of means between control and OA groups in the pilot study.

From the sample size calculation (Appendix I), the percentage of maximum stability and sway velocity in SOT were considered to be important parameters for this study. The sample size values of both parameters were ranging from 5 to 52 with one item had the value of 131 subjects. In this study, two thirds of the sample size values from both parameters (maximum stability and sway velocity in 6 conditions of SOT) were ranging from 5 to 28 subjects. Therefore, in order to cover the majority of the interested parameters, the appropriate sample size for each group used in this study was 30 subjects.

# CHAPTER IV

# RESULTS

## 4.1 Characteristics of the Study Groups

Two groups of female subjects, aged 40-60 years, participated in this study. The mean values of age, weight and height are shown in Table 4.1.There were no significant differences in age, weight and height between these two groups (p>0.05).

**Table 4.1** Characteristics of the study groups

| Characteristics | With OA (n = 30) | Without OA (n =30) | p-value[a] |
|---|---|---|---|
| Age (year) | 51.17 ± 5.58 | 49.77 ± 5.86 | 0.348 |
| Weight (kg.) | 61.90 ± 7.63 | 58.13 ± 7.12 | 0.079 |
| Height (cm.) | 155.40 ± 4.85 | 153.62 ± 5.86 | 0.192 |

a: Independent t-test.

In the preliminary analysis, women with symptomatic knee osteoarthritis were categorized into 2 groups according to the affected side of the knees. The first group named " right OA knee group" included those who had symptoms either on the right knee only or right knee was more severe than the left knee. The second group, left OA knee group, included those who presented with symptom either on the left knee alone or left knee was more severe than the right knee.

Then, the balance performances of right OA knee group and left OA knee group were investigated. The results of comparison between these two groups revealed no significant differences on all measured variables except the sway velocity of the sway-referenced vision (SV) from SOT, maximum excursion and directional control to back target from the limits of stability test (Appendix D). Thus, it was justified to combine data obtained from all measured variables except those mentioned previously for further statistical analysis.

The results of this study are divided into five parts as follows:

1) Comparison of percentage of maximum stability and sway velocity from SOT between women with and without symptomatic knee osteoarthritis.
2) Comparison of sway velocity of center target test and on-axis velocity and directional control from rhythmic weight shift left-right test between women with and without symptomatic knee osteoarthritis.
3) Comparison of reaction time, movement velocity, maximum excursion, end point excursion and directional control from 75% of limits of stability test between women with and without symptomatic knee osteoarthritis.
4) Comparison of error angle obtained from proprioception test between women with and without symptomatic knee osteoarthritis.
5) Comparison of muscle strength between women with and without symptomatic knee osteoarthritis.

## 4.2 Comparison of the percentage of maximum stability (%) and sway velocity (degree/second) from the Sensory Organization Test (SOT) between subjects with and without symptomatic knee osteoarthritis.

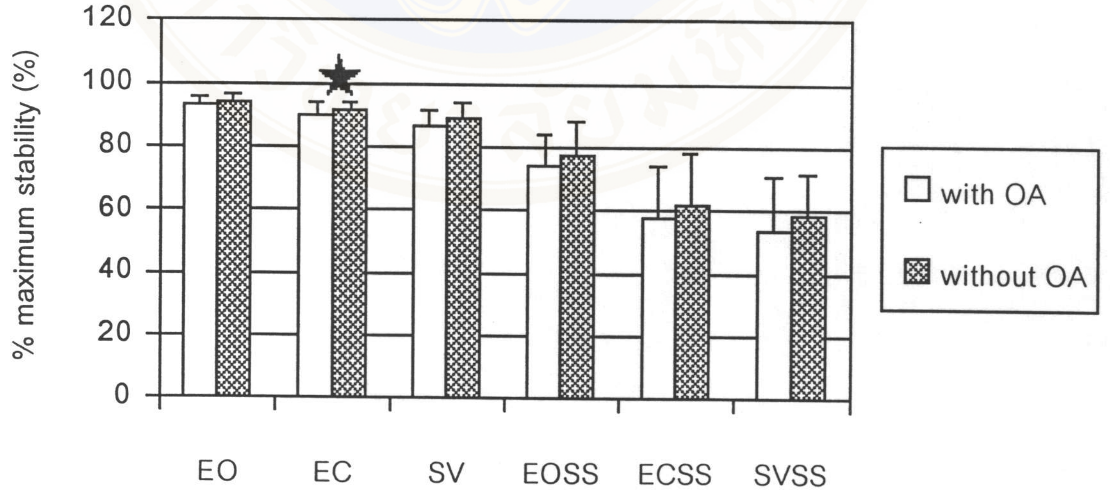
### 4.2.1 The percentage of maximum stability (%)

The mean values and standard deviation of the percentage of maximum stability measured by the SOT in subjects with and without symptomatic knee osteoarthritis are presented in Table 4.2. The mean values of the percentage of maximum stability of subjects without symptomatic knee osteoarthritis groups for eyes open (EO), eyes closed (EC) and sway-referenced vision (SV) on fixed support surface were 94.17%, 91.70% and 89.10%, respectively, and for eyes open (EOSS), eyes closed (ECSS) and sway-referenced vision (SVSS) on sway-referenced support surface were 77.83%, 62.13% and 58.17%, respectively. The mean values of the percentage of maximum stability of subjects with symptomatic knee osteoarthritis groups for eyes open (EO), eyes closed (EC) and sway-referenced vision (SV) on fixed support surface were 93.17%, 90.07% and 86.73%, respectively, and for eyes open (EOSS), eyes closed (ECSS) and sway-referenced vision (SVSS) on sway-reference support surface were 74.53%, 58.07% and 53.63%, respectively. The results of comparison of the percentage of maximum stability of six SOT conditions between subjects with and without symptomatic knee osteoarthritis are shown in Table 4.2 and Figure 4.1. There were significant difference between these two groups on condition 2 of SOT (standing with eyes closed on fixed support surface: EC).

**Table 4.2** Comparison of the percentage of maximum stability obtained from the SOT between females with and without symptomatic knee osteoarthritis

| Conditions[#] | With OA (n = 30) | Without OA (n =30) | p-value[a] |
|---|---|---|---|
| EO | 93.17 ± 2.53 | 94.16 ± 2.21 | 0.109 |
| EC | 90.07 ± 3.39 | 91.70 ± 2.07 | 0.028* |
| SV | 86.73 ± 5.11 | 89.10 ± 4.82 | 0.070 |
| EOSS | 74.53 ± 9.83 | 77.83 ± 10.02 | 0.203 |
| ECSS | 58.07 ± 16.56 | 62.13 ± 15.99 | 0.337 |
| SVSS | 53.63 ± 17.51 | 58.17 ± 13.78 | 0.270 |

#: EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support; a: Independent t-test; * : $p < 0.05$.




EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support

**Figure 4.1** Comparison of the percentage of maximum stability obtained from the SOT between females with and without symptomatic knee osteoarthritis

**4.2.2 Sway velocity (degree per second)**

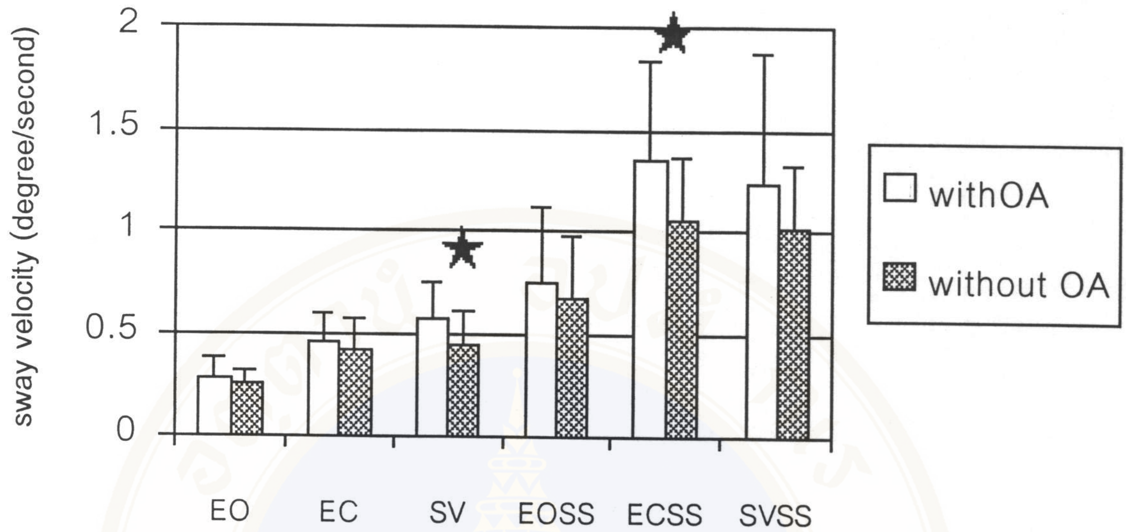
Table4.3 and Figure4.2 presented mean values and standard deviation of sway velocity measured from the SOT in subjects with and without symptomatic knee osteoarthritis. The mean values of sway velocity of subject without symptomatic knee osteoarthritis for eyes open (EO), eyes closed (EC) and sway-referenced vision (SV) on fixed support surface were 0.25, 0.43 and 0.44 degrees per second, respectively. For eyes open (EOSS), eyes closed (ECSS) and sway-referenced vision (SVSS) on sway-referenced support surface were 0.68, 1.06 and 1.02 degrees per second, respectively. The mean values of sway velocity of subject with symptomatic knee osteoarthritis for eyes open (EO), eyes closed (EC) and sway-referenced vision (SV) on fixed support surface were 0.27, 0.46 and 0.53 degrees per second, respectively. For eyes open (EOSS), eyes closed (ECSS) and sway-referenced vision (SVSS) on sway-referenced support surface were 0.75, 1.35 and 1.24 degrees per second, respectively.

Comparison of sway velocity between women with and without symptomatic knee osteoarthritis revealed the significant difference ($p<0.05$) on condition 3 (sway-referenced vision: SV) and condition 5 (eyes closed and sway-referenced support surface: ECSS).

**Table 4.3** Comparison of sway velocity obtained from the SOT between women with and without symptomatic knee osteoarthritis

| Conditions[#] | With OA (n=30) | Without OA (n=30) | p-value[a] |
|---|---|---|---|
| EO | 0.27 ± 0.10 | 0.25 ± 0.07 | 0.272[b] |
| EC | 0.46 ± 0.14 | 0.43 ± 0.15 | 0.300 |
| SV | 0.53 ± 0.18<br>0.63 ± 0.18[c]<br>0.45 ± 0.13[d] | 0.44 ± 0.17 | 0.048*<br>0.005[b]*<br>0.692[b] |
| EOSS | 0.75 ± 0.37 | 0.68 ± 0.31 | 0.381[b] |
| ECSS | 1.35 ± 0.49 | 1.06 ± 0.30 | 0.007* |
| SVSS | 1.24 ± 0.64 | 1.02 ± 0.31 | 0.194[b] |

#: EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support; a: Independent t-test ; b: Mann-Whitney U-test; c : right OA knee group; d: left OA knee group; *: $p<0.05$.




EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support

**Figure 4.2** Comparison of sway velocity obtained from the SOT between women with and without symptomatic knee osteoarthritis

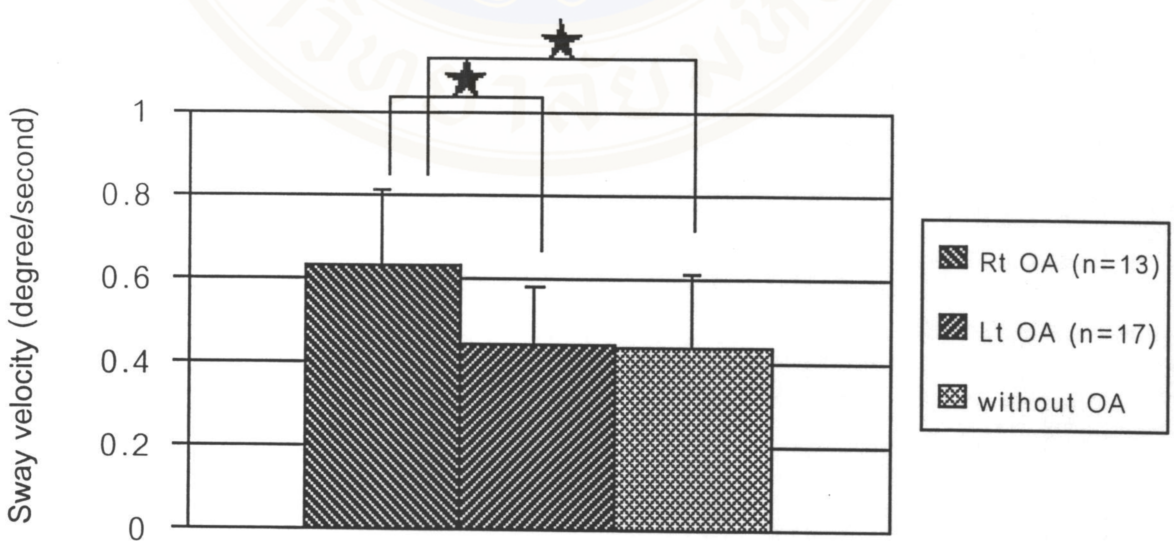



**Figure4.3** Comparison of sway velocity during sway-referenced vision condition from SOT between right OA knee group, left OA knee group and without symptomatic knee osteoarthritis

**Table 4.4** Comparison of the occurrences of Loss of Balance (LOB) during the Sensory Organization Test between women with and without symptomatic knee osteoarthritis

| Sensory Organization Test | %LOB | | Chi-square value | p-value |
|---|---|---|---|---|
| | With OA | Without OA | | |
| Eyes Open | 0 | 0 | - | - |
| Eyes Closed | 0 | 0 | - | - |
| Sway-referenced vision | 0 | 0 | - | - |
| Sway-referenced support, eyes open | 0 | 0 | - | - |
| Sway-referenced support,eyes closed | 3.33 | 0 | 1.017 | 0.312 |
| Sway-referenced support & vision | 6.66 | 0 | 2.068 | 0.152 |

*: $p<0.05$

When comparing the occurrences of LOB (Table4.4), it was found that the differences between these two groups were not statistically significant. From these results, it was apparent that the number of subjects with loss of balance during testing under various conditions of Sensory Organization Test were not different between women with and without symptomatic knee osteoarthritis.

### 4.3 Comparison of sway velocity (degree/second) obtained from Center Target test and on-axis velocity (degree/second) and directional control (%) obtained from the Rhythmic Weight Shift Left/Right test between subjects with and without symptomatic knee osteoarthritis.

The mean values and standard deviations of sway velocity from the Center Target test in subjects with and without symptomatic knee osteoarthritis are shown in Table 4.5. The mean values of sway velocity of subjects without symptomatic knee osteoarthritis was 0.32 degrees/second. Whereas, the sway velocity of subjects with symptomatic knee osteoarthritis was 0.36 degrees/second. The comparison of sway velocity between women with and without symptomatic knee osteoarthritis are shown in Table 4.5 and Figure 4.4. There was no statistical difference in this parameter.

The mean values and standard deviations of on-axis velocity and directional control from the Rhythmic Weight Shift Left/Right test in subjects with and without symptomatic knee osteoarthritis are shown in Table 4.5. The mean values of on-axis velocity of subjects without symptomatic knee osteoarthritis for slow, moderate and fast pacing speeds were 3.16, 4.86 and 9.47 degrees/second, respectively. For the directional control of subjects without symptomatic knee osteoarthritis for slow, moderate and fast pacing speeds were 81.5%, 85.57% and 89.23%, respectively. The mean values of on-axis velocity of subjects with symptomatic knee osteoarthritis for slow, moderate and fast pacing speeds were 3.07, 4.63 and 8.09 degrees/second, respectively. The directional control of subjects with symptomatic knee osteoarthritis for slow, moderate and fast pacing speeds were 80.23%, 84.47% and 89.10%, respectively. The comparisons of on-axis velocity and directional control between women with and without symptomatic knee osteoarthritis are presented in Table 4.5, Figure 4.5 and Figure 4.6, respectively. There was a significant difference in on-axis velocity for fast pacing. In addition, there were no significant differences in directional control for all pacing speeds tested.

**Table 4.5** Comparison of sway velocity (degree/second) obtained from Center Target test and on-axis velocity (degree/second) and directional control (%) obtained from the Rhythmic Weight Shift Left/Right test between subjects with and without symptomatic knee osteoarthritis

| Test | With OA (n=30) | Without OA (n=30) | p-value[a] |
|---|---|---|---|
| **Center Target** | 0.36 ± 0.11 | 0.32 ± 0.12 | 0.094[b] |
| **Rhythmic Weight Shift Left/Right** | | | |
| On-axis velocity | | | |
| Slow | 3.07 ± 0.58 | 3.16 ± 0.38 | 0.477 |
| Moderate | 4.63 ± 0.73 | 4.86 ± 0.54 | 0.158 |
| Fast | 8.09 ± 2.20 | 9.47 ± 1.28 | 0.005* |
| **Directional Control** | | | |
| Slow | 80.23 ± 5.41 | 81.50 ± 4.45 | 0.326 |
| Moderate | 84.47 ± 4.50 | 85.57 ± 4.51 | 0.348 |
| Fast | 89.10 ± 3.78 | 89.23 ± 3.63 | 0.890 |

a: Independent t-test ; b: Mann-Whitney U-test; *: $p < 0.05$.

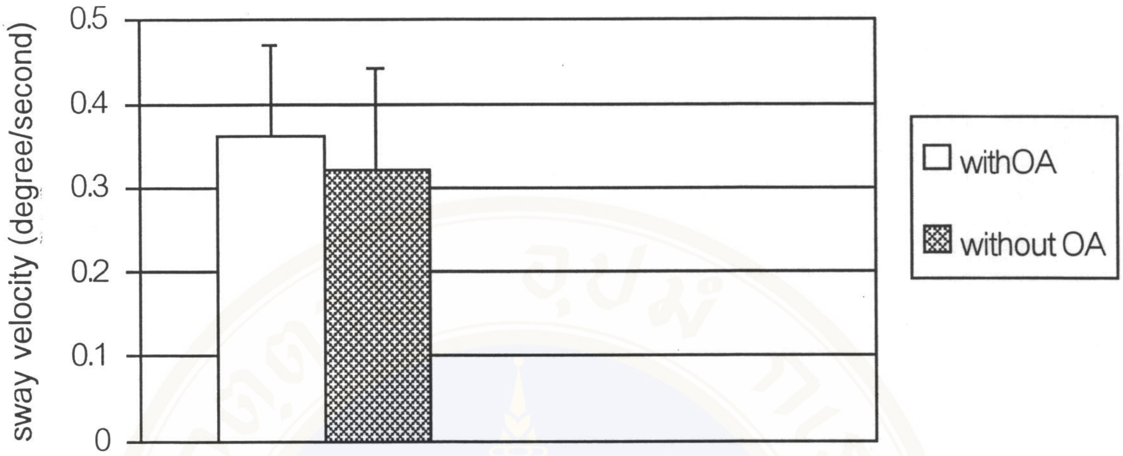



**Figure 4.4** Comparison of sway velocity obtained from Center Target test between women with and without symptomatic knee osteoarthritis

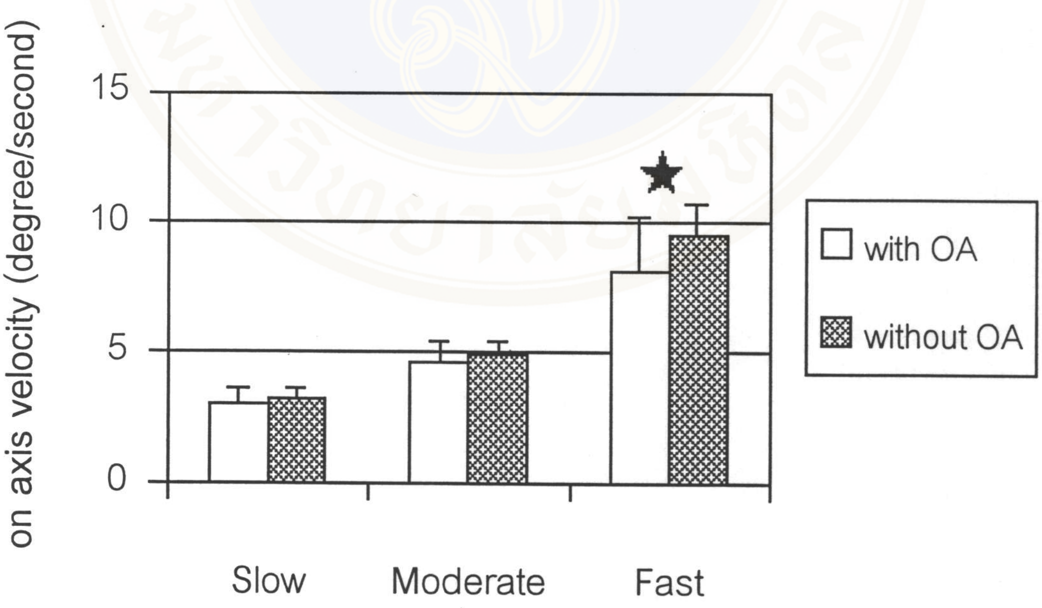



**Figure 4.5** Comparison of on-axis velocity obtained from Rhythmic Weight Shift Left/Right test between women with and without symptomatic knee osteoarthritis

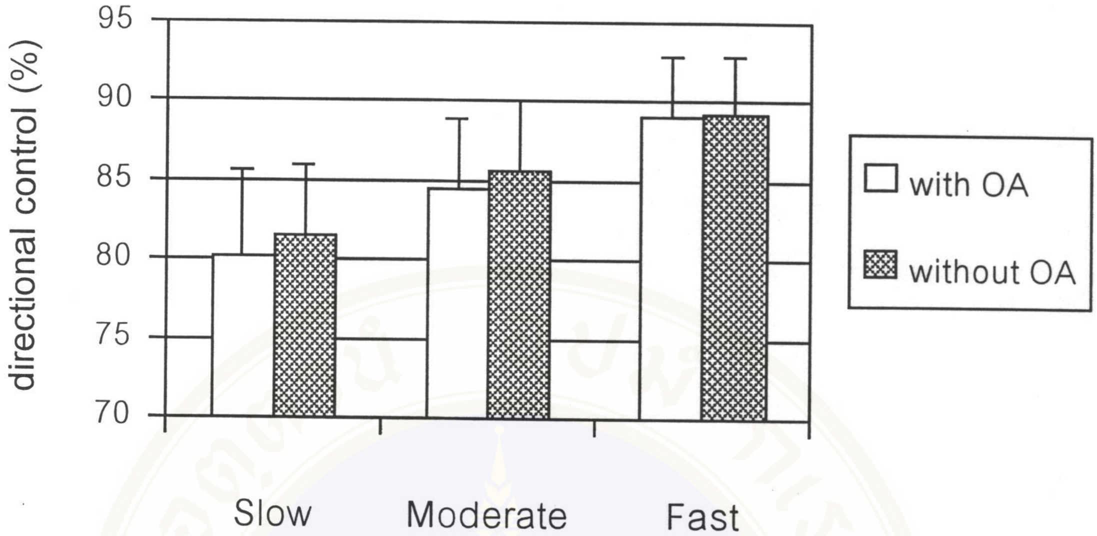



**Figure 4.6** Comparison of directional control obtained from Rhythmic Weight Shift Left/Right test between women with and without symptomatic knee osteoarthritis.

## 4.4 Comparison of five measured variables (reaction time, movement velocity, endpoint excursion, maximum excursion and directional control) obtained from the Limits of Stability (LOS) test between subjects with and without symptomatic knee osteoarthritis.

The mean values and standard deviations of five measured variables obtained from LOS test of subjects with and without symptomatic knee osteoarthritis are shown in Table 4.6. The comparisons of five measured variables between subjects with and without symptomatic knee osteoarthritis are shown in Table 4.6 and Figure 4.7-4.11. This study found that reaction time when COG moved to right-back target was shown to be significantly different between two groups.

**Table 4.6** Comparison of five measured variables (reaction time, movement velocity, end point excursion, maximum excursion and directional control) obtained from the Limits of stability (LOS) test between subjects with and without symptomatic knee osteoarthritis

| Limits of stability | With OA | Without OA | p-value[a] |
|---|---|---|---|
| Reaction time (second) | | | |
| Front | 0.912 ± 0.45 | 0.971 ± 0.33 | 0.570 |
| Right-front | 0.783 ± 0.34 | 0.794 ± 0.37 | 0.907 |
| Right | 0.729 ± 0.29 | 0.687 ± 0.23 | 0.532 |
| Right-back | 0.966 ± 0.38 | 0.757 ± 0.30 | 0.020* |
| Back | 0.837 ± 0.42 | 0.741 ± 0.32 | 0.332 |
| Left-back | 0.831 ± 0.33 | 0.821 ± 0.32 | 0.907 |
| Left | 0.915 ± 0.33 | 0.780 ± 0.28 | 0.094 |
| Left-front | 1.049 ± 0.348 | 0.939 ± 0.36 | 0.231 |

a: Independent t-test ; *: $p<0.05$.

**Table 4.6** Comparison of five measured variables obtained from the Limits of stability (LOS) test between subjects with and without symptomatic knee osteoarthritis (continued)

| Limits of stability | With OA | Without OA | p-value[a] |
|---|---|---|---|
| Movement velocity (degree/second) | | | |
| Front | 3.317 ± 1.41 | 2.963 ± 1.49 | 0.302 |
| Right-front | 4.173 ± 1.42 | 4.757 ± 3.05 | 0.348 |
| Right | 4.303 ± 2.21 | 4.787 ± 2.44 | 0.425 |
| Right-back | 3.460 ± 1.74 | 3.577 ± 1.73 | 0.795 |
| Back | 2.576 ± 1.18 | 3.156 ± 1.88 | 0.152 |
| Left-back | 3.493 ± 1.06 | 3.552 ± 1.46 | 0.860 |
| Left | 4.243 ± 1.82 | 4.773 ± 1.98 | 0.285 |
| Left-front | 3.813 ± 1.35 | 4.163 ± 1.71 | 0.382 |
| End Point Excursion (%) | | | |
| Front | 60.033 ± 14.73 | 59.433 ± 11.95 | 0.863 |
| Right-front | 69.933 ± 12.99 | 70.500 ± 12.63 | 0.865 |
| Right | 65.567 ± 9.02 | 65.733 ± 10.21 | 0.947 |
| Right-back | 67.467 ± 14.74 | 66.433 ± 11.79 | 0.765 |
| Back | 54.552 ± 13.19 | 57.214 ± 11.88 | 0.619 |
| Left-back | 67.300 ± 13.06 | 68.103 ± 13.90 | 0.820 |
| Left | 65.733 ± 10.14 | 67.533 ± 10.55 | 0.503 |
| Left-front | 65.767 ± 12.99 | 68.433 ± 14.35 | 0.454 |

a: Independent t-test.

**Table 4.6** Comparison of five measured variables obtained from the Limits of stability (LOS) test between subjects with and without symptomatic knee osteoarthritis (continued)

| Limits of stability | With OA | Without OA | p-value[a] |
|---|---|---|---|
| Maximum Excursion (%) | | | |
| Front | 75.833 ± 7.76 | 75.900 ± 11.35 | 0.524[b] |
| Right-front | 81.993 ± 6.92 | 79.167 ± 11.11 | 0.609[b] |
| Right | 76.767 ± 4.17 | 76.700 ± 4.86 | 0.955 |
| Right-back | 82.100 ± 8.71 | 80.433 ± 8.08 | 0.446 |
| Back | 73.379 ± 12.38 | 71.500 ± 9.75 | 0.528 |
| | 66.500 ± 13.98[c] | | 0.274[b] |
| | 78.235 ± 8.56[d] | | 0.066[b] |
| Left-back | 78.767 ± 6.97 | 82.448 ± 9.30 | 0.090 |
| Left | 76.667 ± 3.59 | 77.300 ± 3.71 | 0.504 |
| Left-front | 79.900 ± 4.99 | 79.067 ± 6.61 | 0.584 |

a: Independent t-test ; b: Mann-Whitney U-test; c : right OA knee group; d: left OA knee group; *: $p<0.05$ .

**Table 4.6** Comparison of five measured variables obtained from the Limits of stability (LOS) test between subjects with and without symptomatic knee osteoarthritis (continued)

| Limits of stability | With OA | Without OA | p-value[a] |
|---|---|---|---|
| Directional Control (%) | | | |
| Front | 76.333 ± 20.85 | 83.133 ± 17.88 | 0.091[b] |
| Right-front | 79.310 ± 9.70 | 73.933 ± 18.80 | 0.171 |
| Right | 81.207 ± 8.23 | 82.733 ± 11.25 | 0.670 |
| Right-back | 57.103 ± 18.66 | 61.633 ± 23.61 | 0.453 |
| Back | 55.143 ± 29.28 | 67.786 ± 17.90 | 0.071 |
| | 40.750 ± 29.92[c] | | 0.004[b]* |
| | 66.765 ± 23.90[d] | | 0.806[b] |
| Left-back | 57.276 ± 22.22 | 59.655 ± 16.25 | 0.636 |
| Left | 85.586 ± 8.14 | 86.500 ± 6.88 | 0.733 |
| Left-front | 79.552 ± 9.06 | 79.300 ± 13.31 | 0.848 |

a: Independent t-test ; b: Mann-Whitney U-test; c : right OA knee group; d: left OA knee group; *: $p<0.05$ .

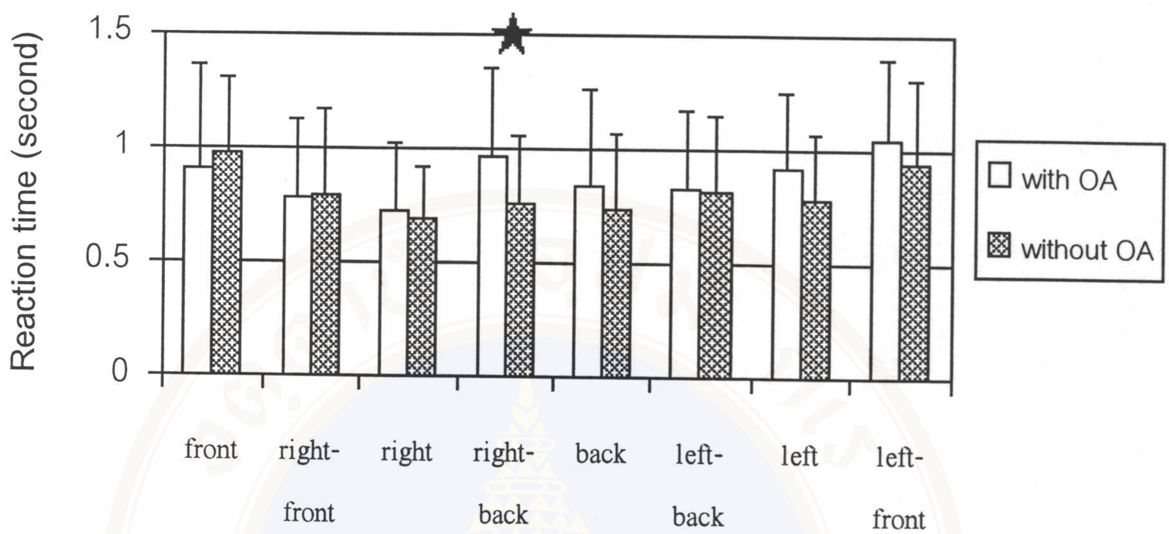



**Figure 4.7** Comparison of reaction time (second) obtained from Limits of Stability test between women with and without symptomatic knee osteoarthritis

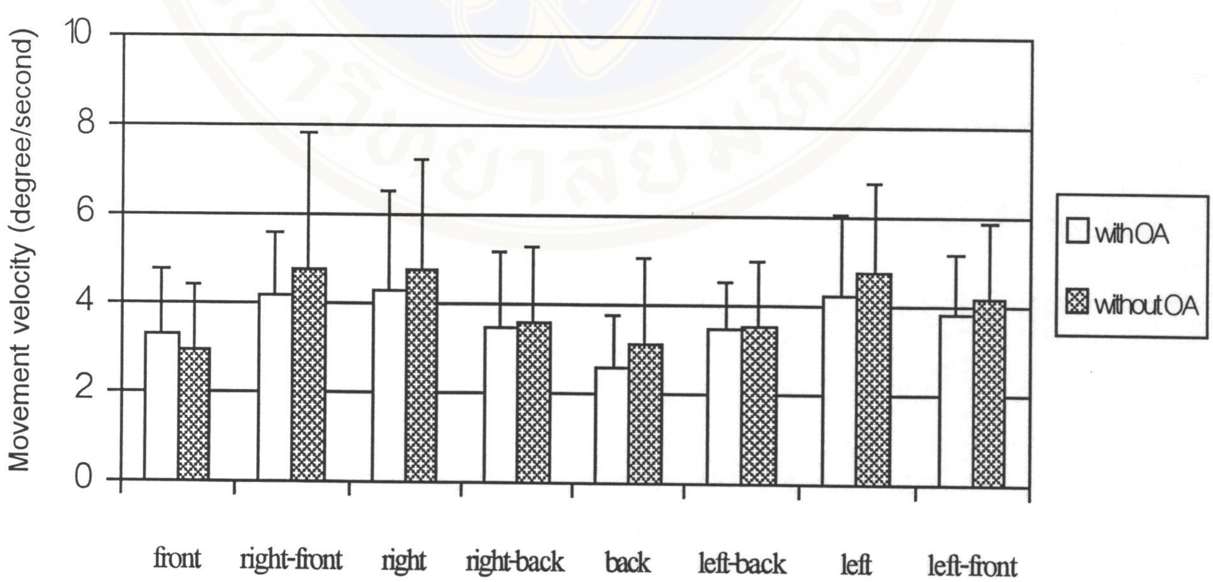



**Figure 4.8** Comparison of movement velocity (degree/second) obtained from Limits of Stability test between women with and without symptomatic knee osteoarthritis

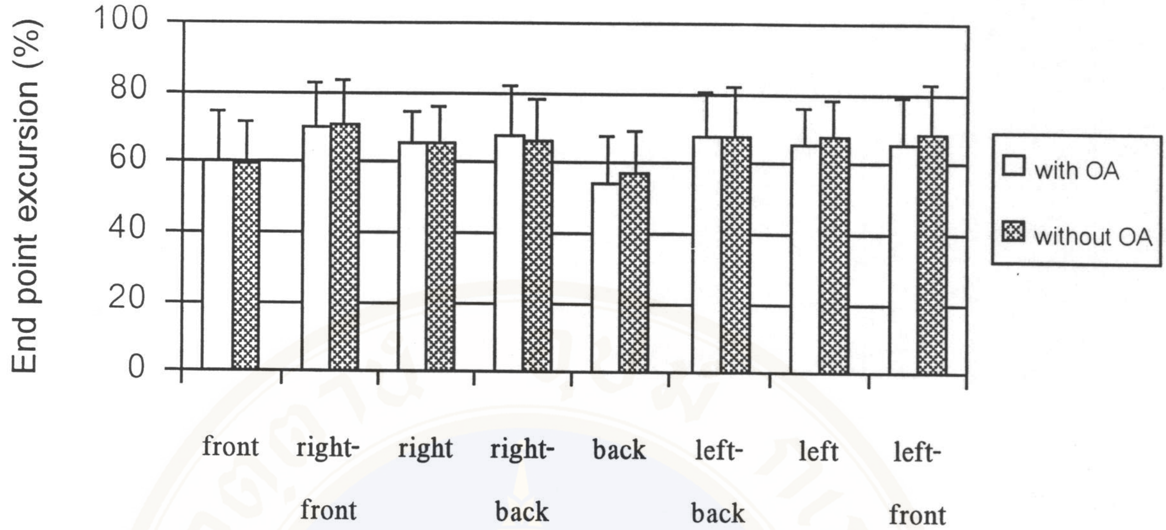



**Figure 4.9** Comparison of end point excursion (%) obtained from Limits of Stability test between women with and without symptomatic knee osteoarthritis

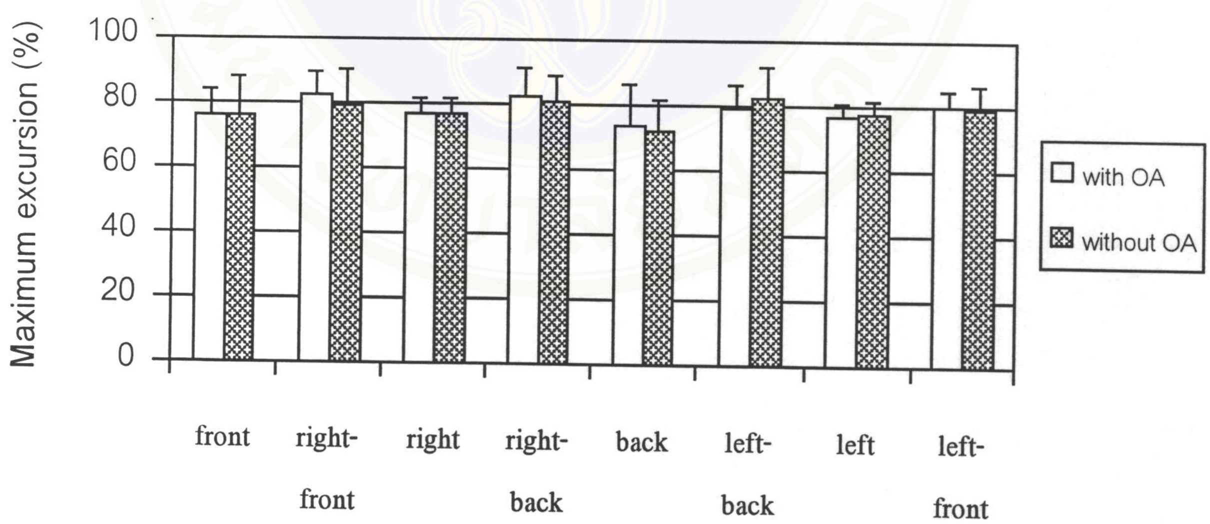



**Figure 4.10** Comparison of maximum excursion (%) obtained from Limits of Stability test between women with and without symptomatic knee osteoarthritis

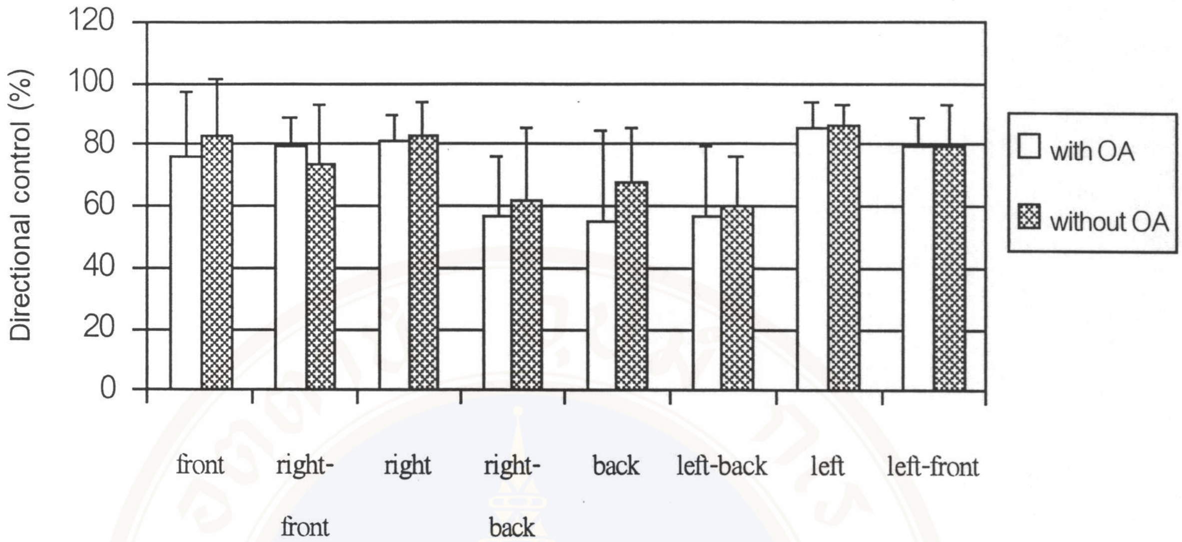



**Figure 4.11** Comparison of directional control (%) obtained from Limits of Stability test between women with and without symptomatic knee osteoarthritis

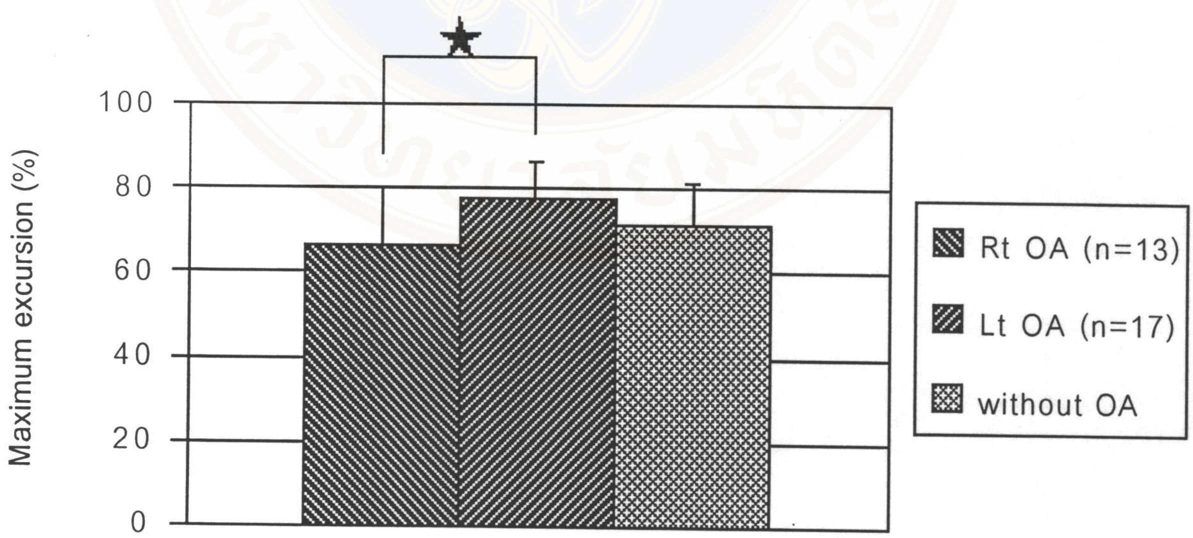



**Figure 4.12** Comparison of maximum excursion (%) to back target from LOS test between right OA knee group, left OA knee group and subjects without symptomatic knee osteoarthritic group

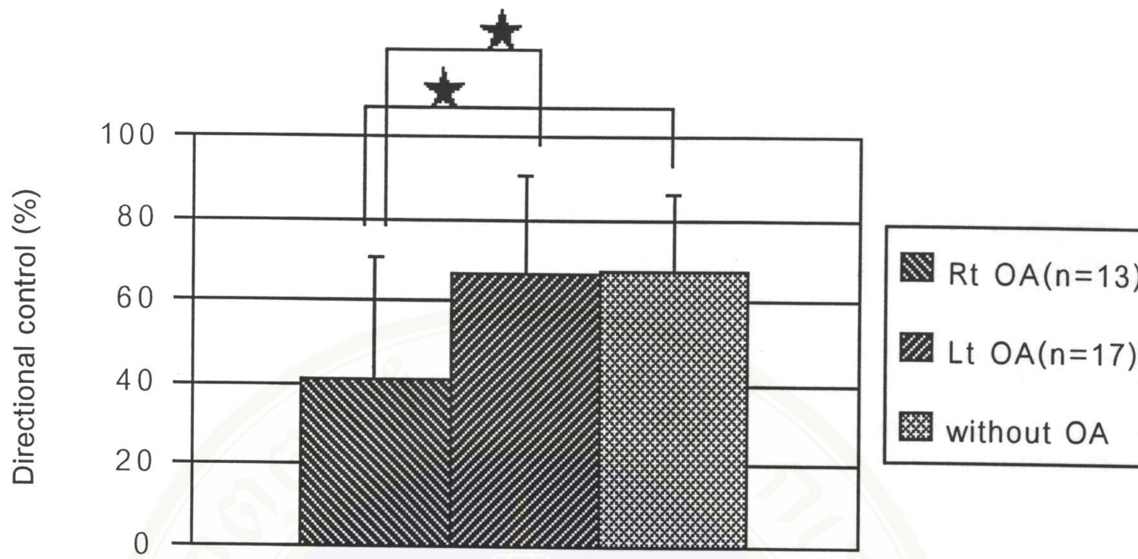



**Figure 4.13** Comparison directional control (%) to back target from LOS test between right OA knee group, left OA knee group and subjects without symptomatic knee osteoarthritic group

## 4.5 Comparison of error angle obtained from proprioception test between subjects with and without symptomatic knee osteoarthritis.

The mean values and standard deviations of error angle in subjects with and without symptomatic knee osteoarthritis are shown in Table 4.7. The comparison of error angle revealed a significant difference at 60° of both knees ($p<0.05$). Figure 4.14 presents the graphic illustration of mean error angle in two groups of women with, and without symptomatic knee osteoarthritis.

**Table 4.7** Comparison of error angle (°) obtained from proprioception test between subjects with and without symptomatic knee osteoarthritis

| Proprioception Test | With OA | Without OA | p-value[a] |
|---|---|---|---|
| 50° | | | |
| Right | 3.742 ± 2.38 | 2.825 ± 1.48 | 0.080 |
| Left | 2.558 ± 1.63 | 2.850 ± 1.41 | 0.461 |
| 60° | | | |
| Right | 3.617 ± 2.03 | 2.442 ± 1.34 | 0.010* |
| Left | 3.658 ± 2.10 | 2.550 ± 1.51 | 0.023* |

a: Independent t-test; *: p<0.05.

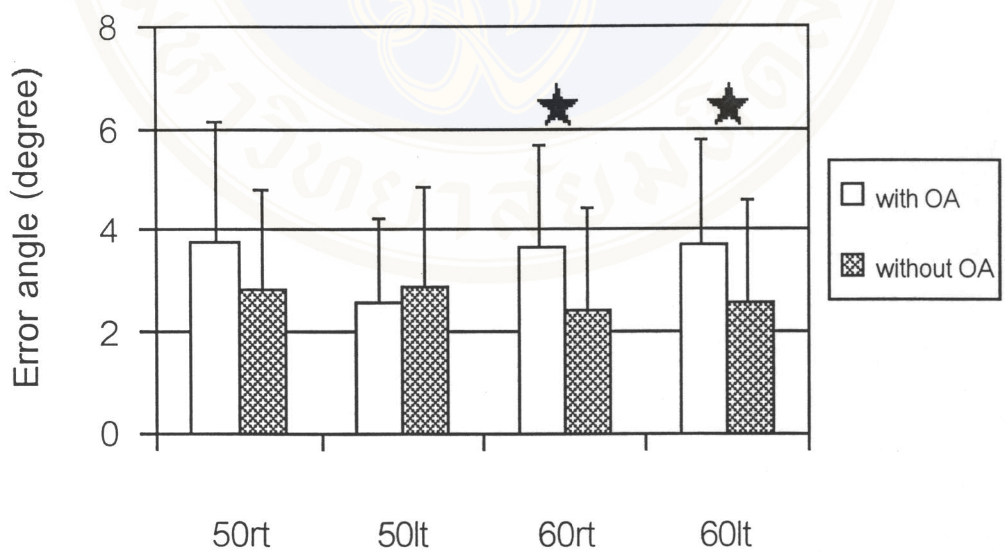



**Figure 4.14** Comparison of error angle (°) obtained from proprioception test between subjects with and without symptomatic knee osteoarthritis

## 4.6 Comparison of muscle strength between subjects with and without symptomatic knee osteoarthritis.

The mean values and standard deviations of muscle strength in subjects with and without symptomatic knee osteoarthritis are shown in Table 4.8. The comparison of muscle strength between subjects with and without symptomatic knee osteoarthritis revealed significant differences in extensor muscle of both knees and flexor muscle of right knee ($p<0.05$). For the flexor group of left knee, though not significantly different but the p-value of 0.07 was approaching the significant level. Figure 4.15 presents the comparison of muscle strength between women with and without symptomatic knee osteoarthritis.

**Table 4.8** Comparison of muscle strength between subjects with and without symptomatic knee osteoarthritis

| Muscle Strength (kg.) | With OA | Without OA | p-value[a] |
|---|---|---|---|
| Flexor group | | | |
| Right | 9.787 ± 3.14 | 11.247 ± 2.26 | 0.044* |
| Left | 9.667 ± 3.45 | 11.003 ± 2.04 | 0.073 |
| Extensor group | | | |
| Right | 20.758 ± 6.46 | 24.553 ± 5.88 | 0.021* |
| Left | 19.603 ± 6.55 | 23.077 ± 4.86 | 0.023* |

a: Independent t-test; *: $p<0.05$.

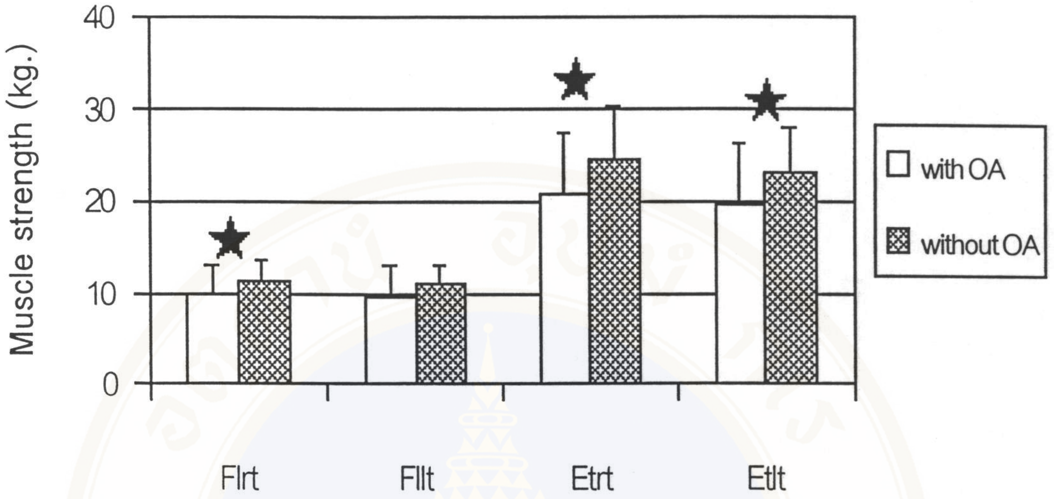



**Figure 4.15** Comparison of muscle strength (kg.) between subjects with and without symptomatic knee osteoarthritis

In summary, this study found that the balance performance was decreased in subjects with symptomatic knee osteoarthritis, especially, when standing with eyes closed (EC) and sway-referenced vision (SV) conditions. In addition, the reaction time to right- back target of OA patients was greater than control. Moreover, the error angle of OA patients from proprioception test at 60° was greater than control group. Finally, the muscle strength of knee flexor and extensor groups in OA patients were weaker than the control group.

# CHAPTER V

# DISSCUSSION

The discussion on balance performance and related measures in women with and without symptomatic knee osteoarthritis was divided into 6 parts; 1)Comparison of percentage of maximum stability and sway velocity from SOT condition. 2) Comparison of sway velocity from center target test. 3) Comparison of on-axis velocity and directional control from rhythmic weight shift left-right test. 4) Comparison of reaction time, movement velocity, maximum excursion, end point excursion and directional control from 75% of limits of stability test. 5) Comparison of error angle from proprioception test. 6) Comparison of muscle strength.

## 5.1 Comparison of the measurement variables obtained from SOT between women with and without symptomatic knee osteoarthritis.

The six conditions of Sensory Organization Test (SOT) were used to assess the ability to effectively use the sensory information (visual, vestibular, somatosensory) for maintaining balance. The testing conditions were divided into fixed support surface and sway-referenced support surface. The fixed support surface was assessed in condition 1-3 whereas, the sway-referenced support surface was assessed in condition 4-6. The measurement variables in SOT conditions were the percentage of maximum stability (%) and sway velocity (degree per second).

### 5.1.1 The percentage of maximum stability (%)

The percentage of maximum stability scores represented the ability to use each sensory input for maintaining stance posture in different SOT conditions. The scores near 100% indicated little sway or good stability whereas, the scores near 0% indicated that sway is nearly the limits of stability (LOS). The percentage of maximum stability takes the peak to peak difference between the maximum anterior and maximum posterior sway of the subjects and divided that value by the maximum theoretical distance sway without loss of balance (12.5 degrees). The percentage of maximum stability can be calculated from the below formula (71).

$$\%\text{Maximum stability} = \frac{12.5 - (\theta ant - \theta post)}{12.5} \times 100$$

From the results of this study, the percentage of maximum stability did not show any significant differences between two groups in conditions 1,3,4,5 and 6 from SOT. Thus, it was probable that the symptomatic OA subjects were able to effectively use sensory information to maintain postural stability during condition 1,3,4,5and 6. However, only in eyes closed on fixed support surface condition (condition2: EC) that the OA subjects could not maintain stance posture as good as the control group in which the statistical analysis showed significant difference in the percentage of maximum stabiiity between two groups. This implied that the patients had poorer ability to use somatosensory input for controlling balance than control group when vision was removed.

Nashner (21) explained that the somatosensory is the main sensory input used for controlling balance under normal support surface condition when vision was removed. OA subjects in this study may not be able to use somatosensory input effectively when compared with the control group. This may be due to proprioceptive deficits associated with OA of the knees. Many studies (13-16) reported the impairment of proprioception in osteoarthritic patients. It was noted that proprioceptive information was received from joint and muscles by the receptors within the knee joint ligament, menisci, tendons, capsules and muscles surrounding the knee (72). Therefore, proprioception, which is an important part of somatosensory input, is essential for balance control. In the study of balance responses in bilateral knee OA, Wegener et al (19) found an increased body sway when vision was deprived in OA patients and surmised that impairment of proprioception could lead to increasing sway in this testing condition.

Moreover, the patients probably relied on vision rather than somatosensory input and swayed more when looking at the moving screen. This was apparent from the result of testing with sway- referenced vision on fixed support, even though not significantly different, but, the p-value (0.07) nearly reached statistical significance implied the tendency of OA group to rely on vision for maintaining balance. This provided additional support for greater range of A-P (antero-posterior) sway in OA group was due to their inability to effectively use information from proprioceptive sense for maintaining quiet stance.

Based on these evidences, it could be concluded that OA patients might have impaired proprioceptive sense. This impairment could lead to increasing body sway when visual information was not provided for controlling balance. Furthermore, the OA patients might develop a habit to rely on vision more than the somatosensory input even though it did not provide accurate feedback for maintaining balance under this testing condition (SOT condition 4).

**5.1.2 Sway velocity (degree per second)**

The average COG movement velocity is derived from dividing the total path length of COG sway by time to arrive at the average velocity. The high velocity of COG indicated that the subject swayed more frequently throughout the 20 seconds test. The results of sway velocity obtained from the SOT showed significant differences in condition 3 and 5 (sway-referenced vision: SV and eyes closed with sway-referenced support surface: ECSS). Such findings may imply that COG sway velocity during sway-referenced vision (SV) and eyes closed with sway-referenced support surface (ECSS) were increased in the patient group.

In testing with sway-referenced vision (SV), the mean sway velocity of OA group was greater than the control subjects. Further analysis to compare sway velocity between the right and left OA knee groups with the control, a significant difference was found only between right OA knee and control groups. For this testing condition, five patients in right OA knee group (n=13) had extreme values of sway velocity (0.7-1.0 degrees/second) which deviated from the majority of OA subjects (sway velocity less than 0.7 degrees/second) whereas only one patient from the left OA knee group (n=17) had sway velocity as high as 0.7 degrees/second. In view of a small sample size of the right OA knee group (n=13), these extreme values obtained from the five patients could effect the group mean and result in significant difference from the control group. Since the sway velocity measured during eyes closed condition of the five patients were similar to the rest of the OA group, it was probable that other factors related to balance, such as motivation, attention, dependency on visual input, could result in increasing the sway velocity. It was possible that the values obtained from the right OA knee group could influence the mean difference between the overall OA group and control group. Therefore, conclusion could not be derived at this time whether these two groups of subjects differed in sway velocity on SOT condition 3 (SV).

In eyes closed with sway-referenced support surface (ECSS), the mean sway velocity of the patient was greater than the control group. Normally, the vestibular was used when the surface was disturbed and vision was removed (21). However, the increasing sway velocity may not be resulted from abnormal vestibular function since all subjects were screened for vestibular pathology before including in this study. It was probable that the weakness of muscle in osteoarthritic patient could lead to an inability to coordinate movement for controlling posture. Balance control depends not only on the sensory input but also the motor output for controlling posture. The lateral vestibulospinal tract has a pronounced facilitatory effect on both alpha and gamma motor neuron that innervate muscle in the limbs (73). If the motor output was not effective, sway may increase during testing in condition 5 (ECSS) of SOT.

Furthermore, the patients with knee osteoarthritis might feel insecure and fear of falling greater than the control group when vision was removed.

## 5.2 Comparison of sway velocity obtained from Center Target Test between women with and without symptomatic knee osteoarthritis.

The center target test was a simplest weight-shifting task used for dynamic balance assessment. The subject was instructed to move the body's center of gravity cursor and keep it inside the center target for 20 seconds. The center target position shown on the screen, is computed from the height of the center of gravity that depends on the height of subject. The measurement variable used in this study was the sway velocity (degree/second). The result of this study revealed no significant differences in sway velocity of center target test between subjects with and without symptomatic knee osteoarthritis. It could happen that the patients leaned their body weight on unaffected sides or less symptomatic sides which made them being able to maintain in the center target. By this way, the result of this test did not find any differences in the ability to voluntarily control movement of the COG to the center target between these two groups of subjects. Even though most patients seemed to have weaker muscle than the control group but this test did not require as much strength for controlling the COG in center target and the assessment time was not too long to cause fatigue while performing this task.

## 5.3 Comparison of on-axis velocity and directional control obtained from Rhythmic Weight Shift left/right Test between women with and without symptomatic knee osteoarthritis.

The rhythmic weight shift left/right test is a voluntary task which requires the subject to shift the COG medially and laterally. The subject was instructed to move her COG follow the blue circle on screen by shifting the body weight from side to side to reach the target lines presented on the screen. When body is moving in a given direction and has to change speed pacing, its existing momentum must be considered in maintaining balance. The rhythmic weight shift test was assessed at 50% of the limits of stability. The speed pacing of this test consisted of three levels: slow (3 seconds), moderate (2 seconds) and fast (1 second). The measured variables of this test were on-axis velocity (degree/second) and directional control (%).

The results of this study revealed significant difference in on-axis velocity for the fast pacing speed between women with and without symptomatic knee osteoarthritis. In patient group, the on-axis velocity of fast pacing speed was less than the control group. Whereas, the slow and moderate pacing speed were nearly the same between two groups. For fast speed pacing test, it was found that the average speed of weight shifting movement of the control group tended to be higher not only than the OA patients group but also greater than the required speed of the test. The higher speed used by the control group may be due to the need to catch up with the fast moving ball. This created greater body momentum which was harder to control when the person was required to move to the opposite direction. In order to compensate for body lagging behind the ball, the subject had to increase the speed of body weight shifting after turning to the opposite direction. It was probable that the control group used greater muscular power than the OA group and than that required for controlling the speed of COG movement. Even though the average speed of weight shifting movement in OA group tended to be higher than the required speed too but it was less than the control. It could be explained that the OA group might increase the speed of weight shifting, however, they could not generate as much muscular power as the control group when changing the direction of COG movement due to weaker muscle of the OA group.

The directional control is the average velocity of an off-axis COG motion expressed as a percentage of the average on-axis velocity. When the directional control value is near 100%, it implies that the subject can control COG in the direction toward the target. The results of this study demonstrated no significant difference in the directional control of all speed pacing between both groups. It could be explained that the OA group controlled the COG toward the target as good as the control group. Rhythmic weight shift left/right which is not a difficult test, thus, was not sensitive enough for testing the subjects in this study.

### 5.4 Comparison of measurement variables obtained from Limits of Stability Test between women with and without symptomatic knee osteoarthritis.

The limits of stability test is designed to assess an individual's ability to volitionally move the COG to eight predetermined positions in space. Subjects were required to lean away from the midline in the direction of each of the eight on screen targets without stepping or moving feet from the standardized foot position. The measurement variables were reaction time (seconds), movement velocity (degree/second), end point excursion (%), maximum excursion (%) and directional control (%).

The reaction time was assessed when the subject saw the circle in the outer target and began to shift COG out of midline. The reaction time was measured in second. The results of this study demonstrated significant difference in reaction time while COG moved to right-back target between women with and without symptomatic knee osteoarthritis. The OA patient's reaction time was longer than the control subject. When compared the reaction time between the right OA knee group and left OA knee group, the reaction time of the left OA knee group was longer than the right OA knee group. It could be explained that most patients included in this study had symptom in the left side which made them harder to initiate movement from their left legs for shifting the COG to right direction. In addition to this, the task for moving the COG to target set more posteriorly was more difficult because the posterior limit of stability (4°) was less than the anterior (6°) (21).

Other measurement variables (movement velocity, endpoint excursion, maximum excursion and directional control) showed no significant differences in all targets between women with and without symptomatic knee osteoarthritis. These variables assessed the ability to voluntarily control of movement which did not require too much muscular strength. Thus, the patients included in this study could control

COG to outer targets following the instruction of tester equally well when compared with the control group.

Further analysis to compare the five measurement variables (reaction time, movement velocity, end point excursion, maximum excursion, directional control) of the right OA knee group with the left OA knee groups revealed no significant differences except in maximum excursion and directional control to back target. For the maximum excursion, the mean value of the right OA knee group did not differ from the control and the mean value of the right, left OA knee groups and control did not reach 100%. It could imply that no group succeeded in controlling COG to the back target. For directional control to the back target, the mean value of right OA knee group differed from the left OA knee and control groups. When considering the raw data, three patients in right OA knee group had extremely low values (-22% to –70%) which deviated from the majority OA subjects whereas only one patient from the left OA knee group (n=17) had directional control value of –3%. In view of a small sample size of the right OA knee group (n=13), these extremely low values from 3 patients could effect the group mean and result in significance difference from control. Since the directional control to other targets of three patients were similar to the rest of the OA group, it was probable that other factors related to balance, such as attention, motivation, could influence the directional control to the back target.

## 5.5 Comparison of error angle obtained from proprioception Test between women with and without symptomatic knee osteoarthritis.

The error angle in this study was calculated from the difference in values of measurement angle and referenced angle in each trial tested. Then, the values obtained from 2 trials were averaged for each subject. The large error angle inferred that subject could not perceive the joint position sense. The result of this study showed significant difference in error angle at 60° of both knees between women with and without symptomatic knee osteoarthritis. Many studies (13-16) in the past also supported these findings and explained that the patients with symptomatic knee osteoarthritis had proprioceptive deficits. Sharma and Pai (14) reviewed the concepts of impaired proprioception in OA knee. They suggested that a proprioceptive impairment may contribute to or result from the OA disease. The decline in proprioception in aging may lead to increasing poorly distributed load and cause OA. On the other hand, the proprioceptive impairment might be the result of osteoarthritic pathology which destroys or disturbs the function of capsule, ligament or muscle-tendon mechanoreceptors. The machanoreceptors which signal mechanically applied pressure or tissue deformation, and nociceptive receptors may be stimulated by the articular damage in OA patients. The afferent fibers of mechanoreceptor also project onto γ-motorneurones in the spinal cord and these γ-motorneurones activate the intra-fusal muscle fibers that make up muscle spindles. So, the muscle spindles sensitivity depends on the excitability of γ-motorneurones. In conclusion, the articular damage in arthritic knee could lead to abnormal information which reduces the excitability of γ-motorneurones and decreases muscle spindles sensitivity, respectively (20,35). In addition, the muscle spindle was not controlled only in the spinal cord level but also it was controlled by the CNS via efferent fiber (48). The proprioceptive inaccuracy may occur according to the mechanism explained above.

On the other hand, at 50° of knee flexion, this study found no significant difference between women with and without symptomatic knee osteoarthritis of both right and left sides. This may be due to greater requirement on muscle contraction which helped to hold the knee joint more firmly at 50° angle than 60° angle. For this reason, it was easier to perceive joint position more accurately at 50° angle. Furthermore, the range of movement to 60° position was smaller than 50° when measured from the same starting position (90°). Therefore, the small range of movement (60°) may be more difficult to perceive during the test than the larger range (50°). Fuchs and coworkers (74) studied the proprioception in patient with and without total knee arthroplasty. The results showed the loss of proprioceptive capabilities, especially at the 60° angle but not at 30°angle. This finding supported that the 60° angle may play an important role perhaps because of the relative joint instability in this angle.

## 5.6 Comparison of muscle strength between women with and without symptomatic knee osteoarthritis.

The Myometer was used to assess muscle strength in both knees. The mean of muscle strength for each subject was calculated from the values obtained from trial1 and trial2. The result of comparison showed significant difference in extensor muscles of both knees and flexor muscle of right knee between the OA patients and control group. This implied that women with osteoarthritis were presented with weaker extensor muscle of both knee and flexor muscle of the right when compared with the control. For left knee flexor muscles, even though not significant difference, but the p-value (0.07) nearly reached statistical significance implied the tendency of OA group to be weaker than control. The evidence supporting the weakness of both extensor and flexor muscles in OA patients were provided by Messier et al. This study found that the peak torque of extensor and flexor muscles of the knee with OA from isokinetic strength testing were less than the control (17). Moreover, Tan et al (32) found that both isometric strength and isokinetic maximum peak torque of the extensor and flexor muscles were lower in patients with knee OA when compared with control. They suggested that strengthening exercise of hamstrings muscle is as important as quadriceps in the treatment plan of knee OA. However the hamstrings weakness is apparent in some studies (17,32), while other studies (20,33) demonstrated only quadriceps weakness in OA knee patients. It could be explained that the hamstrings are two joint muscle spanning both the knee and hip joints which still be contracted and stretched even when the knee is immobilized. Whereas the quadriceps have only one two joint muscle, rectus femoris, to function as a weak hip flexor and thus, could become weakened easily (75).

There are controversies regarding the cause of weakness in osteoarthritic patients. Slemenda and colleague (33) suggested that weakness may be due to muscle dysfunction and may be a risk factor for the initiation and progression of damage to articular cartilage and other tissues in the knee with osteoarthritis. Previous study (76) reported pain that, a common symptom of osteoarthritis, was strongly associated with difficulty in performing muscle strength test in osteoarthritic patients. Shama et al (77) suggested that muscle strength was correlated with physical function. Therefore, muscle weakness could be a risk factor for pain in osteoarthritis and pain could be reduced with muscle strengthening. The reduction of muscle strength may be related with the pathogenesis of the osteoarthritis of the knee. However, many other factors including these may be associated with each other.

The reduction of strength in extensor and flexor muscles may be explained as follows: the skeletal muscle activity is controlled and innervated by peripheral motor nerves which are composed of α- motorneurones. The motor centers of the CNS influence α- motorneurones excitability. The α- motorneurones activates extra-fusal muscle fibers. So, the abnormal information that was stimulated by damaging of articular surface, lead to decrease excitability of α- motorneurones. Factors that decrease the excitability of α- motorneurones reduce muscle activation and decrease γ-motorneurones excitability. Thus, the extensor and flexor muscle may be weak in OA patients (20).

In summary, this study found the impairment of proprioception, reduction of strength and poor balance performance in OA patients. The impairment of proprioception and the weakness of muscle may affect balance control in OA patients. Previous research evidences were still inconclusive regarding the cause of these impairments in OA patients. However, Hurley in 1999 (35) suggested that both motor and sensory dysfunction may be factors influencing pathogenesis of OA and not a consequence of articular damage.

## 5.7 Clinical Implication

The changing in balance characteristics, proprioception and muscle strength were found in women with symptomatic knee osteoarthritis who participated in this study. It is suggested that physiotherapist should assess the balance function, proprioception and muscle strength before planning the treatment goal. For balance function, physiotherapist should assess both the static and dynamic to find the problems that affect instability. In testing knee proprioception, physiotherapist should assess at the 60° angle because this angle was difficult to reproduce in OA knee patients. For muscle strength, physiotherapist should assess both knee flexor and extensor groups because they tended to be weaker in osteoarthritic patients.

This study showed that the women with symptomatic knee osteoarthritis performed poorly on the balance task that vision was disturbed. This result may be interpreted that the women with symptomatic knee osteoarthritis were unable to use somatosensory input effectively due to proprioceptive deficit or had abnormal muscle responses. Thus, balance assessment is essential for planning treatment in women with symptomatic knee. The treatment for improving proprioception and muscle strength are important for OA patients, which, in turn will improve their balance performances. Specific training should include standing or walking on various surface conditions such as sand or grass.

# CHAPTER VI

# CONCLUSION

Thirty women with symptomatic knee osteoarthritis and thirty women without symptomatic knee osteoarthritis , ranging in ages from 40 to 60 years, participated in this study to provide quantitative data about the standing balance performance obtained from the SMART Balance Master, proprioception and muscle strength.

The results of this study indicated the following;

1. The osteoarthritis group had decreasing percentage of maximum stability and increasing sway velocity more than control group in some conditions of SOT. The statistical analysis showed significant difference in the percentage of maximum stability of condition 2 (EC) which implied that the patients were unable to effectively adopt somatosensory information when the vision was removed. For the sway velocity, significant difference was found in condition 5 (ECSS) which may result from the weaker knee muscle together with the insecure feeling and fear of falling in the OA group.

2. The sway velocity obtained from center target test was not significantly different between the osteoarthritic group and control group.

3. Performances on rhythmic weight shift left/right test at slow and moderate speeds were similar between the OA and control groups. For fast speed weight shifting, there was a significant difference between the osteoarthritic and control groups. It was probable that the OA group did not use muscular power the same way as the control group when changing the COG movement direction.

4.In the limits of stability test, the reaction time for shifting COG to right-back target showed statistically significant difference between the osteoarthritic group and control group. Most subjects in OA group had symptom on left side which was used for pushing the COG to the right and it was even harder when required to move COG more posteriorly at the same time.

5. In proprioception test, significant difference between the osteoarthritic and control groups was found at the 60° angle. Therefore, it is appropriate for testing proprioception at 60° angle in knee osteoarthritic patients.

6. In muscle strength test, the extensor and flexor muscles of both knees were found to be weaker in women with symptomatic knee osteoarthritis when compared with the controls.

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# APPENDIX A

## CONSENT FORM

**แบบยินยอมเข้าร่วมการศึกษา**

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

ข้าพเจ้า.........................................อายุ..................ปี อาศัยอยู่บ้านเลขที่................. ถนน........................แขวง........................เขต.........................จังหวัด.....................ได้รับทราบรายละเอียดของโครงการวิจัยเรื่องเปรียบเทียบความสามารถในการทรงตัวในท่ายืน,การรับสัมผัสตำแหน่งและความแข็งแรงของกล้ามเนื้อระหว่างผู้หญิงที่มีและไม่มีข้อเข่าเสื่อม ดังต่อไปนี้คือ เพื่อเปรียบเทียบความแข็งแรงของกล้ามเนื้อ, การรับรู้ของข้อเข่า และความสามารถในการทรงตัวระหว่างผู้หญิงที่มีและไม่มีข้อเข่าเสื่อม ผู้เข้าร่วมวิจัยจะได้รับการตรวจประเมินข้อเข่าและประเมินความรุนแรงของข้อเข่าเสื่อม, ความแข็งแรงของกล้ามเนื้อรอบข้อเข่า, การรับรู้ของข้อเข่า และการวัดการทรงตัวในท่ายืนด้วยเครื่องคอมพิวเตอร์ ผลการศึกษาในครั้งนี้จะเป็นประโยชน์ในการตรวจประเมิน และวางแผนการรักษาทางกายภาพบำบัดในผู้ป่วยข้อเข่าเสื่อมได้อย่างเหมาะสม และมีคุณภาพยิ่งขึ้น ในการเก็บข้อมูลครั้งนี้จะไม่มีผลเสียต่อสุขภาพแต่อย่างใด

หากผู้วิจัยมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์ และโทษที่เกี่ยวข้องกับการวิจัยจะแจ้งให้ข้าพเจ้าทราบอย่างรวดเร็วโดยไม่ปิดบัง

ข้าพเจ้ามีสิทธิ์ที่จะของดการเข้าร่วมโครงการวิจัยโดยมิต้องแจ้งให้ทราบล่วงหน้า โดยการงดการเข้าร่วมการวิจัยนี้จะไม่มีผลกระทบต่อการได้รับบริการหรือการรักษาที่ข้าพเจ้าจะได้รับแต่ประการใด

ข้าพเจ้าได้รับทราบจากผู้วิจัยว่า จะไม่เปิดเผยข้อมูล หรือ ผลการวิจัยของข้าพเจ้าเป็นรายบุคคลต่อสาธารณชน

ข้าพเจ้าได้รับทราบ และ ได้ซักถามผู้วิจัยจนหมดข้อสงสัยโดยตลอดแล้ว และยินดีเข้าร่วมในการวิจัย จึงได้ลงลายมือชื่อไว้เป็นหลักฐานต่อหน้าพยาน

ลงชื่อ...................................ผู้ยินยอม

( )

ลงชื่อ...................................หัวหน้าโครงการ

(นางสาวณรัตน์ พิชัยยงค์วงศ์ดี)

ลงชื่อ...................................พยาน

( )

ลงชื่อ...................................พยาน

( )

# APPENDIX B

## Assessment Form

Comparison of Standing Balance Performance, Proprioception and Muscle Strength between Women with and without Symptomatic Knee Osteoarthritis

**Group………../No……………**
**Date…………………………..**

1.**General history**

1.1 Name…………………………………Age……..yr. Wt………kg. Ht………..cm.
Occupation…………………………Underlying disease………………………..
Address……………………………………Tel………………

| 1.2 Footedness | Rt | Lt |
|---|---|---|
| kick ball | | |
| write "8" | | |
| step on a burning cigarette | | |

1.3 Vision ☐without glass………… ☐with glass……………..

1.4 Health status

☐to be carsick ☐to be boatsick ☐to be trainsick ☐normal

| | | |
|---|---|---|
| Dizziness within 24 hours | ☐no | ☐yes |
| Medical intake | ☐no | ☐yes………… |
| History of disorder of nervous system | ☐no | ☐yes |
| History of falling more than 2 times in 6 months | ☐no | ☐yes |
| History of smoking | ☐no | ☐yes |
| History of surgery at hip, knee, ankle | ☐no | ☐yes………… |
| History of pain at the other region | ☐no | ☐yes………… |
| History of vertigo | ☐no | ☐yes |
| Alcohol intake within 24 hrs. | ☐no | ☐yes |

The exercise level

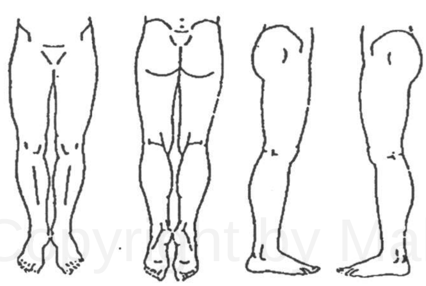
☐ Regularly exercise at least 3 day/wk.
☐ Regularly exercise 1-2 day/wk.
☐ Non exercising

1.5 Work activity ☐sitting ☐standing ☐standing-walking ☐other…………

**2.Physical examination**

2.1 Knee pain onset………years,………months,………..days.

2.2 Site of pain



2.3 Type of pain ☐constant ☐intermittent (Aggravate by.......................)
2.4 Characteristic of pain ☐dull pain ☐deep pain ☐sharp pain ☐other.........
2.5 Visual analogue scale during aggravate activity
no pain ———————————————————— very severe pain
Pain before test
no pain ———————————————————— very severe pain
Pain after test
no pain ———————————————————— very severe pain
2.6 Index of severity for osteoarthritis (Semin Arthritis Rheum1991;20:48-54.)

<u>Pain or discomfort (choose the best choice)</u>

1. during nocturnal bed rest
   - ☐ non or insignificant
   - ☐ only on movement or in certain position
   - ☐ with no movement
2. morning stiffness or regressive pain after raising
   - ☐ 1 minute or less
   - ☐ more than 1 but less than 15 minutes
   - ☐ 15 minutes or more
3. after standing for 30 minutes: ☐ none ☐ pain
4. while ambulating
   - ☐ none
   - ☐ only after ambulate some distance
   - ☐ after initial ambulation and increasingly
5. after getting up from sitting without the help of arms.
   - ☐ none ☐ pain

<u>Maximum distance walked (may walk with pain)</u>

1. ☐unlimited ☐more than 1 km.,but limited ☐about 1 km.(15 min)
   ☐500-900m. (8-15 min) ☐ 300-500m. ☐100-300m. ☐less than 100m.
2. ☐with one walking stick or crutch ☐with two walking sticks or crutch

<u>activities of daily living</u>

1. able to climb up a standard flight of stairs.
   - ☐Without difficulty
   - ☐With difficulty : ☐mild ☐ moderate ☐severe
   - ☐Unable
2. able to climb down a standard flight of stairs
   - ☐Without difficulty
   - ☐With difficulty : ☐mild ☐ moderate ☐severe
   - ☐Unable
3. able to squat or bend on the knee
   - ☐Without difficulty
   - ☐With difficulty : ☐mild ☐moderate ☐severe
   - ☐Unable
4. able to walk on uneven ground
   - ☐Without difficulty
   - ☐With difficulty : ☐mild ☐moderate ☐severe | ☐Unable

2.7 ROM of knee joint

| Flexion/extension | Active | Passive |
|---|---|---|
| Rt | | |
| Lt | | |

2.8Circumference of knee joint

| Circumference(cm.) | Rt | Lt |
|---|---|---|
| Joint line | | |
| Above joint line 10 cm. | | |

2.9 Crepitus Rt………….. Lt……………

2.10 Leg length Rt=……….cm. Lt =…………cm.

2.11 alignment of knee joint

ICD= …………cm. IPD=…………cm. ITD=…………cm.

2.12 special test

| | Rt | | Lt | |
|---|---|---|---|---|
| 1.Valgus test | ☐positive | ☐negative…. | ☐positive | ☐negative……. |
| 2.Valrus test | ☐positive | ☐negative…. | ☐positive | ☐negative……. |
| 3.Anterior Drawer test | ☐positive | ☐negative…. | ☐positive | ☐negative……. |
| 4.Posterior Drawer test | ☐positive | ☐negative…. | ☐positive | ☐negative……. |
| 5.Mc Murray test | ☐positive | ☐negative…. | ☐positive | ☐negative….. |
| 6.Patella gliding | ☐positive | ☐negative…. | ☐positive | ☐negative……. |

2.13 Muscle power

| Muscle power | Rt | Lt |
|---|---|---|
| Flexor m. | | |
| Extensor m. | | |

Score of ISOA and common label of the handicap

| **Points** | **Handicap** |
|---|---|
| ≥14 | Extremely severe |
| 11-13 | Very severe |
| 8-10 | Severe |
| 5-7 | Moderate |
| 1-4 | Minor |

# APPENDIX C

## RAW DATA

**Table C1.** Characteristics of subjects with symptomatic knee osteoarthritis

| Subjects | Age (years) | Weight (kg.) | Height (cm.) | Affected side |
|---|---|---|---|---|
| 1 | 54 | 53 | 149 | Rt>Lt |
| 2 | 60 | 73 | 154 | Lt |
| 3 | 52 | 56 | 155 | Rt>Lt |
| 4 | 50 | 64 | 160 | Rt |
| 5 | 46 | 67 | 155 | Lt>Rt |
| 6 | 45 | 63 | 155 | Rt |
| 7 | 53 | 66 | 157.5 | Rt>Lt |
| 8 | 54 | 72 | 153 | Lt>Rt |
| 9 | 47 | 68 | 150 | Rt>Lt |
| 10 | 55 | 58 | 160 | Rt>Lt |
| 11 | 50 | 67 | 159 | Lt |
| 12 | 60 | 52 | 153 | Lt>Rt |
| 13 | 55 | 48 | 156 | Rt>Lt |
| 14 | 51 | 59 | 160 | Lt>Rt |
| 15 | 50 | 56 | 158.5 | Lt>Rt |
| 16 | 58 | 58 | 146 | Lt>Rt |
| 17 | 49 | 46 | 149 | Lt>Rt |
| 18 | 46 | 73 | 163 | Lt |
| 19 | 40 | 55 | 155 | Lt>Rt |
| 20 | 55 | 68 | 151.5 | Rt>Lt |
| 21 | 50 | 63 | 158 | Rt |
| 22 | 43 | 56 | 150 | Rt |
| 23 | 42 | 64 | 167 | Lt>Rt |
| 24 | 53 | 68 | 155 | Rt |
| 25 | 59 | 63 | 146 | Lt>Rt |
| 26 | 60 | 56 | 155 | Rt>Lt |
| 27 | 54 | 70 | 156 | Lt |
| 28 | 42 | 63 | 161 | Lt |
| 29 | 49 | 50 | 158 | Lt |
| 30 | 53 | 71 | 158 | Lt |

**Table C2.** Characteristics of subjects without symptomatic knee osteoarthritis

| Subjects | Age (years) | Weight (kg.) | Height (cm.) |
|---|---|---|---|
| 1 | 59 | 52 | 153 |
| 2 | 49 | 61 | 154.5 |
| 3 | 59 | 72 | 158 |
| 4 | 57 | 55 | 150 |
| 5 | 47 | 50 | 154 |
| 6 | 40 | 58 | 145.5 |
| 7 | 52 | 67 | 167.5 |
| 8 | 43 | 52 | 152 |
| 9 | 43 | 52 | 153 |
| 10 | 45 | 64 | 166 |
| 11 | 49 | 62 | 152.5 |
| 12 | 42 | 50 | 150 |
| 13 | 55 | 66 | 152.5 |
| 14 | 46 | 63 | 158 |
| 15 | 44 | 50 | 155 |
| 16 | 42 | 53 | 155 |
| 17 | 50 | 54 | 157 |
| 18 | 46 | 54 | 154 |
| 19 | 50 | 58 | 145 |
| 20 | 53 | 60 | 163 |
| 21 | 54 | 76 | 155.5 |
| 22 | 50 | 66 | 157 |
| 23 | 49 | 52 | 148 |
| 24 | 48 | 61 | 148 |
| 25 | 44 | 67 | 163 |
| 26 | 49 | 56 | 147 |
| 27 | 50 | 49 | 145.5 |
| 28 | 59 | 59.3 | 152 |
| 29 | 59 | 50.4 | 150 |
| 30 | 60 | 54.5 | 147 |

**Table C3.** The percentage of maximum stability obtained from SOT

| Subjects | Trial | The percentage of maximum stability (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eye open | | Eye closed | | Sway-referenced vision | | Eye opren and sway-ref erenced surface | | Eye closed and sway-referenced srface | | Sway-refernced vision and surface | |
| | | OA | Control | OA | control | OA | control | OA | control | OA | control | OA | control |
| 1 | 1 | 93 | 95 | 88 | 93 | 89 | 85 | 65 | 77 | 31 | 57 | 34 | N/S |
| | 2 | 95 | 95 | 88 | 94 | 88 | 85 | 69 | 87 | 64 | 59 | 44 | 77 |
| 2 | 1 | 94 | 96 | 88 | 93 | 91 | 93 | 65 | 89 | 61 | 50 | 54 | 40 |
| | 2 | 94 | 93 | 87 | 94 | 87 | 87 | 62 | 63 | 63 | 57 | 58 | 53 |
| 3 | 1 | 93 | 95 | 87 | 79 | 88 | 87 | 75 | 76 | 65 | 66 | 40 | 48 |
| | 2 | 92 | 91 | 89 | 88 | 90 | 91 | 71 | 84 | 52 | 73 | 52 | 65 |
| 4 | 1 | 96 | 90 | 92 | 93 | 90 | 90 | 57 | 84 | N/S | 46 | N/S | 33 |
| | 2 | 91 | 96 | 88 | 90 | 85 | 92 | 60 | 93 | 27 | 78 | 36 | 75 |
| 5 | 1 | 95 | 97 | 91 | 93 | 82 | 84 | 91 | 85 | 58 | 52 | 52 | 62 |
| | 2 | 95 | 96 | 87 | 94 | 84 | 92 | 67 | 86 | 61 | 65 | 63 | 50 |
| 6 | 1 | 94 | 95 | 92 | 93 | 79 | 88 | 80 | 73 | 35 | 70 | N/S | 50 |
| | 2 | 95 | 95 | 91 | 93 | 93 | 91 | 78 | 65 | 31 | 68 | 39 | 61 |
| 7 | 1 | 94 | 97 | 92 | 91 | 88 | 92 | 83 | 84 | N/S | 77 | 53 | 72 |
| | 2 | 92 | 95 | 92 | 92 | 89 | 90 | 85 | 89 | 80 | 74 | 70 | 77 |
| 8 | 1 | 93 | 95 | 90 | 93 | 87 | 95 | 85 | 98 | 70 | 59 | 58 | 58 |
| | 2 | 95 | 96 | 89 | 91 | 84 | 93 | 74 | 84 | 58 | 65 | 64 | 51 |
| 9 | 1 | 91 | 94 | 87 | 89 | 86 | 91 | 57 | 84 | 49 | 58 | N/S | 56 |
| | 2 | 93 | 95 | 91 | 89 | 85 | 90 | 73 | 80 | 66 | 59 | 60 | 74 |
| 10 | 1 | 93 | 94 | 89 | 89 | 73 | 88 | 66 | 68 | 52 | N/S | 44 | N/S |
| | 2 | 91 | 97 | 94 | 94 | .75 | 93 | 81 | 80 | 54 | 28 | 42 | 51 |
| 11 | 1 | 93 | 92 | 88 | 89 | 87 | 83 | 67 | 71 | 50 | 47 | 46 | 49 |
| | 2 | 94 | 92 | 90 | 88 | 97 | 87 | 66 | 68 | 52 | 24 | 47 | 63 |
| 12 | 1 | 92 | 97 | 90 | 91 | 84 | 93 | 86 | 86 | 51 | N/S | 46 | 56 |
| | 2 | 95 | 97 | 86 | 94 | 84 | 94 | 78 | 84 | 51 | 67 | 65 | 42 |
| 13 | 1 | 94 | 89 | 89 | 90 | 82 | 83 | 60 | 79 | 72 | 72 | 66 | 42 |
| | 2 | 93 | 94 | 90 | 89 | 82 | 78 | 77 | 73 | 74 | 60 | 77 | 61 |
| 14 | 1 | 94 | 94 | 83 | 88 | 84 | 77 | 67 | 56 | 48 | 62 | 21 | 45 |
| | 2 | 89 | 93 | 78 | 90 | 80 | 74 | 75 | 84 | 63 | 81 | 62 | 47 |
| 15 | 1 | 92 | 94 | 93 | 92 | 94 | 92 | 84 | 79 | N/S | 43 | 58 | 28 |
| | 2 | 97 | 95 | 93 | 93 | 95 | 92 | 79 | 91 | N/S | 66 | 54 | 60 |

**Table C3.** The percentage of maximum stability obtained from SOT (continued)

| Subjects | Trial | The percentage of maximum stability (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eye open | | Eye closed | | Sway-referenced vision | | Eye opren and sway-ref erenced surface | | Eye closed and sway-referenced srface | | Sway-refernced vision and surface | |
| | | OA | control | OA | control | OA | Control | OA | control | OA | control | OA | Control |
| 16 | 1 | 94 | 92 | 85 | 89 | 84 | 86 | 83 | 79 | 65 | 30 | 61 | 48 |
| | 2 | 95 | 96 | 90 | 93 | 89 | 84 | 71 | 71 | 70 | 36 | 59 | 36 |
| 17 | 1 | 94 | 95 | 92 | 94 | 92 | 93 | 70 | 66 | 21 | 57 | N/S | N/S |
| | 2 | 95 | 90 | 95 | 93 | 81 | 86 | 71 | 70 | 54 | 58 | N/S | 51 |
| 18 | 1 | 95 | 95 | 88 | 91 | 88 | 90 | 66 | 76 | 49 | 62 | 40 | N/S |
| | 2 | 93 | 96 | 88 | 92 | 87 | 91 | 83 | 77 | 62 | 58 | 60 | 64 |
| 19 | 1 | 95 | 91 | 93 | 95 | 96 | 81 | 67 | 81 | 57 | 64 | 45 | 53 |
| | 2 | 94 | 93 | 92 | 91 | 90 | 85 | 70 | 85 | 57 | 78 | 52 | 66 |
| 20 | 1 | 96 | 95 | 84 | 92 | 90 | 92 | 76 | 75 | 77 | 80 | 66 | 65 |
| | 2 | 94 | 89 | 91 | 92 | 84 | 95 | 81 | 74 | 55 | 72 | 63 | 67 |
| 21 | 1 | 88 | 95 | 92 | 92 | 87 | 81 | 67 | 81 | 63 | N/S | 64 | 39 |
| | 2 | 88 | 96 | 93 | 91 | 88 | 87 | 50 | 85 | 64 | 66 | 64 | 63 |
| 22 | 1 | 95 | 94 | 89 | 90 | 94 | 92 | 64 | 67 | 66 | 56 | 60 | 58 |
| | 2 | 92 | 93 | 93 | 90 | 91 | 95 | 87 | 66 | 74 | 64 | 72 | 66 |
| 23 | 1 | 97 | 95 | 92 | 87 | 93 | 91 | 82 | 56 | 80 | 68 | 77 | N/S |
| | 2 | 97 | 93 | 94 | 94 | 92 | 93 | 98 | 77 | 74 | 73 | 73 | 42 |
| 24 | 1 | 93 | 94 | 81 | 91 | 85 | 87 | 73 | 89 | 34 | 86 | N/S | 70 |
| | 2 | 95 | 95 | 91 | 95 | 77 | 85 | 75 | 88 | 41 | 77 | N/S | 81 |
| 25 | 1 | 94 | 95 | 92 | 82 | 79 | 84 | 59 | 46 | 59 | 46 | N/S | 36 |
| | 2 | 90 | 96 | 88 | 91 | 88 | 94 | 71 | 89 | 66 | 78 | 55 | 50 |
| 26 | 1 | 91 | 91 | 86 | 93 | 79 | 82 | 77 | 53 | 41 | 56 | N/S | 40 |
| | 2 | 88 | 89 | 90 | 91 | 83 | 87 | 81 | 53 | 69 | 67 | 57 | 74 |
| 27 | 1 | 92 | 96 | 91 | 93 | 84 | 88 | 52 | 64 | 46 | 64 | N/S | N/S |
| | 2 | 94 | 95 | 91 | 93 | 82 | 92 | 56 | 70 | 62 | 72 | 58 | 33 |
| 28 | 1 | 95 | 92 | 91 | 85 | 90 | 83 | 80 | 74 | 77 | 32 | 55 | 21 |
| | 2 | 93 | 93 | 94 | 89 | 92 | 89 | 81 | 77 | 77 | 41 | 57 | 43 |
| 29 | 1 | 95 | 96 | 92 | 91 | 93 | 80 | 71 | 68 | 44 | 78 | N/S | 49 |
| | 2 | 97 | 95 | 93 | 94 | 92 | 92 | 81 | 81 | 49 | 75 | 58 | 70 |
| 30 | 1 | 94 | 95 | 85 | 92 | 83 | 87 | 81 | 66 | 41 | 29 | 46 | 16 |
| | 2 | 89 | 96 | 86 | 89 | 88 | 89 | 85 | 61 | 72 | 25 | 48 | 32 |

**Table C4.** Sway velocity obtained from SOT

| Subjects | Trial | Sway velocity (degree/second) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eye open | | Eye closed | | Sway-referenced vision | | Eye open and sway-referenced suffuce | | Eye closed and sway-referenced surface | | Sway-referenced vision and surface | |
| | | OA | Control | OA | control | OA | control | OA | control | OA | control | OA | control |
| 1 | 1 | 0.4 | 0.2 | 0.5 | 0.3 | 0.7 | 0.4 | 0.8 | 0.6 | 1.6 | 1.1 | 1.7 | N/S |
| | 2 | 0.3 | 0.2 | 0.6 | 0.3 | 0.9 | 0.5 | 0.6 | 0.4 | 1.5 | 1.0 | 1.3 | 0.7 |
| 2 | 1 | 0.2 | 0.2 | 0.3 | 0.4 | 0.3 | 0.3 | 0.7 | 0.4 | 1.4 | 0.8 | 0.8 | 1.6 |
| | 2 | 0.3 | 0.2 | 0.5 | 0.4 | 0.7 | 0.5 | 0.8 | 1.5 | 1.8 | 1.0 | 0.7 | 1.2 |
| 3 | 1 | 0.4 | 0.2 | 0.6 | 0.7 | 0.6 | 0.4 | 1.1 | 0.5 | N/S | 0.9 | 2.0 | 1.1 |
| | 2 | 0.4 | 0.4 | 0.6 | 0.8 | 0.4 | 0.4 | 0.7 | 0.5 | 3.0 | 1.0 | 1.3 | 0.9 |
| 4 | 1 | 0.2 | 0.3 | 0.4 | 0.3 | 0.3 | 0.4 | 1.0 | 0.4 | 1.2 | 1.1 | N/S | 1.0 |
| | 2 | 0.3 | 0.2 | 0.8 | 0.6 | 0.5 | 0.3 | 2.0 | 0.3 | 1.4 | 0.6 | 3.7 | 0.5 |
| 5 | 1 | 0.2 | 0.2 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.6 | 1.3 | 1.3 | 1.3 | 0.7 |
| | 2 | 0.3 | 0.2 | 0.6 | 0.3 | 0.5 | 0.4 | 0.8 | 0.5 | 1.1 | 0.9 | 0.8 | 1.0 |
| 6 | 1 | 0.3 | 0.1 | 0.3 | 0.3 | 0.6 | 0.3 | 0.5 | 0.5 | N/S | 0.9 | N/S | 1.1 |
| | 2 | 0.3 | 0.1 | 0.4 | 0.3 | 0.4 | 0.2 | 0.5 | 0.6 | 0.6 | 0.8 | 1.8 | 0.9 |
| 7 | 1 | 0.2 | 0.1 | 0.4 | 0.5 | 0.5 | 0.3 | 0.4 | 0.4 | 1.8 | 1.3 | 1.0 | 0.6 |
| | 2 | 0.3 | 0.2 | 0.4 | 0.3 | 0.5 | 0.3 | 0.5 | 0.3 | 1.6 | 1.2 | 0.6 | 0.6 |
| 8 | 1 | 0.3 | 0.2 | 0.3 | 0.4 | 0.4 | 0.2 | 0.7 | 0.2 | 2.6 | 0.8 | 1.7 | 1.1 |
| | 2 | 0.3 | 0.3 | 0.5 | 0.5 | 0.5 | 0.4 | 0.9 | 0.5 | 2.1 | 0.8 | 1.3 | 1.1 |
| 9 | 1 | 0.4 | 0.2 | 0.6 | 0.4 | 0.6 | 0.3 | 0.9 | 0.5 | 2.0 | N/S | N/S | 1.0 |
| | 2 | 0.3 | 0.2 | 0.4 | 0.5 | 0.5 | 0.5 | 0.7 | 0.7 | 1.8 | 1.2 | 1.3 | 0.8 |
| 10 | 1 | 0.3 | 0.3 | 0.4 | 0.5 | 1.0 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 2.3 | N/S |
| | 2 | 0.2 | 0.2 | 0.3 | 0.3 | 1.0 | 0.3 | 0.8 | 0.6 | 1.6 | 1.6 | 1.9 | 0.9 |
| 11 | 1 | 0.2 | 0.3 | 0.4 | 0.3 | 0.4 | 0.4 | 0.8 | 0.8 | 1.5 | 1.1 | 1.1 | 1.4 |
| | 2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.2 | 0.5 | 0.6 | 0.7 | 1.5 | 1.1 | 0.9 | 1.0 |
| 12 | 1 | 0.4 | 0.1 | 0.5 | 0.3 | 0.5 | 0.3 | 0.6 | 0.3 | 1.0 | N/S | 1.5 | 0.7 |
| | 2 | 0.3 | 0.2 | 0.4 | 0.2 | 0.5 | 0.2 | 0.7 | 0.2 | 0.8 | 1.0 | 1.2 | 1.0 |
| 13 | 1 | 0.2 | 0.2 | 0.4 | 0.3 | 0.6 | 0.4 | 1.0 | 0.4 | 1.0 | 1.3 | 0.8 | 1.2 |
| | 2 | 0.3 | 0.2 | 0.5 | 0.6 | 0.6 | 0.7 | 0.8 | 0.6 | 0.8 | 1.3 | 0.6 | 1.8 |
| 14 | 1 | 0.2 | 0.2 | 0.6 | 0.3 | 0.5 | 0.5 | 1.4 | 0.7 | 0.6 | 1.4 | 1.8 | 1.2 |
| | 2 | 0.4 | 0.3 | 0.8 | 0.5 | 0.6 | 0.6 | 0.7 | 0.8 | 1.2 | 1.1 | 1.0 | 1.4 |
| 15 | 1 | 0.2 | 0.3 | 0.3 | 0.4 | 0.2 | 0.3 | 0.4 | 0.7 | N/S | 1.4 | 1.1 | 1.9 |
| | 2 | 0.1 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 | 0.6 | 0.4 | N/S | 1.0 | 1.3 | 1.1 |

**Table C4.** Sway velocity obtained from SOT (continued)

| Subjects | Trial | Sway velocity (degree/second) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Eye open | | Eye colsed | | Sway-referenced vision | | Eye open and sway-referenced surface | | Eye closed and sway-referenced surface | | Sway-referenced vision and surface | |
| | | OA | control | OA | control | OA | control | OA | control | OA | control | OA | control |
| 16 | 1 | 0.3 | 0.2 | 0.7 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 1.2 | 2.1 | 1.0 | 1.3 |
| | 2 | 0.3 | 0.2 | 0.5 | 0.3 | 0.3 | 0.9 | 0.6 | 0.9 | 1.1 | 1.6 | 1.0 | 1.4 |
| 17 | 1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.5 | 0.4 | 1.1 | 1.3 | N/S | N/S |
| | 2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.5 | 0.4 | 0.7 | 0.6 | 0.8 | 0.9 | N/S | 0.9 |
| 18 | 1 | 0.2 | 0.3 | 0.4 | 0.4 | 0.4 | 0.5 | 0.6 | 0.5 | 1.8 | 0.8 | 1.3 | N/S |
| | 2 | 0.2 | 0.2 | 0.4 | 0.6 | 0.5 | 0.6 | 0.8 | 0.7 | 1.4 | 0.9 | 1.3 | 1.1 |
| 19 | 1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 | 0.7 | 0.7 | 0.8 | 1.1 | 1.0 | 1.0 |
| | 2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.3 | 0.5 | 0.5 | 0.9 | 0.8 | 0.9 | 0.8 |
| 20 | 1 | 0.2 | 0.2 | 0.5 | 0.3 | 0.5 | 0.3 | 0.7 | 1.0 | 0.9 | 0.6 | 1.0 | 1.2 |
| | 2 | 0.2 | 0.3 | 0.4 | 0.3 | 0.7 | 0.3 | 0.6 | 0.9 | 1.2 | 1.3 | 0.9 | 1.5 |
| 21 | 1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.9 | 0.6 | 1.2 | N/S | 1.2 | 1.5 |
| | 2 | 0.3 | 0.3 | 0.4 | 0.7 | 0.8 | 0.5 | 1.2 | 0.5 | 1.1 | 1.2 | 1.0 | 1.0 |
| 22 | 1 | 0.3 | 0.2 | 0.6 | 0.4 | 0.4 | 0.2 | 1.2 | 0.8 | 1.6 | 1.1 | 1.6 | 0.8 |
| | 2 | 0.2 | 0.3 | 0.6 | 0.3 | 0.6 | 0.3 | 0.6 | 1.3 | 1.4 | 1.0 | 1.0 | 0.7 |
| 23 | 1 | 0.2 | 0.2 | 0.4 | 0.5 | 0.3 | 0.6 | 0.5 | 1.0 | 1.1 | 0.8 | 1.1 | N/S |
| | 2 | 0.1 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.2 | 0.7 | 0.7 | 0.8 | 1.0 | 1.2 |
| 24 | 1 | 0.3 | 0.3 | 0.7 | 0.4 | 0.8 | 0.4 | 0.6 | 0.4 | 1.4 | 0.5 | N/S | 0.9 |
| | 2 | 0.3 | 0.3 | 0.5 | 0.4 | 0.7 | 0.6 | 0.7 | 0.7 | 1.6 | 1.0 | N/S | 0.8 |
| 25 | 1 | 0.4 | 0.2 | 0.4 | 0.4 | 0.5 | 0.3 | 1.2 | 1.0 | 1.3 | 1.2 | N/S | 1.2 |
| | 2 | 0.6 | 0.2 | 0.5 | 0.2 | 0.5 | 0.2 | 0.5 | 0.3 | 1.0 | 0.6 | 0.8 | 0.8 |
| 26 | 1 | 0.3 | 0.3 | 0.5 | 0.2 | 0.5 | 0.6 | 0.7 | 1.1 | 1.7 | 1.5 | N/S | 1.2 |
| | 2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.6 | 0.7 | 0.9 | 1.2 | 1.1 | 1.4 | 0.7 |
| 27 | 1 | 0.3 | 0.2 | 0.4 | 0.3 | 0.5 | 0.3 | 1.4 | 0.7 | 1.9 | 1.1 | N/S | N/S |
| | 2 | 0.3 | 0.2 | 0.4 | 0.3 | 0.6 | 0.3 | 1.9 | 0.7 | 1.5 | 1.2 | 2.6 | 1.6 |
| 28 | 1 | 0.1 | 0.4 | 0.3 | 0.6 | 0.3 | 0.5 | 0.7 | 0.8 | 1.1 | 1.6 | 1.0 | 2.1 |
| | 2 | 0.2 | 0.4 | 0.3 | 0.7 | 0.3 | 0.6 | 0.4 | 1.0 | 1.1 | 1.3 | 0.9 | 1.2 |
| 29 | 1 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.8 | 0.6 | 2.0 | 1.0 | N/S | 0.9 |
| | 2 | 0.1 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 | 0.9 | 0.7 | 1.8 | 0.8 | 1.0 | 0.6 |
| 30 | 1 | 0.2 | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 | 0.5 | 0.6 | 1.7 | 1.8 | 1.2 | 1.4 |
| | 2 | 0.4 | 0.2 | 0.6 | 0.5 | 0.4 | 0.6 | 0.6 | 1.3 | 1.5 | 2.0 | 1.1 | 1.3 |

**Table C5**. Center Target of subjects with symptomatic knee osteoarthritis

| Subjects | Sway velocity (degree/second) | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 1 | 0.3 | 0.3 |
| 2 | 0.3 | 0.2 |
| 3 | 0.4 | 0.5 |
| 4 | 0.3 | 0.4 |
| 5 | 0.3 | 0.5 |
| 6 | 0.3 | 0.4 |
| 7 | 0.2 | 0.2 |
| 8 | 0.4 | 0.3 |
| 9 | 0.6 | 0.5 |
| 10 | 0.4 | 0.3 |
| 11 | 0.4 | 0.3 |
| 12 | 0.5 | 0.4 |
| 13 | 0.2 | 0.3 |
| 14 | 0.5 | 0.4 |
| 15 | 0.4 | 0.3 |
| 16 | 0.3 | 0.3 |
| 17 | 0.3 | 0.3 |
| 18 | 0.2 | 0.3 |
| 19 | 0.3 | 0.3 |
| 20 | 0.4 | 0.5 |
| 21 | 0.3 | 0.3 |
| 22 | 0.4 | 0.3 |
| 23 | 0.3 | 0.3 |
| 24 | 0.4 | 0.5 |
| 25 | 0.6 | 0.6 |
| 26 | 0.3 | 0.3 |
| 27 | 0.3 | 0.5 |
| 28 | 0.2 | 0.2 |
| 29 | 0.4 | 0.3 |
| 30 | 0.4 | 0.5 |

**Table C6.** Center Target of subjects without symptomatic knee osteoarthritis

| Subjects | Sway velocity (degree/second) | |
|---|---|---|
| | Trial 1 | Trial 2 |
| 1 | 0.3 | 0.2 |
| 2 | 0.4 | 0.5 |
| 3 | 0.4 | 0.2 |
| 4 | 0.5 | 0.5 |
| 5 | 0.3 | 0.2 |
| 6 | 0.2 | 0.3 |
| 7 | 0.3 | 0.2 |
| 8 | 0.3 | 0.2 |
| 9 | 0.3 | 0.3 |
| 10 | 0.2 | 0.3 |
| 11 | 0.3 | 0.5 |
| 12 | 0.4 | 0.2 |
| 13 | 0.3 | 0.5 |
| 14 | 0.3 | 0.3 |
| 15 | 0.7 | 0.4 |
| 16 | 0.3 | 0.2 |
| 17 | 0.3 | 0.4 |
| 18 | 0.4 | 0.2 |
| 19 | 0.5 | 0.3 |
| 20 | 0.4 | 0.3 |
| 21 | 0.4 | 0.3 |
| 22 | 0.2 | 0.2 |
| 23 | 0.8 | 0.4 |
| 24 | 0.4 | 0.4 |
| 25 | 0.2 | 0.2 |
| 26 | 0.3 | 0.3 |
| 27 | 0.3 | 0.3 |
| 28 | 0.5 | 0.7 |
| 29 | 0.2 | 0.3 |
| 30 | 0.2 | 0.3 |

**Table C7.** On axis velocity and directional control obtained from Rhythmic Weight shift Left/Right of subjects with symptomatic knee osteoarthritis

| Subjects | On axis velocity(degree/second) | | | | | | Directional Control (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slow | | Moderate | | Fast | | Slow | | Moderate | | Fast | |
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 2.2 | 2.4 | 3.7 | 4.1 | 8.6 | 7.3 | 69 | 68 | 84 | 88 | 92 | 87 |
| 2 | 3.2 | 2.5 | 5.2 | 4.8 | 8.7 | 11.6 | 79 | 74 | 80 | 83 | 89 | 88 |
| 3 | 2.5 | 3.3 | 4.4 | 4.3 | 7.7 | 8.5 | 81 | 85 | 85 | 87 | 86 | 85 |
| 4 | 2.8 | 3.0 | 5.6 | 4.2 | 10.4 | 9.0 | 78 | 78 | 87 | 86 | 90 | 85 |
| 5 | 2.7 | 2.5 | 4.3 | 4.0 | 7.0 | 7.4 | 76 | 79 | 82 | 83 | 84 | 87 |
| 6 | 2.9 | 3.5 | 4.8 | 5.7 | 12.1 | 12.0 | 82 | 79 | 84 | 84 | 93 | 90 |
| 7 | 3.4 | 3.2 | 4.5 | 4.8 | 8.0 | 7.9 | 85 | 84 | 87 | 89 | 93 | 92 |
| 8 | 2.8 | 3.4 | 4.8 | 5.2 | 5.0 | 8.3 | 81 | 89 | 87 | 89 | 89 | 89 |
| 9 | 3.1 | 2.5 | 4.0 | 4.3 | 7.0 | 8.1 | 84 | 83 | 87 | 87 | 89 | 90 |
| 10 | 2.9 | 2.9 | 4.1 | 4.6 | 9.2 | 9.3 | 75 | 79 | 88 | 85 | 87 | 92 |
| 11 | 3.3 | 3.6 | 4.8 | 4.9 | 7.7 | 7.1 | 73 | 87 | 91 | 87 | 87 | 89 |
| 12 | 1.5 | 2.3 | 2.7 | 3.1 | 3.0 | 4.2 | 69 | 66 | 82 | 74 | 79 | 97 |
| 13 | 3.0 | 2.9 | 2.7 | 4.6 | 9.2 | 8.0 | 85 | 88 | 87 | 87 | 92 | 90 |
| 14 | 4.1 | 5.2 | 4.0 | 7.0 | 6.8 | 8.3 | 79 | 80 | 78 | 84 | 87 | 89 |
| 15 | 3.3 | 3.3 | 5.3 | 4.5 | 10.2 | 10.0 | 77 | 82 | 89 | 88 | 91 | 90 |
| 16 | 3.2 | 3.0 | 5.4 | 5.0 | 11.4 | 10.1 | 81 | 83 | 86 | 82 | 94 | 90 |
| 17 | 3.6 | 3.3 | 3.8 | 4.7 | 7.6 | 9.6 | 41 | 75 | 69 | 84 | 87 | 90 |
| 18 | 3.1 | 3.5 | 4.5 | 5.3 | 6.3 | 5.1 | 77 | 79 | 85 | 88 | 87 | 84 |
| 19 | 3.3 | 3.1 | 5.1 | 5.2 | 13.0 | 12.0 | 88 | 86 | 91 | 92 | 90 | 93 |
| 20 | 2.8 | 2.9 | 4.5 | 4.1 | 10.4 | 4.0 | 84 | 81 | 83 | 86 | 93 | 81 |
| 21 | 2.9 | 3.1 | 4.5 | 4.9 | 6.0 | 9.0 | 79 | 79 | 83 | 83 | 88 | 91 |
| 22 | 2.5 | 2.8 | 4.7 | 4.6 | 7.3 | 7.9 | 79 | 82 | 90 | 87 | 88 | 92 |
| 23 | 2.9 | 3.0 | 3.6 | 4.4 | 9.3 | 9.4 | 83 | 86 | 79 | 91 | 81 | 95 |
| 24 | 2.3 | 2.7 | 4.9 | 4.0 | 7.1 | 8.7 | 72 | 83 | 80 | 72 | 91 | 88 |
| 25 | 2.7 | 2.4 | 4.1 | 4.0 | 6.0 | 8.7 | 81 | 73 | 86 | 80 | 78 | 83 |
| 26 | 2.7 | 2.5 | 3.6 | 3.6 | 8.1 | 5.4 | 71 | 76 | 84 | 80 | 85 | 87 |
| 27 | 2.7 | 2.7 | 3.1 | 4.3 | 6.6 | 3.7 | 83 | 78 | 83 | 80 | 88 | 82 |
| 28 | 2.6 | 3.3 | 3.9 | 5.1 | 8.2 | 8.9 | 85 | 83 | 89 | 86 | 90 | 93 |
| 29 | 2.9 | 3.2 | 4.4 | 4.0 | 5.6 | 4.8 | 76 | 84 | 87 | 79 | 88 | 90 |
| 30 | 3.3 | 4.0 | 4.6 | 5.5 | 9.4 | 8.6 | 75 | 78 | 84 | 83 | 85 | 94 |

**Table C8.** On axis velocity and directional control obtained from Rhythmic Weight shift Left/Right of subjects without symptomatic knee osteoarthritis

| Subjects | On axis velocity(degree/second) | | | | | | Directional Control (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slow | | Moderate | | Fast | | Slow | | Moderate | | Fast | |
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 2.6 | 2.8 | 4.0 | 4.5 | 7.6 | 8.6 | 81 | 72 | 87 | 80 | 89 | 82 |
| 2 | 2.8 | 2.8 | 4.8 | 4.6 | 10.0 | 9.3 | 78 | 78 | 88 | 84 | 92 | 84 |
| 3 | 2.8 | 2.7 | 4.8 | 5.0 | 9.4 | 8.2 | 83 | 75 | 85 | 85 | 92 | 85 |
| 4 | 3.9 | 3.8 | 5.4 | 5.3 | 11.2 | 9.7 | 83 | 81 | 89 | 89 | 92 | 92 |
| 5 | 2.6 | 3.3 | 5.0 | 5.0 | 10.5 | 10.3 | 86 | 84 | 89 | 85 | 86 | 91 |
| 6 | 3.6 | 3.2 | 4.8 | 4.5 | 7.2 | 8.2 | 88 | 87 | 91 | 89 | 94 | 89 |
| 7 | 3.0 | 3.1 | 4.4 | 4.9 | 7.7 | 8.3 | 84 | 85 | 87 | 91 | 94 | 96 |
| 8 | 2.7 | 4.3 | 5.3 | 4.5 | 8.2 | 9.8 | 77 | 77 | 84 | 80 | 89 | 85 |
| 9 | 3.1 | 3.2 | 5.1 | 5.8 | 10.6 | 11.4 | 78 | 88 | 87 | 91 | 90 | 89 |
| 10 | 3.3 | 3.4 | 6.0 | 5.8 | 12.9 | 11.0 | 87 | 81 | 85 | 85 | 92 | 87 |
| 11 | 3.4 | 3.7 | 5.8 | 5.5 | 12.1 | 8.6 | 76 | 78 | 82 | 83 | 93 | 84 |
| 12 | 3.1 | 2.9 | 5.2 | 5.2 | 9.3 | 9.2 | 83 | 83 | 81 | 88 | 76 | 94 |
| 13 | 3.1 | 3.0 | 4.1 | 4.7 | 7.1 | 8.4 | 86 | 84 | 87 | 91 | 92 | 92 |
| 14 | 2.9 | 3.0 | 5.1 | 4.4 | 8.1 | 10.9 | 68 | 73 | 79 | 78 | 83 | 88 |
| 15 | 2.9 | 3.3 | 4.8 | 4.9 | 5.9 | 8.6 | 66 | 80 | 75 | 77 | 79 | 89 |
| 16 | 4.0 | 3.3 | 5.9 | 5.1 | 8.0 | 10.7 | 83 | 86 | 88 | 83 | 91 | 91 |
| 17 | 2.7 | 3.1 | 4.4 | 4.4 | 6.4 | 10.9 | 79 | 80 | 87 | 86 | 88 | 92 |
| 18 | 3.2 | 3.3 | 5.0 | 5.5 | 10.4 | 10.6 | 86 | 86 | 78 | 82 | 93 | 91 |
| 19 | 4.2 | 3.4 | 6.6 | 6.1 | 12.3 | 9.4 | 68 | 79 | 84 | 87 | 91 | 91 |
| 20 | 1.9 | 2.8 | 4.1 | 4.4 | 8.1 | 9.8 | 69 | 85 | 76 | 91 | 90 | 96 |
| 21 | 2.8 | 2.7 | 3.7 | 3.7 | 9.7 | 9.3 | 81 | 81 | 84 | 82 | 86 | 90 |
| 22 | 3.2 | 3.2 | 4.1 | 5.3 | 11.2 | 11.2 | 87 | 87 | 87 | 90 | 93 | 92 |
| 23 | 3.2 | 3.6 | 4.4 | 5.0 | 10.5 | 9.3 | 78 | 86 | 79 | 86 | 86 | 89 |
| 24 | 3.3 | 2.8 | 2.9 | 4.5 | 6.1 | 7.7 | 87 | 86 | 84 | 91 | 88 | 93 |
| 25 | 2.9 | 3.1 | 4.3 | 4.7 | 9.5 | 10.3 | 86 | 81 | 92 | 93 | 87 | 89 |
| 26 | 2.9 | 2.9 | 2.6 | 4.7 | 10.2 | 10.8 | 79 | 82 | 73 | 87 | 86 | 86 |
| 27 | 2.9 | 2.8 | 3.9 | 4.7 | 9.7 | 6.3 | 75 | 82 | 86 | 89 | 90 | 85 |
| 28 | 2.9 | 3.5 | 3.6 | 4.9 | 10.4 | 11.0 | 80 | 74 | 78 | 79 | 90 | 91 |
| 29 | 2.6 | 3.1 | 5.4 | 4.3 | 8.3 | 7.6 | 83 | 86 | 88 | 86 | 83 | 84 |
| 30 | 2.9 | 2.6 | 3.6 | 4.0 | 7.9 | 8.6 | 86 | 78 | 89 | 79 | 88 | 90 |

**Table C9.** Reaction time (second) obtained from the Limits of Stability test of subjects with symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 1.36 | 0.32 | 1.28 | 1.18 | 1.08 | 0.64 | 0.72 | 0.52 | 0.42 | 0.92 | 0.96 | 0.70 | 0.66 | 0.60 | 1.08 | 0.88 |
| 2 | 1.00 | 1.44 | 1.34 | 1.72 | 1.50 | 1.40 | 2.02 | 1.78 | 1.82 | 2.20 | 1.78 | 1.08 | 1.68 | 1.46 | 2.16 | 1.28 |
| 3 | 3.14 | 0.50 | 0.54 | 0.72 | 0.78 | 0.76 | N/S | 1.22 | N/S | 0.42 | N/S | 1.10 | 0.50 | 1.04 | 1.60 | 1.62 |
| 4 | 0.56 | 0.78 | 0.70 | 0.46 | 0.98 | 0.84 | 1.16 | 0.62 | 0.74 | N/S | 0.68 | 0.60 | 1.22 | 1.22 | 1.24 | 0.74 |
| 5 | 3.30 | 0.64 | 2.80 | 0.48 | 0.56 | 0.60 | 0.50 | 1.18 | 0.20 | 1.20 | 0.60 | 0.66 | 0.44 | 1.06 | 1.02 | 1.24 |
| 6 | 2.00 | 0.52 | 0.60 | 0.66 | 1.30 | 0.60 | 1.14 | 1.22 | 0.76 | 0.70 | 0.36 | 1.16 | 0.70 | 0.70 | 1.46 | 1.32 |
| 7 | 4.34 | 1.42 | 1.08 | 1.28 | 1.38 | 0.76 | 1.72 | 1.50 | 0.48 | 1.40 | 1.76 | 1.58 | 1.38 | 1.30 | 0.88 | 1.16 |
| 8 | 2.28 | 0.66 | 1.94 | 0.62 | 0.82 | 1.22 | N/S | 1.20 | 1.12 | 0.38 | 0.60 | 1.20 | 1.30 | 1.16 | 1.30 | 0.60 |
| 9 | 1.36 | 0.66 | 1.20 | 0.60 | 1.26 | 1.16 | 0.58 | 1.14 | 0.28 | 0.56 | 1.08 | 1.22 | 1.30 | 1.34 | 1.40 | 0.70 |
| 10 | 1.52 | 1.46 | 0.80 | 0.62 | 0.72 | 0.64 | 0.50 | 0.94 | 1.08 | 0.38 | 0.74 | 1.32 | 1.20 | 1.34 | 0.74 | 1.30 |
| 11 | 0.74 | 1.44 | 4.70 | 1.34 | 4.36 | 0.60 | 1.30 | 0.80 | 1.20 | 0.84 | 1.04 | 0.90 | 1.34 | 0.42 | 1.20 | 0.66 |
| 12 | 1.84 | 1.64 | N/S | 0.66 | 3.02 | 0.66 | 0.56 | 1.10 | 1.00 | 0.92 | 0.68 | 0.92 | 0.62 | 1.00 | 1.20 | 1.10 |
| 13 | 2.22 | 0.56 | 1.18 | 0.64 | 0.74 | 0.64 | 0.86 | 1.28 | 0.62 | 1.62 | 0.68 | 1.20 | 0.30 | 1.18 | 0.56 | 1.58 |
| 14 | 3.26 | 1.28 | 1.66 | 0.40 | 0.98 | 0.88 | 1.58 | 1.66 | 1.04 | 0.26 | 1.38 | 1.28 | 1.40 | 1.34 | 0.66 | 1.32 |
| 15 | 0.84 | 0.68 | 0.82 | 1.10 | 1.10 | 0.56 | 0.94 | 1.34 | 0.68 | 1.02 | 1.26 | 0.54 | 1.14 | 1.02 | 1.16 | 1.56 |
| 16 | 0.58 | 1.00 | 0.58 | 0.48 | 0.64 | 0.16 | 0.98 | 1.36 | 0.54 | 1.04 | 1.16 | 0.44 | 1.04 | 0.98 | 0.50 | 1.32 |
| 17 | 2.42 | 2.26 | 1.40 | 0.70 | 1.40 | 0.40 | 0.66 | 0.52 | 0.80 | 0.46 | 0.78 | 0.58 | 1.20 | 0.66 | 0.72 | 0.58 |
| 18 | 1.14 | 0.42 | 1.26 | 0.86 | 1.24 | 1.26 | 1.08 | 1.22 | N/S | 1.00 | 1.24 | 0.58 | 0.84 | 1.26 | 0.54 | 1.24 |
| 19 | 0.50 | 0.48 | 0.42 | 0.42 | 0.52 | 0.46 | 0.52 | 0.50 | 0.60 | 0.42 | 0.58 | 0.94 | 0.42 | 0.40 | 0.54 | 0.50 |
| 20 | 0.90 | 0.72 | 0.38 | 0.64 | 0.40 | 0.64 | 0.50 | 0.76 | N/S | 0.86 | 0.74 | 0.68 | 1.12 | 0.76 | 0.20 | 0.88 |
| 21 | 0.94 | 1.16 | 1.34 | 0.50 | 1.14 | 0.54 | 1.08 | 0.44 | 0.60 | 0.94 | 0.66 | 0.48 | 0.38 | 0.46 | 1.34 | 0.56 |
| 22 | 1.02 | 1.16 | 0.66 | 1.32 | 1.42 | 1.26 | 1.08 | 0.56 | N/S | 0.44 | 1.18 | 0.28 | 0.72 | 1.14 | 1.28 | 0.98 |
| 23 | 0.52 | 0.50 | 0.88 | 0.46 | 0.62 | 0.48 | 0.56 | 0.62 | 0.56 | 0.90 | 0.60 | 0.54 | 0.52 | 0.58 | 0.64 | 1.08 |
| 24 | N/S | 0.72 | N/S | 0.64 | 1.12 | 1.00 | 0.88 | 0.76 | 0.70 | 1.00 | 0.50 | 0.56 | 0.72 | 0.58 | 1.08 | 1.28 |
| 25 | 0.88 | 1.20 | 0.82 | 0.94 | 2.16 | 0.74 | 1.26 | 1.12 | 1.82 | 0.56 | 0.76 | 1.06 | 0.98 | 0.58 | 0.92 | 0.72 |
| 26 | 1.10 | 0.62 | 1.28 | 0.72 | 0.54 | 0.74 | 0.88 | 0.44 | 1.12 | 0.92 | 0.60 | 0.54 | 1.24 | 0.74 | 1.30 | 1.12 |
| 27 | N/S | 0.84 | 0.72 | 0.86 | 0.54 | 0.48 | 0.52 | 0.68 | 0.26 | 0.80 | 1.04 | 1.12 | 0.44 | 0.42 | 1.14 | 0.54 |
| 28 | 0.56 | 0.72 | 0.50 | 0.60 | 0.54 | 0.46 | 0.54 | 1.14 | 0.58 | 0.58 | 0.52 | 0.54 | 0.52 | 0.52 | 0.52 | 1.30 |
| 29 | 0.74 | 1.16 | 1.02 | 0.60 | 0.52 | 0.54 | 0.60 | 0.76 | 1.26 | 1.04 | 1.26 | 0.52 | 1.22 | 1.14 | 1.36 | 0.76 |
| 30 | N/S | 0.40 | 1.28 | 1.28 | 2.96 | 0.76 | 1.84 | 0.60 | 1.34 | 0.50 | 0.30 | 0.62 | 0.56 | 1.04 | 1.12 | 1.56 |

**Table C10.** Reaction time (second) obtained from the Limits of Stability test of subjects without symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 1.60 | 0.76 | 0.82 | 0.58 | 0.64 | 0.68 | 0.72 | 0.72 | 1.02 | 1.22 | 0.70 | 1.16 | 0.84 | 0.70 | 0.70 | 0.80 |
| 2 | 0.52 | 0.78 | 1.24 | 0.52 | 1.02 | 0.58 | 1.04 | 0.52 | 0.80 | 0.56 | 0.76 | 1.14 | 0.74 | 0.54 | 0.62 | 1.28 |
| 3 | 1.74 | 0.98 | 1.46 | 0.70 | 0.56 | 0.64 | 0.92 | 0.44 | 1.16 | N/S | 1.26 | N/S | 0.66 | 0.48 | 0.68 | 1.28 |
| 4 | 0.92 | 1.18 | 0.82 | 0.44 | 0.76 | 0.62 | 1.12 | 0.46 | 0.88 | 0.52 | 0.66 | 0.64 | 0.58 | 0.44 | 0.48 | 0.54 |
| 5 | 1.04 | 0.72 | 0.92 | 0.50 | 0.54 | 0.48 | 0.46 | 0.70 | 0.32 | N/S | 0.80 | 1.12 | 0.70 | 0.80 | 0.64 | 0.64 |
| 6 | 2.68 | 0.82 | 1.12 | 0.58 | 0.66 | 0.42 | 1.04 | 0.50 | 0.86 | 0.72 | 1.02 | 0.44 | 0.92 | 0.56 | 0.78 | 0.38 |
| 7 | 1.22 | 1.10 | 0.70 | 0.50 | 0.48 | 0.48 | 1.02 | 0.58 | 0.40 | 0.48 | 0.50 | 0.60 | 0.56 | 0.54 | 0.54 | 1.04 |
| 8 | 1.22 | 0.72 | 0.84 | 1.38 | N/S | 0.60 | 1.66 | 1.32 | 0.90 | 1.10 | 0.70 | 0.60 | 1.46 | 1.10 | 1.58 | 0.74 |
| 9 | 0.60 | 0.92 | 0.74 | 1.00 | 1.12 | 0.60 | 1.14 | 0.96 | 1.12 | 0.78 | 1.30 | 1.24 | 0.62 | 0.62 | 0.88 | 1.18 |
| 10 | 1.16 | 0.88 | 1.04 | 0.72 | 0.40 | 1.16 | 1.06 | 0.52 | 0.84 | 0.44 | 0.76 | 1.08 | 0.52 | 0.52 | 1.18 | 0.66 |
| 11 | 0.72 | 0.70 | 0.60 | 1.02 | 0.64 | 1.06 | 0.42 | 1.02 | 0.88 | 0.50 | 0.54 | 0.52 | 0.62 | 1.04 | 0.56 | 1.06 |
| 12 | 0.78 | 1.20 | 1.24 | 0.60 | 1.22 | 1.26 | 1.34 | 1.22 | 1.28 | 1.08 | 1.16 | 0.64 | 1.32 | 1.12 | 1.34 | 1.28 |
| 13 | 1.10 | 1.74 | 1.12 | 0.58 | 0.78 | 0.62 | 1.70 | 1.36 | 1.68 | 1.24 | 1.24 | 1.06 | 2.98 | 0.94 | 1.54 | 0.78 |
| 14 | 0.64 | 0.60 | 0.72 | 0.60 | 0.52 | 0.70 | 0.62 | 0.46 | 0.70 | 0.72 | 1.28 | 0.64 | 0.84 | 0.62 | 0.64 | 1.08 |
| 15 | 0.96 | 1.08 | 1.12 | 0.78 | 0.60 | 0.56 | 1.14 | 0.46 | 1.18 | 0.54 | 0.34 | 0.54 | 1.10 | 0.62 | 1.16 | 0.80 |
| 16 | 2.24 | 1.20 | 1.00 | 0.70 | 0.52 | 0.58 | 0.80 | 1.10 | 1.08 | 1.12 | 0.34 | 1.10 | 0.72 | 0.74 | 0.52 | 1.50 |
| 17 | 0.94 | 1.12 | 1.32 | 0.64 | 1.08 | 0.58 | 0.70 | 0.56 | 1.00 | 0.68 | 0.70 | 0.60 | 0.62 | 0.96 | 0.68 | 0.56 |
| 18 | 0.48 | 0.44 | 0.64 | 0.42 | 0.54 | 0.52 | 0.52 | 0.54 | 0.32 | 0.42 | 0.66 | 0.52 | 0.64 | 0.52 | 0.98 | 0.56 |
| 19 | 1.26 | 0.64 | 1.52 | 0.40 | 0.82 | 0.74 | 0.48 | 0.84 | 0.10 | 0.42 | 0.62 | 0.52 | 0.70 | 0.88 | 0.56 | 0.50 |
| 20 | 2.44 | 1.08 | 0.90 | 1.22 | 1.10 | 0.88 | 0.64 | 0.64 | 1.00 | 0.48 | 0.80 | 0.48 | 1.16 | 0.56 | 0.70 | 1.12 |
| 21 | N/S | 0.46 | 0.72 | 0.44 | 0.58 | 0.48 | 0.40 | 0.52 | 0.60 | 0.46 | 0.82 | 1.16 | 0.44 | 0.60 | 0.84 | 0.66 |
| 22 | N/S | 1.44 | 0.92 | 1.20 | 0.58 | 0.46 | 0.96 | 0.50 | 0.88 | 0.60 | 0.54 | 0.52 | 0.48 | 0.52 | 1.30 | 1.16 |
| 23 | 1.10 | 0.50 | 0.98 | 0.56 | 0.62 | 0.62 | 0.62 | 1.14 | 1.16 | 1.14 | 0.76 | 0.48 | 0.64 | 0.74 | 1.12 | 0.70 |
| 24 | 1.82 | 0.94 | N/S | 1.98 | 2.02 | 0.92 | 0.78 | 0.62 | 1.68 | 0.98 | 0.96 | 1.24 | 1.20 | 0.58 | 1.40 | 1.14 |
| 25 | 1.02 | 1.16 | 0.80 | 1.24 | 0.86 | 1.28 | 1.28 | 1.20 | 1.96 | 1.50 | 0.78 | 1.50 | 1.54 | 1.34 | 1.28 | 1.02 |
| 26 | N/S | 0.94 | 1.7 | 1.10 | 1.4 | 0.72 | 1.70 | 0.78 | 1.88 | 0.50 | 1.42 | 1.06 | 1.50 | 1.38 | 1.92 | 1.94 |
| 27 | 1.34 | 1.26 | 1.10 | 1.10 | 1.16 | 0.44 | 1.16 | 0.50 | 1.14 | 0.42 | 1.18 | 1.16 | 1.26 | 1.12 | 1.36 | 1.46 |
| 28 | 0.46 | 1.16 | 0.64 | 0.74 | 0.74 | 0.66 | 0.28 | 0.92 | 1.28 | 0.34 | 0.92 | 0.50 | 0.52 | 0.60 | 0.72 | 0.60 |
| 29 | 0.68 | 1.76 | 0.16 | 1.10 | 1.20 | 0.68 | 0.66 | 1.08 | 0.88 | 0.88 | 0.46 | 0.72 | 1.34 | 1.26 | 1.52 | 0.64 |
| 30 | 1.56 | 0.84 | 0.86 | 0.48 | 0.60 | 0.58 | 0.50 | 0.52 | 0.28 | 0.90 | 0.74 | 0.84 | 0.76 | 0.96 | 1.14 | 1.06 |

**Table C11.** Movement velocity (degree/second) obtained from the Limits of Stability test of subjects with symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 8.1 | 4.0 | 2.5 | 3.8 | 9.9 | 9.3 | 6.0 | 8.7 | 3.9 | 4.6 | 7.0 | 5.6 | 8.3 | 7.6 | 4.4 | 5.2 |
| 2 | 2.3 | 2.2 | 3.0 | 3.0 | 1.8 | 2.4 | 1.4 | 1.6 | 1.8 | 3.2 | 1.6 | 1.8 | 1.8 | 2.8 | 1.6 | 3.0 |
| 3 | 6.2 | 6.1 | 3.2 | 4.5 | 3.5 | 4.1 | N/S | 2.2 | N/S | 2.2 | N/S | 3.6 | 2.5 | 4.2 | 8.6 | 4.3 |
| 4 | 10.8 | 2.2 | 4.1 | 6.4 | 2.6 | 2.2 | 2.5 | 2.8 | 2.0 | N/S | 2.5 | 3.8 | 2.2 | 4.6 | 3.0 | 2.5 |
| 5 | 4.1 | 5.2 | 4.7 | 4.4 | 7.1 | 2.8 | 6.6 | 2.6 | 3.7 | 1.6 | 6.0 | 3.2 | 6.7 | 4.4 | 5.3 | 3.0 |
| 6 | 4.9 | 2.9 | 5.8 | 4.3 | 3.2 | 5.0 | 4.5 | 3.6 | 2.6 | 1.7 | 2.5 | 2.8 | 4.8 | 5.0 | 4.4 | 3.6 |
| 7 | 1.6 | 1.7 | 3.4 | 2.3 | 2.7 | 2.4 | 1.2 | 3.0 | 1.8 | 2.3 | 1.9 | 2.5 | 2.7 | 2.8 | 1.8 | 3.0 |
| 8 | 4.1 | 4.8 | 5.9 | 7.0 | 6.3 | 5.3 | N/S | 2.6 | 2.8 | 2.3 | 1.5 | 3.9 | 5.6 | 3.0 | 3.8 | 3.5 |
| 9 | 2.2 | 2.3 | 3.5 | 3.7 | 2.4 | 2.7 | 2.2 | 2.5 | 1.9 | 2.3 | 2.1 | 2.6 | 2.3 | 3.2 | 3.5 | 1.9 |
| 10 | 5.6 | 3.0 | 6.8 | 2.8 | 6.4 | 3.2 | 2.0 | 2.6 | 1.6 | 3.4 | 2.9 | 3.4 | 3.5 | 2.6 | 2.6 | 2.7 |
| 11 | 1.7 | 4.9 | 5.6 | 5.2 | 5.2 | 6.7 | 2.1 | 2.5 | 2.9 | 1.5 | 1.8 | 2.6 | 5.0 | 7.1 | 2.9 | 4.1 |
| 12 | 2.7 | 5.2 | N/S | 3.3 | 3.1 | 3.1 | 2.8 | 2.1 | 2.2 | 3.4 | 2.4 | 4.5 | 2.0 | 4.7 | 2.3 | 3.6 |
| 13 | 2.6 | 1.9 | 6.7 | 2.7 | 2.7 | 2.8 | 3.0 | 2.7 | 4.5 | 2.2 | 5.8 | 4.4 | 2.2 | 1.9 | 3.6 | 2.0 |
| 14 | 1.9 | 2.3 | 6.1 | 3.8 | 3.2 | 3.1 | 2.4 | 2.2 | 1.8 | 1.3 | 3.9 | 2.8 | 2.3 | 3.9 | 4.8 | 3.5 |
| 15 | 3.9 | 1.5 | 2.7 | 2.7 | 3.3 | 2.2 | 2.4 | 2.4 | 1.5 | 1.5 | 2.4 | 1.4 | 2.4 | 1.9 | 1.8 | 1.9 |
| 16 | 2.7 | 2.2 | 6.9 | 4.8 | 4.7 | 3.1 | 4.9 | 3.2 | 2.5 | 3.3 | 5.2 | 3.3 | 4.5 | 4.4 | 3.4 | 4.3 |
| 17 | 1.3 | 3.7 | 4.8 | 7.5 | 7.1 | 8.1 | 3.5 | 7.7 | 1.7 | 3.7 | 2.7 | 2.8 | 2.4 | 5.3 | 3.1 | 7.4 |
| 18 | 3.9 | 1.7 | 3.1 | 3.1 | 3.4 | 2.6 | 2.2 | 1.3 | N/S | 1.3 | 1.1 | 2.0 | 4.1 | 2.2 | 1.7 | 2.5 |
| 19 | 7.6 | 6.3 | 10.4 | 4.0 | 7.8 | 10.2 | 6.6 | 6.1 | 1.9 | 4.3 | 5.5 | 5.5 | 6.3 | 9.9 | 5.0 | 6.3 |
| 20 | 5.9 | 2.5 | 4.8 | 4.3 | 8.4 | 4.6 | 4.3 | 3.4 | N/S | 1.5 | 3.6 | 4.0 | 5.0 | 6.1 | 7.0 | 5.5 |
| 21 | 4.5 | 5.2 | 3.5 | 6.7 | 5.0 | 6.1 | 3.3 | 3.7 | 3.5 | 1.8 | 4.4 | 5.2 | 3.5 | 6.5 | 4.0 | 6.2 |
| 22 | 8.2 | 2.3 | 4.0 | 2.3 | 2.7 | 2.0 | 2.8 | 3.4 | N/S | 2.0 | 2.6 | 3.0 | 3.6 | 1.7 | 4.7 | 3.3 |
| 23 | 4.7 | 3.3 | 5.1 | 5.2 | 3.8 | 4.2 | 6.0 | 4.8 | 3.8 | 3.0 | 4.7 | 4.0 | 5.4 | 4.2 | 7.5 | 3.5 |
| 24 | N/S | 4.5 | N/S | 4.2 | 3.6 | 3.4 | 4.7 | 2.9 | 3.0 | 6.6 | 3.4 | 3.9 | 4.3 | 3.9 | 8.6 | 3.2 |
| 25 | 0.7 | 1.7 | 3.0 | 3.5 | 2.1 | 3.0 | 4.1 | 1.7 | 1.4 | 3.0 | 5.2 | 3.1 | 2.2 | 4.8 | 3.8 | 3.5 |
| 26 | 2.7 | 2.5 | 1.4 | 2.5 | 3.9 | 3.2 | 4.1 | 5.9 | 4.4 | 2.3 | 2.8 | 3.7 | 4.5 | 4.0 | 4.0 | 3.2 |
| 27 | N/S | 3.0 | 2.3 | 5.8 | 3.2 | 8.1 | 3.8 | 2.4 | 2.8 | 1.7 | 2.6 | 2.8 | 3.9 | 3.0 | 2.9 | 3.7 |
| 28 | 8.5 | 4.6 | 8.3 | 3.0 | 9.9 | 5.1 | 3.9 | 4.0 | 5.3 | 2.5 | 4.2 | 4.5 | 4.9 | 4.1 | 4.8 | 3.7 |
| 29 | 1.8 | 3.0 | 3.4 | 3.4 | 3.0 | 3.3 | 4.7 | 4.4 | 2.0 | 1.6 | 2.6 | 5.1 | 2.9 | 3.6 | 3.1 | 5.3 |
| 30 | N/S | 2.8 | 4.1 | 5.0 | 1.7 | 4.8 | 1.6 | 4.8 | 2.1 | 2.6 | 2.7 | 3.0 | 2.0 | 3.9 | 1.7 | 5.0 |

**Table C12.** Movement velocity (degree/second) obtained from the Limits of Stability test of subjects without symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 5.4 | 5.4 | 4.1 | 6.1 | 5.1 | 6.6 | 2.4 | 2.9 | 1.4 | 2.9 | 2.3 | 3.7 | 7.0 | 6.7 | 5.6 | 4.0 |
| 2 | 3.5 | 2.5 | 4.2 | 3.6 | 3.3 | 3.3 | 1.5 | 4.5 | 2.3 | 3.8 | 4.1 | 1.9 | 5.5 | 3.3 | 2.4 | 3.2 |
| 3 | 5.7 | 2.1 | 5.0 | 5.4 | 7.6 | 6.9 | 8.2 | 6.5 | 7.4 | N/S | 4.0 | N/S | 9.2 | 10.0 | 4.1 | 2.7 |
| 4 | 7.0 | 3.0 | 3.9 | 8.8 | 7.6 | 4.9 | 3.3 | 5.9 | 3.6 | 3.9 | 4.1 | 3.0 | 7.9 | 4.3 | 5.2 | 6.1 |
| 5 | 2.9 | 3.3 | 5.5 | 8.8 | 4.0 | 8.3 | 3.1 | 5.5 | 3.4 | N/S | 3.3 | 2.7 | 4.1 | 5.6 | 3.2 | 5.0 |
| 6 | 3.2 | 1.9 | 3.8 | 4.6 | 3.7 | 8.1 | 3.9 | 4.3 | 2.0 | 7.5 | 5.7 | 5.5 | 3.1 | 4.2 | 3.4 | 5.0 |
| 7 | 1.8 | 2.3 | 3.6 | 9.7 | 6.7 | 8.0 | 1.9 | 2.8 | 2.5 | 2.1 | 4.3 | 4.4 | 5.0 | 5.7 | 3.6 | 4.1 |
| 8 | 3.2 | 2.7 | 8.2 | 2.7 | N/S | 2.8 | 2.0 | 2.6 | 2.7 | 2.8 | 2.2 | 2.5 | 2.9 | 3.4 | 2.5 | 2.3 |
| 9 | 6.9 | 2.5 | 2.4 | 2.7 | 3.2 | 1.9 | 2.3 | 2.2 | 2.5 | 1.8 | 3.4 | 3.1 | 3.2 | 2.7 | 5.3 | 2.6 |
| 10 | 4.5 | 2.1 | 4.1 | 2.1 | 10.5 | 4.8 | 5.2 | 3.9 | 3.0 | 3.7 | 2.8 | 3.0 | 2.7 | 4.4 | 1.8 | 4.2 |
| 11 | 3.0 | 2.1 | 3.9 | 2.8 | 4.3 | 3.6 | 3.2 | 1.4 | 2.3 | 3.5 | 2.7 | 2.9 | 3.0 | 3.3 | 3.0 | 3.3 |
| 12 | 2.6 | 1.5 | 2.0 | 1.6 | 1.9 | 1.9 | 1.2 | 1.5 | 1.6 | 1.8 | 2.0 | 2.8 | 2.1 | 2.9 | 2.1 | 2.2 |
| 13 | 3.2 | 2.8 | 5.4 | 5.5 | 3.6 | 4.3 | 1.6 | 2.7 | 2.6 | 2.5 | 2.8 | 4.4 | 7.3 | 7.2 | 4.4 | 4.2 |
| 14 | 2.2 | 3.6 | 7.3 | 13.1 | 8.5 | 4.4 | 5.8 | 5.0 | 3.0 | 2.4 | 3.1 | 4.1 | 4.2 | 6.2 | 6.3 | 4.6 |
| 15 | 5.4 | 2.8 | 5.7 | 3.4 | 2.4 | 3.1 | 3.8 | 3.0 | 1.5 | 1.7 | 3.7 | 3.8 | 3.0 | 5.7 | 3.8 | 4.9 |
| 16 | 3.5 | 4.4 | 5.4 | 3.8 | 6.3 | 2.2 | 3.6 | 2.0 | 2.8 | 1.7 | 4.2 | 2.0 | 4.7 | 3.1 | 2.3 | 4.0 |
| 17 | 5.0 | 2.0 | 5.3 | 7.7 | 6.7 | 8.6 | 4.9 | 7.7 | 4.8 | 4.9 | 3.6 | 7.4 | 8.0 | 4.4 | 2.7 | 8.0 |
| 18 | 6.6 | 2.6 | 6.5 | 6.3 | 11.2 | 7.6 | 9.2 | 7.4 | 1.7 | 2.3 | 6.5 | 7.7 | 8.0 | 8.3 | 10.3 | 4.4 |
| 19 | 3.1 | 8.1 | 8.1 | 11.2 | 6.9 | 9.9 | 5.0 | 5.5 | 2.9 | 9.0 | 12.3 | 4.0 | 7.5 | 4.8 | 8.0 | 9.5 |
| 20 | 1.0 | 1.9 | 5.2 | 2.5 | 4.3 | 3.3 | 4.4 | 2.9 | 2.3 | 2.7 | 6.3 | 2.9 | 3.0 | 4.1 | 3.4 | 3.1 |
| 21 | N/S | 5.2 | 4.0 | 3.3 | 5.7 | 4.1 | 2.1 | 2.6 | 3.0 | 2.2 | 6.1 | 2.5 | 6.3 | 3.5 | 3.7 | 3.8 |
| 22 | N/S | 5.6 | 4.3 | 5.6 | 5.3 | 4.4 | 4.7 | 2.6 | 2.4 | 1.8 | 4.4 | 4.1 | 4.0 | 3.8 | 3.8 | 4.6 |
| 23 | 6.7 | 3.5 | 4.7 | 4.4 | 6.8 | 3.6 | 5.8 | 3.4 | 2.7 | 4.4 | 6.4 | 5.5 | 4.1 | 4.1 | 3.6 | 4.7 |
| 24 | 2.1 | 1.6 | N/S | 2.4 | 2.7 | 2.3 | 1.6 | 4.1 | 2.3 | 1.5 | 4.1 | 2.3 | 1.9 | 3.1 | 3.1 | 5.8 |
| 25 | 2.4 | 2.7 | 3.6 | 1.9 | 3.1 | 5.5 | 2.7 | 2.8 | 3.7 | 1.7 | 2.3 | 2.1 | 1.5 | 4.3 | 1.7 | 2.3 |
| 26 | N/S | 2.2 | 2.3 | 3.6 | 2.6 | 3.0 | 2.4 | 1.6 | 2.9 | 1.7 | 3.3 | 2.1 | 5.4 | 2.4 | 3.1 | 1.8 |
| 27 | 1.5 | 1.7 | 2.1 | 2.4 | 2.5 | 2.9 | 2.0 | 1.9 | 2.2 | 1.1 | 3.1 | 2.6 | 3.2 | 2.9 | 2.2 | 2.1 |
| 28 | 1.2 | 2.6 | 4.4 | 4.3 | 3.7 | 8.9 | 2.0 | 3.5 | 3.9 | 2.7 | 2.6 | 3.1 | 3.7 | 7.4 | 3.9 | 3.6 |
| 29 | 3.8 | 1.1 | 1.8 | 3.1 | 2.1 | 2.6 | 2.1 | 2.1 | 3.8 | 5.1 | 2.0 | 3.8 | 1.7 | 2.7 | 2.4 | 3.0 |
| 30 | 3.9 | 2.0 | 2.0 | 2.3 | 2.4 | 1.8 | 2.2 | 2.5 | 1.8 | 6.0 | 5.5 | 3.1 | 4.4 | 8.7 | 6.3 | 5.8 |

**Table C13.** Endpoint Excursion (%) obtained from the Limits of Stability test of subjects with symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 16 | 32 | 57 | 73 | 62 | 64 | 96 | 82 | 56 | 56 | 65 | 84 | 70 | 59 | 58 | 76 |
| 2 | 72 | 69 | 72 | 71 | 68 | 55 | 62 | 57 | 55 | 49 | 55 | 63 | 58 | 62 | 77 | 74 |
| 3 | 56 | 55 | 90 | 82 | 50 | 69 | N/S | 53 | N/S | 74 | N/S | 69 | 68 | 67 | 64 | 71 |
| 4 | 68 | 45 | 61 | 60 | 55 | 75 | 52 | 59 | 55 | N/S | 81 | 66 | 77 | 72 | 65 | 73 |
| 5 | 65 | 48 | 65 | 46 | 66 | 70 | 67 | 70 | 45 | 63 | 59 | 60 | 53 | 50 | 63 | 67 |
| 6 | 54 | 89 | 78 | 80 | 82 | 66 | 55 | 69 | 67 | 47 | 44 | 59 | 83 | 56 | 100 | 89 |
| 7 | 23 | 47 | 53 | 67 | 66 | 71 | 85 | 62 | 41 | 46 | 86 | 77 | 66 | 75 | 79 | 78 |
| 8 | 57 | 76 | 89 | 67 | 54 | 52 | N/S | 83 | 38 | 86 | 49 | 73 | 84 | 73 | 63 | 67 |
| 9 | 58 | 66 | 76 | 67 | 73 | 55 | 40 | 53 | 74 | 38 | 62 | 75 | 42 | 58 | 69 | 74 |
| 10 | 63 | 54 | 67 | 67 | 60 | 65 | 73 | 73 | 46 | 46 | 80 | 87 | 67 | 63 | 68 | 51 |
| 11 | 49 | 52 | 70 | 66 | 67 | 54 | 79 | 56 | 48 | 67 | 67 | 54 | 56 | 56 | 49 | 45 |
| 12 | 55 | 66 | N/S | 68 | 74 | 66 | 58 | 62 | 57 | 65 | 51 | 73 | 62 | 62 | 67 | 46 |
| 13 | 45 | 72 | 84 | 80 | 75 | 56 | 68 | 53 | 52 | 70 | 66 | 60 | 69 | 65 | 93 | 65 |
| 14 | 73 | 64 | 92 | 90 | 62 | 73 | 68 | 54 | 74 | 58 | 45 | 69 | 82 | 75 | 76 | 80 |
| 15 | 48 | 67 | 78 | 77 | 76 | 63 | 72 | 70 | 47 | 52 | 65 | 50 | 61 | 70 | 61 | 65 |
| 16 | 68 | 68 | 77 | 72 | 66 | 67 | 107 | 98 | 50 | 46 | 82 | 85 | 87 | 74 | 88 | 74 |
| 17 | 70 | 70 | 71 | 71 | 72 | 62 | 66 | 74 | 63 | 46 | 49 | 45 | 62 | 49 | 76 | 57 |
| 18 | 74 | 71 | 73 | 88 | 75 | 69 | 77 | 50 | N/S | 33 | 58 | 55 | 61 | 78 | 74 | 81 |
| 19 | 86 | 83 | 114 | 83 | 80 | 70 | 70 | 56 | 49 | 49 | 47 | 69 | 79 | 74 | 78 | 71 |
| 20 | 50 | 83 | 87 | 54 | 54 | 69 | 65 | 61 | N/S | 30 | 67 | 69 | 75 | 51 | 73 | 68 |
| 21 | 39 | 53 | 83 | 57 | 50 | 75 | 91 | 103 | 44 | 70 | 50 | 72 | 65 | 51 | 63 | 58 |
| 22 | 65 | 46 | 64 | 72 | 67 | 73 | 43 | 77 | N/S | 36 | 55 | 74 | 71 | 81 | 45 | 64 |
| 23 | 74 | 51 | 50 | 100 | 48 | 79 | 65 | 73 | 66 | 71 | 77 | 52 | 80 | 71 | 56 | 61 |
| 24 | N/S | 79 | N/S | 65 | 70 | 71 | 82 | 89 | 64 | 52 | 87 | 81 | 76 | 72 | 54 | 66 |
| 25 | 31 | 67 | 63 | 63 | 76 | 69 | 43 | 51 | 62 | 50 | 42 | 44 | 71 | 61 | 59 | 37 |
| 26 | 51 | 59 | 48 | 41 | 56 | 62 | 76 | 71 | 65 | 56 | 67 | 73 | 71 | 71 | 78 | 46 |
| 27 | N/S | 40 | 48 | 55 | 59 | 49 | 67 | 64 | . 80 | 51 | 88 | 42 | 40 | 46 | 51 | 62 |
| 28 | 57 | 45 | 60 | 79 | 69 | 43 | 85 | 82 | 61 | 55 | 88 | 88 | 82 | 73 | 90 | 93 |
| 29 | 59 | 38 | 54 | 81 | 78 | 79 | 65 | 41 | 38 | 50 | 66 | 67 | 70 | 78 | 69 | 54 |
| 30 | N/S | 46 | 45 | 56 | 49 | 76 | 51 | 78 | 73 | 70 | 57 | 84 | 69 | 79 | 40 | 60 |

**Table C14.** Endpoint Excursion (%) obtained from the Limits of Stability test of subjects without symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 64 | 56 | 59 | 67 | 51 | 55 | 67 | 66 | 51 | 57 | 43 | 53 | 50 | 69 | 59 | 76 |
| 2 | 73 | 62 | 81 | 75 | 65 | 65 | 76 | 56 | 47 | 42 | 83 | 74 | 56 | 75 | 68 | 80 |
| 3 | 54 | 57 | 79 | 90 | 84 | 55 | 89 | 64 | 56 | N/S | 77 | N/S | 77 | 75 | 58 | 50 |
| 4 | 59 | 64 | 92 | 86 | 73 | 68 | 90 | 60 | 41 | 48 | 44 | 40 | 55 | 88 | 48 | 77 |
| 5 | 52 | 49 | 92 | 64 | 69 | 64 | 40 | 46 | 24 | N/S | 70 | 81 | 67 | 60 | 74 | 55 |
| 6 | 38 | 74 | 70 | 61 | 70 | 69 | 51 | 47 | 68 | 69 | 66 | 48 | 73 | 80 | 81 | 64 |
| 7 | 47 | 52 | 89 | 71 | 41 | 55 | 59 | 82 | 68 | 80 | 77 | 100 | 72 | 80 | 63 | 48 |
| 8 | 40 | 70 | 58 | 57 | N/S | 73 | 70 | 71 | 71 | 58 | 91 | 72 | 59 | 77 | 59 | 82 |
| 9 | 67 | 64 | 80 | 66 | 70 | 66 | 42 | 54 | 61 | 56 | 70 | 57 | 79 | 71 | 70 | 62 |
| 10 | 50 | 74 | 82 | 74 | 56 | 61 | 119 | 75 | 45 | 55 | 72 | 75 | 70 | 82 | 72 | 42 |
| 11 | 70 | 58 | 83 | 81 | 81 | 84 | 81 | 50 | 71 | 55 | 67 | 78 | 76 | 67 | 70 | 81 |
| 12 | 75 | 70 | 79 | 74 | 81 | 74 | 57 | 67 | 50 | 45 | 47 | 63 | 69 | 51 | 74 | 77 |
| 13 | 35 | 69 | 51 | 67 | 62 | 61 | 43 | 41 | 39 | 31 | 81 | 55 | 69 | 64 | 70 | 61 |
| 14 | 70 | 74 | 78 | 58 | 63 | 76 | 52 | 88 | 63 | 77 | 72 | 77 | 47 | 63 | 72 | 97 |
| 15 | 64 | 55 | 53 | 76 | 68 | 67 | 45 | 72 | 47 | 46 | 77 | 66 | 66 | 72 | 66 | 79 |
| 16 | 73 | 46 | 47 | 73 | 57 | 58 | 59 | 74 | 58 | 58 | 83 | 72 | 75 | 73 | 77 | 82 |
| 17 | 46 | 82 | 62 | 64 | 59 | 52 | 47 | 75 | 53 | 49 | 79 | 49 | 48 | 71 | 67 | 75 |
| 18 | 52 | 46 | 82 | 67 | 60 | 67 | 88 | 73 | 62 | 69 | 55 | 65 | 51 | 57 | 52 | 68 |
| 19 | 54 | 53 | 65 | 58 | 52 | 60 | 58 | 75 | 57 | 78 | 69 | 89 | 65 | 61 | 102 | 45 |
| 20 | 41 | 67 | 75 | 87 | 40 | 67 | 50 | 75 | 44 | 55 | 66 | 85 | 85 | 75 | 76 | 90 |
| 21 | N/S | 46 | 89 | 80 | 49 | 80 | 68 | 81 | 55 | 60 | 49 | 58 | 77 | 61 | 74 | 81 |
| 22 | N/S | 70 | 65 | 72 | 59 | 69 | 42 | 74 | 63 | 45 | 61 | 64 | 79 | 77 | 54 | 82 |
| 23 | 64 | 59 | 88 | 76 | 47 | 87 | 64 | 60 | 49 | 71 | 74 | 71 | 82 | 77 | 81 | 67 |
| 24 | 57 | 19 | N/S | 22 | 43 | 63 | 76 | 53 | 47 | 53 | 63 | 86 | 68 | 57 | 47 | 49 |
| 25 | 56 | 61 | 77 | 83 | 64 | 42 | 77 | 66 | 44 | 48 | 75 | 76 | 73 | 62 | 62 | 67 |
| 26 | N/S | 57 | 32 | 75 | 87 | 69 | 56 | 71 | 52 | 44 | 70 | 78 | 70 | 69 | 50 | 50 |
| 27 | 41 | 58 | 79 | 67 | 80 | 73 | 66 | 69 | 57 | 55 | 71 | 56 | 66 | 66 | 72 | 72 |
| 28 | 62 | 60 | 56 | 81 | 59 | 48 | 62 | 82 | 59 | 68 | 67 | 71 | 59 | 49 | 77 | 73 |
| 29 | 72 | 55 | 72 | 67 | 74 | 78 | 41 | 57 | 44 | 55 | 57 | 66 | 64 | 47 | 53 | 69 |
| 30 | 60 | 56 | 70 | 76 | 52 | 66 | 71 | 69 | 66 | 47 | 69 | 50 | 62 | 50 | 44 | 52 |

**Table C15.** Maximum Excursion (%) obtained from the Limits of Stability test of subjects with symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 24 | 51 | 75 | 73 | 82 | 80 | 96 | 82 | 64 | 60 | 84 | 93 | 76 | 79 | 58 | 83 |
| 2 | 79 | 75 | 78 | 72 | 72 | 71 | 70 | 69 | 55 | 73 | 62 | 87 | 74 | 71 | 77 | 75 |
| 3 | 87 | 88 | 90 | 90 | 68 | 69 | N/S | 71 | N/S | 74 | N/S | 69 | 74 | 74 | 91 | 79 |
| 4 | 77 | 79 | 75 | 83 | 71 | 75 | 77 | 94 | 55 | N/S | 90 | 74 | 77 | 80 | 77 | 75 |
| 5 | 65 | 75 | 87 | 74 | 77 | 75 | 81 | 79 | 78 | 77 | 71 | 72 | 75 | 77 | 84 | 84 |
| 6 | 67 | 89 | 85 | 80 | 82 | 88 | 83 | 93 | 71 | 74 | 77 | 68 | 87 | 81 | 100 | 89 |
| 7 | 23 | 70 | 80 | 75 | 81 | 76 | 85 | 93 | 69 | 70 | 86 | 79 | 78 | 77 | 79 | 88 |
| 8 | 73 | 76 | 92 | 93 | 80 | 79 | N/S | 83 | 68 | 91 | 65 | 88 | 84 | 80 | 79 | 82 |
| 9 | 83 | 70 | 76 | 75 | 73 | 71 | 73 | 82 | 74 | 70 | 73 | 83 | 71 | 73 | 71 | 75 |
| 10 | 94 | 82 | 82 | 82 | 69 | 75 | 80 | 77 | 62 | 63 | 80 | 87 | 78 | 72 | 83 | 76 |
| 11 | 49 | 75 | 70 | 84 | 70 | 74 | 79 | 78 | 74 | 74 | 70 | 77 | 74 | 71 | 72 | 74 |
| 12 | 82 | 80 | N/S | 91 | 74 | 76 | 98 | 75 | 76 | 87 | 74 | 78 | 79 | 70 | 73 | 78 |
| 13 | 64 | 76 | 95 | 80 | 79 | 73 | 68 | 98 | 81 | 88 | 100 | 88 | 75 | 72 | 107 | 78 |
| 14 | 73 | 66 | 92 | 90 | 78 | 81 | 76 | 73 | 74 | 89 | 78 | 77 | 82 | 75 | 76 | 80 |
| 15 | 76 | 76 | 78 | 77 | 78 | 74 | 95 | 77 | 77 | 74 | 78 | 80 | 75 | 80 | 77 | 76 |
| 16 | 78 | 76 | 88 | 74 | 78 | 73 | 107 | 98 | 72 | 78 | 100 | 85 | 87 | 74 | 88 | 81 |
| 17 | 80 | 79 | 85 | 85 | 84 | 80 | 79 | 83 | 76 | 73 | 79 | 81 | 75 | 78 | 78 | 78 |
| 18 | 91 | 71 | 85 | 88 | 75 | 77 | 77 | 71 | N/S | 58 | 74 | 66 | 80 | 78 | 96 | 81 |
| 19 | 86 | 83 | 114 | 83 | 80 | 77 | 79 | 76 | 77 | 70 | 81 | 70 | 79 | 80 | 80 | 80 |
| 20 | 86 | 83 | 87 | 82 | 74 | 75 | 65 | 77 | N/S | 50 | 76 | 74 | 77 | 80 | 83 | 81 |
| 21 | 74 | 73 | 97 | 77 | 78 | 76 | 91 | 103 | 77 | 74 | 82 | 80 | 72 | 74 | 80 | 77 |
| 22 | 76 | 77 | 86 | 74 | 78 | 79 | 72 | 78 | N/S | 36 | 86 | 80 | 76 | 84 | 71 | 73 |
| 23 | 94 | 79 | 96 | 100 | 78 | 79 | 78 | 80 | 66 | 75 | 77 | 74 | 81 | 79 | 79 | 85 |
| 24 | N/S | 79 | N/S | 80 | 76 | 74 | 82 | 89 | 75 | 59 | 87 | 81 | 76 | 76 | 83 | 81 |
| 25 | 31 | 72 | 73 | 76 | 76 | 80 | 75 | 75 | 76 | 75 | 71 | 72 | 78 | 76 | 77 | 73 |
| 26 | 78 | 82 | 93 | 80 | 64 | 75 | 86 | 81 | 76 | 80 | 75 | 79 | 75 | 77 | 79 | 82 |
| 27 | N/S | 59 | 80 | 83 | 83 | 87 | 83 | 83 | 80 | 89 | 88 | 69 | 72 | 73 | 73 | 74 |
| 28 | 81 | 84 | 80 | 79 | 78 | 78 | 95 | 88 | 66 | 88 | 88 | 88 | 82 | 79 | 90 | 93 |
| 29 | 66 | 73 | 75 | 88 | 79 | 80 | 96 | 79 | 69 | 77 | 80 | 80 | 77 | 80 | 76 | 79 |
| 30 | N/S | 77 | 78 | 90 | 49 | 76 | 81 | 78 | 73 | 82 | 80 | 84 | 78 | 80 | 73 | 87 |

**Table C16.** Maximum Excursion (%) obtained from the Limits of Stability test of subjects without symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 85 | 83 | 76 | 80 | 72 | 84 | 88 | 84 | 80 | 57 | 55 | 53 | 74 | 74 | 89 | 76 |
| 2 | 76 | 76 | 81 | 77 | 75 | 71 | 76 | 74 | 58 | 57 | 83 | 79 | 73 | 75 | 75 | 80 |
| 3 | 77 | 73 | 79 | 90 | 84 | 73 | 89 | 73 | 56 | N/S | 77 | N/S | 77 | 77 | 84 | 76 |
| 4 | 79 | 77 | 92 | 86 | 81 | 78 | 90 | 78 | 68 | 65 | 81 | 77 | 77 | 88 | 90 | 83 |
| 5 | 55 | 83 | 92 | 87 | 78 | 74 | 57 | 65 | 48 | N/S | 78 | 81 | 76 | 81 | 74 | 78 |
| 6 | 38 | 75 | 81 | 82 | 77 | 75 | 84 | 88 | 68 | 72 | 77 | 83 | 77 | 80 | 81 | 77 |
| 7 | 72 | 72 | 89 | 80 | 77 | 80 | 86 | 84 | 86 | 80 | 77 | 100 | 77 | 80 | 82 | 80 |
| 8 | 76 | 75 | 76 | 73 | N/S | 77 | 78 | 88 | 87 | 80 | 91 | 90 | 77 | 78 | 74 | 82 |
| 9 | 76 | 76 | 80 | 77 | 73 | 72 | 83 | 73 | 73 | 77 | 76 | 70 | 79 | 72 | 74 | 75 |
| 10 | 83 | 74 | 85 | 80 | 92 | 75 | 119 | 87 | 66 | 55 | 79 | 83 | 91 | 82 | 74 | 72 |
| 11 | 78 | 84 | 83 | 81 | 81 | 84 | 81 | 77 | 74 | 69 | 86 | 78 | 80 | 79 | 76 | 811 |
| 12 | 75 | 77 | 79 | 76 | 81 | 77 | 72 | 69 | 65 | 58 | 91 | 77 | 85 | 75 | 74 | 77 |
| 13 | 53 | 78 | 78 | 74 | 68 | 69 | 44 | 76 | 72 | 53 | 85 | 91 | 69 | 68 | 83 | 77 |
| 14 | 71 | 74 | 82 | 86 | 83 | 77 | 100 | 88 | 77 | 81 | 87 | 79 | 75 | 80 | 80 | 97 |
| 15 | 82 | 77 | 88 | 78 | 81 | 76 | 80 | 76 | 77 | 79 | 77 | 84 | 76 | 77 | 91 | 79 |
| 16 | 80 | 84 | 91 | 82 | 78 | 70 | 93 | 83 | 89 | 77 | 83 | 76 | 79 | 78 | 77 | 82 |
| 17 | 79 | 82 | 74 | 78 | 73 | 72 | 75 | 80 | 72 | 83 | 80 | 94 | 72 | 76 | 74 | 79 |
| 18 | 81 | 78 | 87 | 79 | 77 | 77 | 88 | 92 | 77 | 79 | 78 | 83 | 80 | 78 | 80 | 80 |
| 19 | 76 | 86 | 80 | 76 | 74 | 77 | 89 | 83 | 86 | 79 | 89 | 101 | 78 | 83 | 102 | 82 |
| 20 | 79 | 78 | 76 | 87 | 77 | 77 | 85 | 79 | 68 | 71 | 78 | 85 | 85 | 75 | 99 | 90 |
| 21 | N/S | 76 | 89 | 82 | 78 | 80 | 85 | 86 | 76 | 65 | 80 | 79 | 77 | 74 | 79 | 81 |
| 22 | N/S | 81 | 77 | 79 | 71 | 69 | 48 | 74 | 63 | 55 | 66 | 74 | 79 | 77 | 86 | 82 |
| 23 | 79 | 81 | 88 | 89 | 79 | 87 | 79 | 90 | 72 | 79 | 88 | 75 | 83 | 78 | 81 | 85 |
| 24 | 61 | 19 | N/S | 25 | 76 | 69 | 82 | 67 | 70 | 74 | 78 | 86 | 83 | 77 | 59 | 62 |
| 25 | 75 | 78 | 85 | 83 | 78 | 77 | 84 | 80 | 73 | 84 | 84 | 88 | 73 | 78 | 79 | 76 |
| 26 | N/S | 75 | 61 | 77 | 87 | 85 | 80 | 71 | 65 | 72 | 92 | 88 | 78 | 79 | 78 | 80 |
| 27 | 74 | 77 | 87 | 80 | 80 | 79 | 66 | 76 | 75 | 68 | 71 | 86 | 75 | 74 | 82 | 78 |
| 28 | 78 | 76 | 85 | 82 | 83 | 83 | 96 | 100 | 83 | 83 | 89 | 91 | 78 | 77 | 93 | 85 |
| 29 | 93 | 79 | 77 | 86 | 76 | 78 | 74 | 90 | 61 | 76 | 76 | 83 | 77 | 76 | 83 | 78 |
| 30 | 79 | 73 | 77 | 83 | 75 | 79 | 83 | 82 | 71 | 74 | 99 | 77 | 75 | 73 | 84 | 62 |

**Table C17.** Directional Control (%) obtained from the Limits of Stability test of subjects with symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | -337 | -36 | 49 | 69 | 88 | 77 | 45 | 28 | 10 | -70 | 21 | 39 | 83 | 79 | 29 | 79 |
| 2 | 93 | 85 | 87 | 77 | 77 | 64 | 58 | 61 | 86 | 75 | 35 | 59 | 76 | 91 | 93 | 88 |
| 3 | 78 | 81 | 81 | 63 | 49 | 63 | N/S | 20 | N/S | 59 | N/S | -11 | 61 | 55 | 84 | 86 |
| 4 | 86 | 93 | 70 | 74 | 79 | 92 | 71 | 78 | 60 | N/S | 70 | 6 | 81 | 84 | 63 | 86 |
| 5 | -1 | 93 | 83 | 80 | 65 | 75 | 27 | 56 | 87 | 83 | 31 | 57 | 80 | 90 | 79 | 69 |
| 6 | -5 | 80 | 79 | 83 | 87 | 88 | 69 | 0 | 62 | 71 | 63 | 48 | 80 | 87 | 80 | 91 |
| 7 | -168 | 70 | 91 | 90 | 87 | 84 | 65 | 48 | 55 | 63 | 86 | 87 | 85 | 82 | 86 | 78 |
| 8 | 21 | 50 | 76 | 76 | 84 | 81 | N/S | 47 | -33 | 23 | 67 | 65 | 87 | 96 | 77 | 73 |
| 9 | 93 | 64 | 74 | 57 | 55 | 71 | -10 | 61 | 51 | 65 | 72 | 65 | 50 | 90 | 63 | 82 |
| 10 | 85 | 88 | 85 | 90 | 42 | 64 | 79 | 56 | 63 | 31 | 65 | 63 | 83 | 77 | 75 | 78 |
| 11 | -24 | 86 | 85 | 74 | 87 | 91 | 68 | 82 | 91 | 86 | 89 | 58 | 92 | 80 | 77 | 73 |
| 12 | 22 | 63 | N/S | 86 | 90 | 88 | 44 | 70 | 39 | -3 | 44 | 87 | 92 | 85 | 63 | 88 |
| 13 | -49 | 89 | 74 | 87 | 88 | 88 | -54 | 46 | 41 | 48 | 34 | 45 | 87 | 84 | 73 | 71 |
| 14 | 89 | 80 | 74 | 82 | 77 | 81 | 79 | 39 | 77 | 80 | 45 | 59 | 73 | 72 | 77 | 82 |
| 15 | 65 | 94 | 90 | 94 | 94 | 87 | 66 | 61 | 82 | 87 | 68 | 89 | 93 | 93 | 81 | 86 |
| 16 | 92 | 94 | 78 | 86 | 51 | 80 | 80 | 62 | 74 | 78 | 34 | 34 | 89 | 92 | 77 | 75 |
| 17 | 80 | 81 | 90 | 88 | 79 | 82 | 68 | 68 | 71 | 65 | 57 | 85 | 82 | 89 | 84 | 84 |
| 18 | 60 | 88 | 84 | 82 | 91 | 82 | 62 | 67 | N/S | 62 | 77 | 67 | 83 | 83 | 91 | 75 |
| 19 | 89 | 96 | 80 | 85 | 91 | 91 | 68 | 69 | 76 | 79 | 61 | 59 | 91 | 88 | 80 | 81 |
| 20 | -38 | 67 | 75 | 66 | 76 | 85 | 49 | 80 | N/S | -39 | 65 | 56 | 94 | 88 | 70 | 75 |
| 21 | 84 | 76 | 66 | 84 | 92 | 84 | 68 | 70 | 55 | 63 | 81 | 67 | 82 | 91 | 78 | 92 |
| 22 | 69 | 91 | 66 | 72 | 96 | 88 | 71 | 52 | N/S | 14 | 26 | 54 | 87 | 93 | 66 | 57 |
| 23 | 66 | 88 | 61 | 94 | 85 | 79 | 41 | 62 | 51 | 89 | 8 | 74 | 94 | 90 | 85 | 92 |
| 24 | N/S | 39 | N/S | 74 | 72 | 71 | 71 | 47 | 29 | -22 | 58 | 53 | 90 | 94 | 83 | 67 |
| 25 | 34 | 66 | 63 | 88 | 80 | 76 | 26 | 76 | 53 | 79 | 66 | 23 | 86 | 80 | 67 | 59 |
| 26 | 76 | 84 | 85 | 88 | 41 | 81 | 52 | 70 | 88 | 75 | 73 | 73 | 91 | 93 | 81 | 86 |
| 27 | N/S | 43 | 87 | 77 | 82 | 87 | 80 | 74 | -0 | 55 | 65 | 38 | 63 | 85 | 67 | 86 |
| 28 | 94 | 91 | 62 | 69 | 84 | 86 | 59 | 65 | 74 | 61 | 51 | 84 | 92 | 87 | 77 | 86 |
| 29 | 87 | 87 | 78 | 78 | 90 | 94 | 55 | 69 | 49 | 80 | 65 | 57 | 86 | 93 | 87 | 89 |
| 30 | N/S | 83 | 64 | 65 | 80 | 89 | 75 | 41 | 54 | 53 | 65 | 67 | 78 | 84 | 33 | 82 |

**Table C18.** Directional Control (%) obtained from the Limits of Stability test of subjects without symptomatic knee osteoarthritis

| Subjects | front | | right-front | | right | | right-back | | back | | left-back | | left | | left-front | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 | Trial1 | Trial2 |
| 1 | 96 | 88 | 85 | 89 | 81 | 88 | 85 | 70 | 51 | 53 | -0 | 31 | 68 | 88 | 87 | 92 |
| 2 | 85 | 92 | 85 | 96 | 94 | 92 | 79 | 66 | 51 | 48 | 67 | 72 | 88 | 91 | 90 | 90 |
| 3 | 89 | 79 | 65 | 60 | 90 | 90 | 40 | 40 | 43 | N/S | 15 | N/S | 92 | 93 | 61 | 76 |
| 4 | 86 | 95 | 89 | 79 | 77 | 82 | 63 | 69 | 67 | 75 | 69 | 26 | 68 | 92 | 70 | 66 |
| 5 | 13 | 74 | 50 | 63 | 67 | 76 | 11 | 1 | -8 | N/S | 55 | 63 | 83 | 83 | 80 | 82 |
| 6 | -108 | 83 | 83 | 72 | 90 | 76 | 57 | 8 | 84 | 33 | 30 | 21 | 87 | 90 | 81 | 82 |
| 7 | 86 | 92 | 88 | 78 | 89 | 89 | 85 | 82 | 77 | 87 | 66 | 64 | 85 | 89 | 78 | 83 |
| 8 | 50 | 78 | 64 | 78 | N/S | 95 | 90 | 89 | 54 | 85 | 72 | 81 | 89 | 94 | 83 | 85 |
| 9 | 92 | 93 | 94 | 87 | 92 | 93 | 64 | 80 | 79 | 84 | 62 | 64 | 82 | 92 | 79 | 93 |
| 10 | 80 | 91 | 76 | 87 | 82 | 86 | 52 | 72 | 53 | 29 | 38 | 58 | 89 | 94 | 91 | 77 |
| 11 | 80 | 85 | 84 | 86 | 77 | 84 | 42 | 77 | 80 | 73 | 67 | 69 | 66 | 93 | 87 | 86 |
| 12 | 89 | 91 | 83 | 85 | 88 | 90 | 85 | 63 | 86 | 54 | 61 | 62 | 91 | 86 | 84 | 91 |
| 13 | 65 | 78 | 82 | 72 | 86 | 78 | 49 | 55 | 30 | 31 | 55 | 67 | 83 | 83 | 61 | 71 |
| 14 | 59 | 71 | 49 | 43 | 85 | 94 | 32 | 59 | 21 | 82 | 45 | 53 | 88 | 92 | 66 | 64 |
| 15 | 83 | 94 | 82 | 85 | 92 | 90 | 88 | 80 | 72 | 88 | 42 | 63 | 89 | 86 | 82 | 88 |
| 16 | 89 | 91 | 83 | 90 | 74 | 79 | 85 | 92 | 34 | 72 | 23 | 61 | 76 | 86 | 86 | 91 |
| 17 | 92 | 94 | 76 | 87 | 78 | 76 | 13 | 37 | 81 | 78 | 67 | 25 | 66 | 86 | 91 | 86 |
| 18 | 81 | 85 | 47 | 79 | 76 | 86 | 72 | 53 | 88 | 84 | 47 | 53 | 88 | 86 | 65 | 89 |
| 19 | 85 | 56 | 93 | 43 | 85 | 86 | 59 | 3 | 58 | 49 | 71 | 73 | 73 | 67 | 40 | 68 |
| 20 | 89 | 88 | 75 | 78 | 89 | 93 | 56 | 73 | 31 | 68 | 25 | 53 | 90 | 78 | 79 | 81 |
| 21 | N/S | 86 | 82 | 82 | 55 | 58 | 54 | 81 | 73 | 68 | 40 | 83 | 86 | 89 | 89 | 80 |
| 22 | N/S | 83 | 65 | 77 | 55 | 43 | -26 | 74 | 69 | 60 | 56 | 50 | 89 | 81 | 78 | 73 |
| 23 | 77 | 89 | 79 | 70 | 88 | 89 | 62 | 71 | 79 | 64 | 77 | 77 | 87 | 89 | 83 | 78 |
| 24 | 92 | -15 | N/S | -21 | 83 | 89 | 85 | 60 | 78 | 66 | 87 | 68 | 88 | 88 | 55 | 50 |
| 25 | 95 | 91 | 72 | 75 | 71 | 84 | 81 | 85 | 81 | 90 | 58 | 65 | 89 | 88 | 93 | 72 |
| 26 | N/S | 93 | 8 | 60 | 77 | 81 | 66 | 61 | 62 | 87 | 65 | 70 | 88 | 90 | 89 | 86 |
| 27 | 81 | 91 | 84 | 78 | 90 | 87 | 59 | 49 | 54 | 85 | 41 | 80 | 84 | 89 | 73 | 84 |
| 28 | 80 | 89 | 67 | 69 | 82 | 67 | 62 | 67 | 73 | 74 | 20 | 63 | 84 | 90 | 76 | 88 |
| 29 | 89 | 95 | 86 | 83 | 93 | 73 | -16 | 56 | 77 | 57 | 47 | 62 | 92 | 73 | 92 | 94 |
| 30 | 78 | 79 | 79 | 84 | 88 | 88 | 60 | 76 | 82 | 74 | 52 | 53 | 91 | 69 | 38 | 33 |

**Table C19.** The error angle obtained from the proprioception test of subjects with symptomatic knee osteoarthritis

| Subjects | 50° | | | | | | 60° | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Right | | | Left | | | Right | | | Left | | |
| | Trial1 | Trial2 | Erorr angle | Trial1 | Trial2 | Error angle | Trial1 | Trial2 | Erorr angle | Trial1 | Trial2 | Erorr angle |
| 1 | 47.0 | 48.0 | 2.50 | 43.0 | 43.0 | 7.00 | 55.0 | 57.0 | 4.00 | 48.0 | 52.0 | 10.00 |
| 2 | 55.0 | 53.0 | 4.00 | 54.0 | 51.5 | 2.75 | 58.0 | 62.0 | 2.00 | 64.0 | 61.0 | 2.50 |
| 3 | 49.5 | 51.0 | 0.75 | 50.0 | 49.0 | 0.50 | 55.0 | 59.0 | 3.00 | 55.5 | 56.5 | 4.00 |
| 4 | 49.0 | 50.5 | 0.75 | 50.0 | 50.0 | 0.00 | 57.0 | 56.0 | 3.50 | 61.0 | 64.0 | 2.50 |
| 5 | 43.0 | 45.0 | 6.00 | 42.0 | 49.0 | 4.50 | 56.5 | 51.0 | 6.25 | 53.5 | 56.5 | 5.00 |
| 6 | 45.5 | 44.5 | 5.00 | 51.0 | 51.0 | 1.00 | 61.5 | 62.0 | 1.75 | 60.0 | 64.0 | 2.00 |
| 7 | 39.0 | 45.0 | 8.00 | 50.0 | 46.5 | 1.75 | 51.0 | 49.0 | 10.00 | 53.5 | 55.0 | 5.75 |
| 8 | 53.0 | 44.5 | 4.25 | 49.5 | 48.0 | 1.25 | 56.0 | 55.5 | 4.25 | 63.5 | 59.0 | 2.25 |
| 9 | 39.0 | 45.0 | 8.00 | 55.0 | 53.0 | 4.00 | 59.0 | 61.5 | 1.25 | 58.5 | 58.0 | 1.75 |
| 10 | 48.0 | 48.5 | 1.75 | 48.0 | 45.0 | 3.50 | 54.0 | 54.0 | 6.00 | 53.0 | 56.0 | 5.50 |
| 11 | 48.0 | 48.5 | 1.75 | 49.0 | 49.0 | 1.00 | 54.0 | 57.0 | 4.50 | 51.0 | 56.0 | 6.50 |
| 12 | 46.0 | 43.0 | 5.50 | 55.0 | 50.0 | 2.50 | 53.5 | 57.0 | 4.75 | 54.5 | 57.0 | 4.25 |
| 13 | 48.0 | 45.0 | 3.50 | 51.0 | 48.5 | 1.25 | 57.0 | 56.5 | 3.25 | 59.0 | 59.0 | 1.00 |
| 14 | 42.0 | 41.0 | 8.50 | 43.0 | 43.0 | 7.00 | 51.0 | 52.5 | 8.25 | 55.5 | 54.5 | 5.00 |
| 15 | 45.0 | 44.0 | 5.50 | 48.0 | 48.0 | 2.00 | 55.0 | 53.0 | 6.00 | 59.0 | 58.0 | 1.50 |
| 16 | 45.5 | 46.0 | 4.25 | 51.5 | 48.5 | 1.50 | 57.5 | 59.0 | 1.75 | 58.5 | 57.0 | 2.25 |
| 17 | 43.0 | 39.5 | 8.75 | 48.0 | 45.0 | 3.50 | 58.0 | 55.0 | 3.50 | 55.0 | 54.0 | 5.50 |
| 18 | 45.0 | 45.5 | 4.75 | 45.0 | 48.0 | 3.50 | 55.0 | 57.5 | 3.75 | 52.0 | 52.5 | 7.75 |
| 19 | 49.0 | 48.0 | 1.50 | 48.0 | 48.0 | 2.00 | 63.5 | 62.0 | 2.75 | 57.5 | 59.0 | 1.75 |
| 20 | 50.0 | 50.5 | 0.25 | 46.5 | 51.0 | 2.25 | 57.0 | 57.5 | 2.75 | 56.5 | 58.5 | 2.50 |
| 21 | 45.5 | 45.0 | 4.75 | 52.0 | 50.0 | 1.00 | 57.5 | 62.0 | 2.25 | 60.5 | 58.0 | 1.25 |
| 22 | 50.0 | 47.5 | 1.25 | 51.0 | 52.5 | 1.75 | 57.0 | 58.0 | 2.50 | 55.0 | 57.5 | 3.75 |
| 23 | 49.5 | 46.5 | 2.00 | 52.0 | 44.0 | 4.00 | 57.0 | 56.5 | 3.25 | 58.5 | 55.5 | 3.00 |
| 24 | 47.0 | 47.0 | 3.00 | 45.0 | 49.5 | 2.75 | 58.0 | 61.5 | 1.75 | 58.5 | 56.0 | 2.75 |
| 25 | 49.0 | 53.0 | 2.00 | 48.0 | 47.0 | 2.50 | . 58.5 | 61.5 | 1.50 | 56.0 | 53.0 | 5.50 |
| 26 | 48.0 | 47.0 | 2.50 | 48.0 | 46.0 | 3.00 | 56.0 | 55.0 | 4.50 | 57.0 | 58.0 | 2.50 |
| 27 | 49.0 | 48.0 | 1.50 | 47.5 | 47.0 | 2.75 | 57.0 | 57.5 | 2.75 | 55.5 | 58.5 | 3.00 |
| 28 | 48.0 | 44.0 | 4.00 | 48.0 | 49.5 | 1.25 | 55.5 | 59.0 | 2.75 | 58.0 | 59.0 | 1:50 |
| 29 | 52.5 | 46.0 | 3.25 | 51.0 | 46.0 | 2.50 | 57.0 | 60.0 | 1.50 | 58.0 | 53.0 | 4.50 |
| 30 | 50.5 | 45.0 | 2.75 | 47.0 | 48.0 | 2.50 | 57.5 | 57.5 | 2.50 | 57.5 | 57.0 | 2.75 |

**Table C20.** The error angle obtained from the proprioception test of subjects without symptomatic knee osteoarthritis

| Subjects | 50° | | | | | | 60° | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Right | | | Left | | | Right | | | Left | | |
| | Trial1 | Trial2 | Erorr angle | Trial1 | Trial2 | Error angle | Trial1 | Trial2 | Erorr angle | Trial1 | Trial2 | Erorr angle |
| 1 | 49.0 | 42.0 | 4.50 | 49.0 | 48.0 | 1.50 | 60.0 | 58.0 | 1.00 | 62.0 | 57.0 | 2.50 |
| 2 | 53.5 | 46.0 | 3.75 | 44.5 | 43.5 | 6.00 | 57.5 | 58.0 | 2.25 | 55.0 | 57.0 | 4.00 |
| 3 | 48.0 | 47.5 | 2.25 | 49.0 | 49.5 | 0.75 | 60.0 | 52.0 | 4.00 | 56.0 | 60.0 | 2.00 |
| 4 | 51.0 | 49.0 | 1.00 | 55.5 | 50.0 | 2.25 | 59.0 | 57.0 | 2.00 | 59.0 | 58.0 | 1.50 |
| 5 | 48.0 | 47.0 | 2.50 | 47.0 | 52.5 | 2.75 | 59.0 | 58.5 | 1.25 | 62.0 | 58.0 | 2.00 |
| 6 | 50.0 | 47.0 | 1.50 | 47.5 | 51.0 | 1.75 | 59.0 | 55.0 | 3.00 | 57.5 | 60.0 | 1.25 |
| 7 | 43.5 | 49.0 | 3.75 | 46.0 | 48.0 | 3.00 | 60.5 | 61.0 | 0.75 | 55.0 | 58.5 | 3.25 |
| 8 | 47.5 | 49.0 | 1.75 | 51.0 | 49.0 | 1.00 | 55.5 | 59.0 | 2.75 | 59.0 | 58.0 | 1.50 |
| 9 | 47.5 | 44.0 | 4.25 | 48.0 | 44.5 | 3.75 | 56.5 | 55.5 | 4.00 | 55.5 | 57.5 | 3.50 |
| 10 | 50.5 | 49.0 | 0.75 | 43.0 | 46.0 | 5.50 | 55.0 | 60.0 | 2.50 | 55.0 | 55.0 | 5.00 |
| 11 | 45.0 | 46.0 | 4.50 | 47.0 | 45.5 | 3.75 | 56.5 | 57.0 | 3.25 | 56.0 | 59.0 | 2.50 |
| 12 | 48.0 | 46.0 | 3.00 | 49.0 | 45.5 | 2.75 | 58.5 | 55.5 | 3.00 | 57.0 | 59.5 | 1.75 |
| 13 | 47.0 | 52.5 | 2.75 | 45.0 | 49.0 | 3.00 | 57.0 | 56.0 | 3.50 | 57.0 | 60.0 | 1.50 |
| 14 | 44.0 | 47.0 | 4.50 | 47.5 | 47.5 | 2.50 | 55.0 | 51.5 | 6.75 | 55.0 | 53.5 | 5.75 |
| 15 | 46.5 | 49.0 | 2.25 | 52.0 | 50.5 | 1.25 | 58.0 | 58.5 | 1.75 | 60.5 | 61.5 | 1.00 |
| 16 | 42.0 | 51.0 | 4.50 | 44.5 | 46.5 | 4.50 | 57.0 | 55.5 | 3.75 | 57.5 | 52.0 | 5.25 |
| 17 | 49.5 | 49.0 | 0.75 | 47.0 | 46.0 | 3.50 | 55.0 | 60.0 | 2.50 | 55.0 | 58.0 | 3.50 |
| 18 | 49.0 | 46.0 | 2.50 | 45.5 | 44.0 | 5.25 | 57.5 | 55.0 | 3.75 | 52.5 | 55.5 | 6.00 |
| 19 | 48.5 | 44.5 | 3.50 | 46.0 | 54.5 | 4.25 | 59.0 | 59.5 | 0.75 | 62.5 | 60.5 | 1.50 |
| 20 | 50.0 | 49.0 | 0.50 | 48.0 | 47.5 | 2.25 | 61.5 | 58.5 | 1.50 | 61.0 | 58.5 | 1.25 |
| 21 | 45.0 | 47.5 | 3.75 | 48.0 | 52.5 | 2.25 | 59.0 | 61.0 | 1.00 | 57.5 | 59.0 | 1.75 |
| 22 | 45.5 | 55.0 | 4.75 | 46.0 | 50.0 | 2.00 | 58.0 | 59.5 | 1.25 | 57.0 | 61.5 | 2.25 |
| 23 | 50.5 | 51.5 | 1.00 | 50.0 | 50.5 | 0.25 | 59.0 | 60.0 | 0.50 | 57.5 | 61.0 | 1.75 |
| 24 | 45.0 | 42.5 | 6.25 | 54.5 | 49.0 | 2.75 | 64.5 | 60.0 | 2.25 | 59.0 | 60.0 | 1.00 |
| 25 | 47.5 | 46.5 | 3.00 | 47.0 | 45.5 | 3.75 | 59.0 | 58.0 | 1.50 | 55.0 | 56.5 | 4.25 |
| 26 | 50.0 | 53.5 | 1.75 | 49.0 | 48.0 | 1.50 | 62.5 | 56.0 | 3.25 | 59.5 | 55.5 | 2.50 |
| 27 | 49.5 | 52.0 | 1.25 | 47.0 | 51.5 | 2.25 | 55.0 | 58.0 | 3.50 | 59.0 | 58.5 | 1.25 |
| 28 | 46.0 | 45.5 | 4.25 | 45.0 | 47.0 | 4.00 | 58.0 | 60.5 | 1.25 | 58.5 | 59.0 | 1.25 |
| 29 | 48.0 | 49.0 | 1.50 | 46.5 | 46.0 | 3.75 | 58.5 | 56.0 | 2.75 | 55.0 | 58.0 | 3.50 |
| 30 | 47.0 | 48.0 | 2.50 | 52.5 | 49.0 | 1.75 | 58.5 | 57.5 | 2.00 | 59.5 | 60.5 | 0.50 |

**Table C21.** Muscle Strength of subjects with symptomatic knee osteoarthritis

| Subjects | Flexor group(kg.) | | | | | | Extensor group (kg.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Right | | | Left | | | Right | | | Left | | |
| | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean |
| 1 | 6.3 | 5.4 | 5.85 | 5.3 | 5.7 | 5.50 | 13.1 | 12.4 | 12.75 | 12.2 | 13.9 | 13.05 |
| 2 | 8.9 | 8.9 | 8.90 | 9.5 | 9.2 | 9.35 | 23.4 | 23.3 | 23.35 | 22.0 | 24.4 | 23.20 |
| 3 | 5.4 | 5.6 | 5.50 | 9.2 | 8.4 | 8.80 | 17.1 | 14.4 | 15.75 | 15.2 | 14.8 | 15.00 |
| 4 | 5.1 | 5.9 | 5.50 | 9.1 | 9.0 | 9.05 | 13.5 | 12.1 | 12.80 | 17.5 | 15.8 | 16.65 |
| 5 | 13.5 | 13.6 | 13.55 | 14.0 | 14.6 | 14.3 | 18.0 | 20.4 | 19.20 | 19.2 | 21.8 | 20.50 |
| 6 | 13.2 | 13.0 | 13.10 | 14.5 | 13.6 | 14.05 | 32.7 | 30.1 | 31.40 | 42.6 | 43.0 | 42.80 |
| 7 | 6.3 | 7.2 | 6.75 | 8.8 | 10.0 | 9.40 | 18.1 | 15.2 | 16.65 | 18.5 | 19.9 | 19.20 |
| 8 | 10.0 | 9.2 | 9.60 | 7.4 | 6.9 | 7.15 | 18.8 | 19.8 | 19.30 | 7.1 | 7.6 | 7.35 |
| 9 | 10.9 | 9.9 | 10.40 | 10.8 | 10.2 | 10.5 | 18.5 | 22.6 | 20.55 | 23.7 | 22.9 | 23.30 |
| 10 | 15.2 | 15.6 | 15.40 | 16.3 | 18.3 | 17.3 | 20.5 | 19.0 | 19.75 | 20.2 | 18.8 | 19.50 |
| 11 | 9.8 | 8.9 | 9.35 | 8.4 | 7.6 | 8.00 | 15.0 | 13.0 | 14.00 | 14.2 | 15.0 | 14.60 |
| 12 | 6.4 | 6.9 | 6.65 | 7.2 | 7.2 | 7.20 | 18.3 | 16.2 | 17.25 | 17.7 | 16.2 | 16.95 |
| 13 | 9.5 | 8.9 | 9.20 | 9.1 | 11.6 | 10.35 | 27.1 | 28.2 | 27.65 | 21.4 | 21.1 | 21.25 |
| 14 | 5.4 | 5.4 | 5.40 | 4.5 | 4.1 | 4.30 | 15.0 | 13.7 | 14.35 | 13.6 | 9.7 | 11.65 |
| 15 | 6.2 | 6.1 | 6.15 | 5.8 | 6.6 | 6.20 | 14.0 | 15.5 | 14.75 | 12.4 | 12.0 | 12.20 |
| 16 | 11.1 | 12.5 | 11.80 | 12.1 | 13.3 | 12.70 | 28.1 | 31.1 | 29.60 | 29.4 | 29.4 | 29.40 |
| 17 | 7.1 | 7.2 | 7.15 | 7.4 | 7.6 | 7.50 | 13.0 | 15.7 | 14.35 | 18.6 | 18.5 | 18.55 |
| 18 | 14.5 | 15.3 | 14.90 | 9.3 | 10.1 | 9.70 | 30.8 | 30.1 | 30.45 | 19.2 | 20.7 | 19.95 |
| 19 | 10.9 | 9.8 | 10.35 | 10.6 | 11.3 | 10.95 | 27.0 | 30.7 | 28.85 | 25.7 | 23.2 | 24.45 |
| 20 | 9.1 | 9.1 | 9.10 | 9.1 | 8.8 | 8.95 | 13.3 | 14.1 | 13.70 | 19.4 | 21.3 | 20.35 |
| 21 | 9.1 | 10.7 | 9.90 | 10.1 | 10.6 | 10.35 | 18.8 | 21.2 | 20.00 | 25.1 | 26.7 | 25.90 |
| 22 | 10.5 | 9.2 | 9.85 | 10.1 | 10.3 | 10.20 | 18.9 | 16.1 | 17.50 | 16.5 | 16.7 | 16.60 |
| 23 | 11.4 | 12.6 | 12.00 | 8.2 | 7.6 | 7.90 | 17.0 | 20.9 | 18.95 | 19.2 | 18.8 | 19.00 |
| 24 | 6.8 | 6.7 | 6.75 | 9.9 | 9.3 | 9.60 | 24.8 | 23.1 | 23.95 | 23.7 | 26.6 | 25.15 |
| 25 | 9.9 | 9.3 | 9.60 | 10.1 | 10.0 | 10.05 | 10.0 | 10.0 | 10.00 | 14.1 | 13.1 | 13.60 |
| 26 | 11.0 | 10.0 | 10.50 | 10.8 | 9.1 | 9.95 | 26.0 | 25.8 | 25.90 | 23.8 | 22.3 | 23.05 |
| 27 | 9.3 | 9.2 | 9.25 | 12.9 | 12.0 | 12.45 | 23.6 | 25.6 | 24.60 | 17.2 | 19.1 | 18.15 |
| 28 | 15.9 | 16.5 | 16.20 | 19.4 | 18.6 | 19.00 | 27.8 | 27.4 | 27.60 | 22.4 | 23.8 | 23.10 |
| 29 | 9.0 | 10.3 | 9.65 | 6.2 | 6.2 | 6.20 | 24.1 | 24.5 | 24.30 | 20.1 | 20.5 | 20.30 |
| 30 | 14.2 | 16.4 | 15.30 | 2.3 | 3.8 | 3.05 | 32.3 | 34.7 | 33.50 | 13.8 | 12.9 | 13.35 |

**Table C22.** Muscle Strength of subjects without symptomatic knee osteoarthritis

| Subjects | Flexor group(kg.) | | | | | | Extensor group (kg.) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Right | | | Left | | | Right | | | Left | | |
| | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean | Trial1 | Trial2 | Mean |
| 1 | 13.7 | 12.2 | 12.95 | 13.1 | 13.0 | 13.05 | 24.1 | 24.7 | 24.40 | 28.0 | 28.3 | 28.15 |
| 2 | 13.1 | 11.6 | 12.35 | 12.4 | 12.0 | 12.20 | 24.1 | 22.2 | 23.15 | 23.7 | 24.9 | 24.30 |
| 3 | 12.5 | 12.7 | 12.60 | 10.4 | 13.5 | 11.95 | 23.4 | 21.8 | 22.60 | 19.6 | 23.3 | 21.45 |
| 4 | 12.4 | 12.4 | 12.40 | 12.2 | 11.7 | 11.95 | 25.1 | 26.1 | 25.60 | 20.4 | 22.9 | 21.65 |
| 5 | 11.5 | 11.9 | 11.70 | 11.5 | 12.9 | 12.20 | 21.3 | 21.4 | 21.35 | 21.9 | 21.0 | 21.45 |
| 6 | 10.4 | 11.5 | 10.95 | 10.2 | 10.0 | 10.10 | 23.4 | 26.7 | 25.05 | 22.0 | 21.8 | 21.90 |
| 7 | 10.0 | 9.9 | 9.95 | 8.2 | 7.5 | 7.85 | 17.4 | 18.0 | 17.70 | 22.3 | 19.2 | 20.75 |
| 8 | 10.0 | 9.1 | 9.55 | 10.2 | 10.5 | 10.35 | 19.1 | 21.1 | 20.10 | 20.3 | 19.1 | 19.70 |
| 9 | 8.4 | 10.6 | 9.50 | 9.0 | 10.1 | 9.55 | 20.5 | 17.2 | 18.85 | 14.0 | 14.5 | 14.25 |
| 10 | 11.7 | 10.5 | 11.10 | 8.5 | 12.5 | 10.50 | 23.9 | 22.1 | 23.00 | 18.8 | 18.8 | 18.80 |
| 11 | 10.0 | 8.9 | 9.45 | 9.9 | 12.3 | 11.10 | 22.4 | 20.4 | 21.40 | 15.0 | 14.9 | 14.95 |
| 12 | 11.7 | 12.3 | 12.00 | 10.2 | 11.3 | 10.75 | 30.6 | 33.7 | 32.15 | 25.8 | 21.5 | 23.65 |
| 13 | 7.9 | 8.4 | 8.15 | 6.4 | 7.0 | 6.70 | 16.5 | 17.8 | 17.15 | 17.2 | 17.7 | 17.45 |
| 14 | 9.0 | 9.3 | 9.15 | 12.9 | 11.0 | 11.95 | 28.5 | 33.2 | 30.85 | 34.2 | 36.3 | 35.25 |
| 15 | 9.9 | 10.1 | 10.00 | 9.6 | 11.6 | 10.60 | 19.1 | 21.8 | 20.45 | 22.6 | 23.7 | 23.15 |
| 16 | 8.7 | 10.3 | 9.50 | 7.9 | 8.3 | 8.10 | 15.6 | 16.9 | 16.25 | 20.6 | 18.5 | 19.55 |
| 17 | 9.4 | 11.0 | 10.20 | 8.7 | 8.9 | 8.80 | 20.5 | 22.4 | 21.45 | 20.4 | 21.8 | 21.10 |
| 18 | 9.0 | 10.0 | 9.50 | 10.8 | 10.6 | 10.70 | 17.4 | 21.1 | 19.25 | 22.0 | 21.6 | 21.80 |
| 19 | 13.3 | 14.6 | 13.95 | 14.2 | 16.0 | 15.10 | 40.2 | 40.1 | 40.15 | 24.7 | 25.5 | 25.10 |
| 20 | 15.2 | 15.4 | 15.3 | 11.7 | 12.8 | 12.25 | 26.0 | 28.8 | 27.40 | 25.7 | 24.4 | 25.05 |
| 21 | 12.8 | 12.1 | 12.45 | 9.8 | 9.9 | 9.85 | 36.1 | 36.2 | 36.15 | 32.2 | 30.4 | 31.30 |
| 22 | 10.1 | 10.6 | 10.35 | 8.8 | 8.9 | 8.85 | 24.3 | 22.8 | 23.55 | 22.2 | 21.0 | 21.60 |
| 23 | 6.5 | 6.5 | 6.50 | 10.3 | 10.9 | 10.60 | 20.2 | 19.2 | 19.70 | 25.9 | 26.5 | 26.20 |
| 24 | 10.5 | 9.8 | 10.15 | 11.7 | 10.0 | 10.85 | 24.2 | 23.3 | 23.75 | 28.9 | 28.4 | 28.65 |
| 25 | 17.1 | 16.4 | 16.75 | 13.5 | 13.3 | 13.40 | 22.9 | 24.8 | 23.85 | 20.4 | 23.7 | 22.05 |
| 26 | 12.5 | 14.1 | 13.30 | 11.4 | 11.7 | 11.55 | 33.8 | 32.9 | 33.35 | 27.8 | 29.3 | 28.55 |
| 27 | 14.1 | 14.2 | 14.15 | 11.9 | 12.4 | 12.15 | 31.5 | 31.4 | 31.45 | 24.2 | 22.6 | 23.40 |
| 28 | 14.0 | 13.9 | 13.95 | 16.2 | 16.0 | 16.10 | 31.4 | 31.2 | 31.30 | 29.2 | 29.0 | 29.10 |
| 29 | 8.3 | 8.9 | 8.60 | 8.7 | 8.6 | 8.65 | 20.7 | 20.6 | 20.65 | 15.0 | 14.5 | 14.75 |
| 30 | 10.7 | 11.2 | 10.95 | 12.4 | 12.4 | 12.40 | 23.2 | 25.9 | 24.55 | 27.4 | 27.1 | 27.25 |

# APPENDIX D

# RESULTS OF COMPARISION BETWEEN RIGHT AND LEFT OA KNEE GROUPS

**Table D1.** Comparison of the percentage of maximum stability obtained from SOT between the right and left OA knee groups

| Condition# | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| EO | 92.23 ± 2.35 | 93.88 ± 2.49 | 0.530 |
| EC | 90.85 ± 1.86 | 89.47 ± 4.17 | 0.385 |
| SV | 85.39 ± 5.28 | 87.76 ± 4.88 | 0.385 |
| EOSS | 74.46 ± 10.28 | 74.59 ± 9.79 | 0.711 |
| ECSS | 57.77 ± 16.56 | 58.29 ± 17.06 | 0.902 |
| SVSS | 52.00 ± 20.40 | 54.88 ± 15.48 | 0.773 |

#: EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support; a: Mann-Whitney U-test; * : $p < 0.05$

**Table D2.** Comparison of the sway velocity obtained from SOT between the right and left OA knee groups

| Condition# | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| EO | 0.28 ± 0.05 | 0.26 ± 0.13 | 0.408 |
| EC | 0.48 ± 0.13 | 0.44 ± 0.15 | 0.341 |
| SV | 0.63 ± 0.18 | 0.45 ± 0.13 | 0.007* |
| EOSS | 0.80 ± 0.40 | 0.72 ± 0.35 | 0.711 |
| ECSS | 1.47 ± 0.62 | 1.25 ± 0.33 | 0.351 |
| SVSS | 1.40 ± 0.83 | 1.11 ± 0.44 | 0.241 |

#: EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support; a: Mann-Whitney U-test; * : $p < 0.05$

**Table D3.** Comparison of the sway velocity obtained from center target test and on-axis velocity and directional control obtained from rhythmic weight sift left/right test between the right and left OA knee groups

| Test | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| Center Target (degree/sec) | 0.37 ±0.10 | 0.35 ±0.11 | 0.604 |
| Rhythmic Weight Shift L/R | | | |
| On-axis velocity(degree/sec) | | | |
| Slow | 2.90 ±0.33 | 3.19 ±0.69 | 0.172 |
| Moderate | 4.45 ±0.52 | 4.76 ±0.84 | 0.193 |
| Fast | 8.08 ±1.91 | 8.09 ±2.45 | 0.691 |
| Directional Control (%) | | | |
| Slow | 80.38 ±4.94 | 80.12 ±5.89 | 0.916 |
| Moderate | 84.69 ±4.48 | 84.29 ±4.65 | 0.599 |
| Fast | 88.46 ±3.36 | 89.59 ±4.11 | 0.527 |

a: Mann-Whitney U-test.

**Table D4.** Comparison of measurement variables from the limits of stability test between right and left OA knee groups

| Limits of Stability | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| Reaction time (second) | | | |
| Front | 0.82 ± 0.36 | 0.99 ± 0.51 | 0.463 |
| Right-front | 0.77 ± 0.29 | 0.79 ± 0.38 | 0.785 |
| Right | 0.78 ± 0.22 | 0.69 ± 0.33 | 0.111 |
| Right-back | 0.88 ± 0.36 | 1.03 ± 0.38 | 0.335 |
| Back | 0.85 ± 0.38 | 0.83 ± 0.45 | 0.929 |
| Left-back | 0.88 ± 0.39 | 0.80 ± 0.28 | 0.438 |
| Left | 0.95 ± 0.32 | 0.88 ± 0.35 | 0.368 |
| Left-front | 1.08 ± 0.33 | 1.02 ± 0.37 | 0.572 |
| Movement velocity (degree/second) | | | |
| Front | 3.16 ± 1.36 | 3.44 ± 1.47 | 0.660 |
| Right-front | 3.88 ± 1.43 | 4.39 ± 1.42 | 0.249 |
| Right | 3.92 ± 2.01 | 4.59 ± 2.37 | 0.451 |
| Right-back | 3.65 ± 1.77 | 3.32 ± 1.75 | 0.267 |
| Back | 2.74 ± 1.48 | 2.46 ± 0.94 | 0.773 |
| Left-back | 3.73 ± 0.94 | 3.31 ± 1.14 | 0.335 |
| Left | 4.16 ± 1.79 | 4.31 ± 1.89 | 0.867 |
| Left-front | 3.58 ± 1.34 | 3.99 ± 1.36 | 0.285 |

a: Mann-Whitney U-test.

**Table D4.** Comparison of measurement variables from the limits of stability test between right and left OA knee groups (continued)

| Limits of Stability | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| End point excursion (%) | | | |
| Front | 60.00 ± 16.82 | 60.06 ± 13.45 | 0.983 |
| Right-front | 66.54 ± 11.62 | 72.53 ± 13.73 | 0.267 |
| Right | 67.00 ± 6.51 | 64.47 ± 10.61 | 0.571 |
| Right-back | 69.62 ± 15.23 | 65.82 ± 14.59 | 0.615 |
| Back | 51.75 ± 14.13 | 56.53 ± 12.53 | 0.387 |
| Left-back | 72.77 ± 8.41 | 63.12 ± 14.59 | 0.051 |
| Left | 64.69 ± 9.38 | 66.53 ± 10.90 | 0.530 |
| Left-front | 67.61 ± 11.45 | 64.35 ± 14.24 | 0.476 |
| Maximum excursion(%) | | | |
| Front | 76.85 ± 9.79 | 75.06 ± 5.99 | 0.304 |
| Right-front | 79.31 ± 4.61 | 83.94 ± 7.80 | 0.085 |
| Right | 75.85 ± 4.65 | 77.47 ± 3.74 | 0.152 |
| Right-back | 86.00 ± 9.63 | 79.12 ± 6.79 | 0.056 |
| Back | 66.50 ± 13.98 | 78.23 ± 8.56 | 0.012* |
| Left-back | 79.62 ± 7.24 | 78.12 ± 6.90 | 0.615 |
| Left | 76.85 ± 3.78 | 76.53 ± 3.56 | 0.883 |
| Left-front | 79.77 ± 4.90 | 80.00 ± 5.22 | 0.983 |

a: Mann-Whitney U-test; *: $p<0.05$.

**Table D4.** Comparison of measurement variables from the limits of stability test between right and left OA knee groups (continued)

| Limits of Stability | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| Directional control (%) | | | |
| Front | 70.92 ± 5.82 | 80.47 ± 15.68 | 0.217 |
| Right-front | 76.69 ± 1.06 | 81.23 ± 7.98 | 0.314 |
| Right | 79.69 ± 9.61 | 83.12 ± 7.33 | 0.438 |
| Right-back | 50.46 ± 23.37 | 62.88 ± 11.70 | 0.173 |
| Back | 40.75 ± 29.92 | 66.76 ± 23.90 | 0.009* |
| Left-back | 50.46 ± 24.54 | 62.47 ± 18.60 | 0.137 |
| Left | 84.38 ± 10.36 | 86.94 ± 5.98 | 0.644 |
| Left-front | 79.08 ± 9.91 | 80.47 ± 8.63 | 0.689 |

a: Mann -Whitney U-test; *: $p<0.05$.

**Table D5.** Comparison of error angle from the proprioception test between right and left OA knee groups

| Proprioception test | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| 50° Right | 3.23 ± 2.57 | 4.13 ± 2.23 | 0.187 |
| Left | 2.29 ± 1.84 | 2.76 ± 1.46 | 0.266 |
| 60° Right | 3.58 ± 2.31 | 3.65 ± 1.86 | 0.690 |
| Left | 3.48 ± 2.45 | 3.79 ± 1.87 | 0.450 |

a: Mann-Whitney U-test.

**Table D6.** Comparison of muscle strength between right and left OA knee groups

| Muscle strength (kg.) | Right OA knee group (n=13) | Left OA knee group (n=17) | p-value[a] |
|---|---|---|---|
| Flexor group | | | |
| Right | 9.06 ± 3.00 | 10.34 ± 3.23 | 0.391 |
| Left | 10.31 ± 2.79 | 9.18 ± 3.90 | 0.233 |
| Extensor group | | | |
| Right | 19.87 ± 5.91 | 21.44 ± 6.95 | 0.572 |
| Left | 21.68 ± 7.44 | 18.02 ± 5.49 | 0.174 |

a: Mann -Whitney U-test.

# APPENDIX E

# RESULTS OF PILOT STUDY

Five females with and without symptomatic osteoarthritis who had similar age, weight and height were included in pilot study. Table E1 showed no significant difference in characteristics of the subjects between two groups (p>0.05).

**Table E1.** Characteristics of the study groups

| Characteristic | With OA(n=5) Mean±SD | Without OA(n=5) Mean±SD | p-value[#] |
|---|---|---|---|
| Age (years) | 52.4±5.18 | 54.2±5.76 | 0.753 |
| Weight (kg.) | 62.6±8.14 | 58.0±8.86 | 0.251 |
| Height (cm.) | 154.6±3.91 | 153.0±2.86 | 0.458 |

[#] : Mann-Whitney U-test.

**Table E2.** Static balance test: Comparison of the percentage of maximum stability between subjects with and without symptomatic knee osteoarthritis.

| SOT condition[a] | % of Maximum Stability | | p-value[#] |
|---|---|---|---|
| | With OA Mean±SD | Without OA Mean±SD | |
| 1.EO | 93.4±1.82 | 94.2±2.17 | 0.395 |
| 2.EC | 87.8±0.84 | 92.0±2.83 | 0.024* |
| 3.SV | 86.8±2.39 | 89.4±3.21 | 0.171 |
| 4.EOSS | 65.8±4.66 | 82.6±11.46 | 0.047* |
| 5.ECSS | 53.4±15.50 | 66.4±8.99 | 0.175 |
| 6.SVSS | 50.6±10.80 | 64.0±12.33 | 0.117 |

[#]: Mann-Whitney U-test., *: statistical significant at $p < 0.05$.
a: EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support.

**Table E3.** Static balance test: Comparison of sway velocity between subjects with and without symptomatic knee osteoarthritis

| SOT condition[a] | Sway Velocity (degree/second) | | p-value[#] |
|---|---|---|---|
| | With OA Mean±SD | Without OA Mean±SD | |
| 1.EO | 0.32±0.05 | 0.24±0.09 | 0.074 |
| 2.EC | 0.62±0.11 | 0.48±0.22 | 0.233 |
| 3.SV | 0.60±0.20 | 0.42±0.08 | 0.102 |
| 4.EOSS | 0.98±0.58 | 0.64±0.49 | 0.074 |
| 5.ECSS | 1.72±0.79 | 0.90±0.17 | 0.056 |
| 6.SVSS | 1.56±1.23 | 0.86±0.27 | 0.207 |

[#] : Mann-Whitney U-test
a : EO= eyes open, EC= eyes closed, SV= sway-referenced vision, EOSS= eyes open and sway-referenced support, ECSS= eyes closed and sway-referenced support, SVSS= sway-referenced vision and support.

**Table E4.** Comparison of center target and on-axis velocity, directional control from Rhythmic Weight Shift Left/Right between subjects with and without symptomatic knee osteoarthritis

| Test | With OA Mean±SD | Without OA Mean±SD | p-value[#] |
|---|---|---|---|
| Center Target (degree/second) | 0.38±0.13 | 0.32±0.16 | 0.504 |
| **Rhythmic Weight Shift Left/Right** | | | |
| On-axis velocity (degree/second) | | | |
| slow | 2.74±0.39 | 3.08±0.47 | 0.206 |
| moderate | 4.28±0.31 | 4.88±0.33 | 0.028* |
| fast | 8.76±1.74 | 9.22±0.84 | 0.347 |
| Directional Control (%) | | | |
| slow | 76.8±6.30 | 78.0±4.74 | 0.834 |
| moderate | 85.4±2.30 | 84.6±3.21 | 0.753 |
| fast | 86.4±1.34 | 86.8±4.44 | 0.750 |

[#] : Mann-Whitney U-test, *: statistical significant at $p < 0.05$.

**Table E5.** Comparison of Limits of Stability between subjects with and without symptomatic knee osteoarthritis

| Limits of Stability | With OA Mean±SD | Without OA Mean±SD | p-value# |
|---|---|---|---|
| Reaction time(second) | | | |
| Front | 0.74± 0.43 | 0.88 ± 0.19 | 0.295 |
| right-front | 0.91± 0.54 | 0.55 ± 0.10 | 0.347 |
| right | 0.85 ± 0.32 | 0.60± 0.08 | 0.094 |
| right-back | 1.06± 0.51 | 0.57 ± 0.13 | 0.094 |
| back | 1.19± 0.75 | 0.77 ± 0.39 | 0.724 |
| left-back | 0.83 ± 0.24 | 1.00± 0.25 | 0.142 |
| left | 1.08± 0.32 | 0.59 ± 0.15 | 0.028* |
| left-front | 1.15 ± 0.35 | 0.90 ± 0.35 | 0.341 |
| Movement Velocity (degree/second) | | | |
| Front | 3.94 ± 1.75 | 3.26 ± 1.28 | 0.600 |
| right-front | 4.42 ± 1.26 | 6.54 ± 2.26 | 0.173 |
| right | 4.16 ± 2.97 | 6.00 ± 1.93 | 0.175 |
| right-back | 3.58 ± 2.90 | 5.06 ± 1.41 | 0.117 |
| back | 2.90 ± 1.31 | 3.53 ± 0.55 | 0.480 |
| left-back | 3.60 ± 1.36 | 2.83 ± 0.75 | 0.327 |
| left | 4.72 ± 1.76 | 5.98 ± 2.59 | 0.465 |
| left-front | 3.60 ± 1.12 | 4.20 ± 1.37 | 0.463 |
| End Point Excursion(%) | | | |
| Front | 49.80 ± 13.59 | 57.60 ± 5.86 | 0.175 |
| right-front | 66.40 ± 13.83 | 76.40 ± 11.41 | 0.251 |
| right | 66.60± 7.57 | 61.40 ± 6.02 | 0.203 |
| right-back | 64.20 ± 11.78 | 58.40 ± 7.92 | 0.602 |
| back | 60.50 ± 10.66 | 49.00 ± 7.55 | 0.157 |
| left-back | 68.40 ± 9.34 | 62.00 ± 18.89 | 0.624 |
| left | 62.00± 8.34 | 73.40 ± 10.21 | 0.075 |
| left-front | 72.20± 3.42 | 67.60 ± 13.97 | 0.675 |
| Maximum Excursion (%) | | | |
| front | 73.60 ± 13.70 | 78.40 ± 4.45 | 0.599 |
| right-front | 78.40 ± 7.83 | 84.00 ± 5.34 | 0.209 |
| right | 74.00 ± 4.24 | 76.00 ± 5.15 | 0.674 |
| right-back | 79.00 ± 9.98 | 74.80 ± 6.98 | 0.602 |
| back | 71.00 ± 7.53 | 59.67 ± 4.62 | 0.074 |
| left-back | 79.00 ± 10.42 | 72.50 ± 13.10 | 0.806 |
| left | 76.20 ± 3.70 | 79.00 ± 5.70 | 0.462 |
| left-front | 79.20 ± 4.27 | 78.60 ± 2.97 | 1.000 |
| Directional Control (%) | | | |
| front | 70.40 ± 39.70 | 85.60 ± 8.85 | 0.917 |
| right-front | 72.60 ± 6.73 | 77.40 ± 15.76 | 0.675 |
| right | 74.20 ± 11.77 | 85.60 ± 6.54 | 0.142 |
| right-back | 48.60 ± 24.06 | 49.20 ± 29.64 | 0.754 |
| back | 54.25 ± 37.51 | 58.67 ± 14.36 | 0.593 |
| left-back | 32.20 ± 27.85 | 48.00 ± 22.91 | 0.327 |
| left | 79.80 ± 14.69 | 89.40 ± 4.04 | 0.142 |
| left-front | 81.60 ± 7.83 | 81.20 ± 10.64 | 0.917 |

#: Mann-Whitney U-test, *: statistical significant at $p < 0.05$.

**Table E6.** Comparison the error angle of proprioception at 50°and 60° of right and left knee between subjects with and without symptomatic knee osteoarthritis

| Proprioception (degree) | | With OA Mean±SD | Without OA Mean±SD | p-value# |
|---|---|---|---|---|
| 50° | Right | 2.80 ±2.25 | 2.80 ±1.36 | 0.834 |
| | Left | 2.95 ±2.89 | 2.75 ±2.01 | 0.916 |
| 60° | Right | 3.75±1.58 | 2.10 ±1.18 | 0.115 |
| | Left | 5.00 ±3.14 | 2.40 ±0.96 | 0.055 |

#: Mann-Whitney U-test.

**Table E7.**Comparison of muscle strength of right and left knee between subjects with and without symptomatic knee osteoarthritis

| Muscle Strength (kg.) | | With OA Mean±SD | Without OA Mean±SD | p-value# |
|---|---|---|---|---|
| Flexor | Right | 7.86±3.49 | 12.40±0.46 | 0.116 |
| | Left | 9.37±3.16 | 12.27±0.45 | 0.115 |
| Extensor | Right | 16.77±4.53 | 23.41±1.64 | 0.047* |
| | Left | 17.68±4.13 | 23.40±2.92 | 0.047* |

#: Mann-Whitney U-test. *: statistical significant at $p < 0.05$.

# APPENDIX F

## RAW DATA OF PILOT STUDY

**Table F1** Characteristics of five females with symptomatic knee osteoarthritis

| Subjects | Age(years) | Weight(kg) | Height(cm) | Affected side |
|---|---|---|---|---|
| 1 | 54 | 53 | 149 | Rt > Lt |
| 2 | 60 | 73 | 154 | Lt |
| 3 | 52 | 56 | 155 | Rt > Lt |
| 4 | 50 | 64 | 160 | Lt |
| 5 | 46 | 67 | 155 | Lt >Rt |

**Table F2** Characteristics of five females without symptomatic knee osteoarthritis

| Subjects | Age (years) | Weight (kg) | Height(cm) |
|---|---|---|---|
| 1 | 59 | 52 | 153 |
| 2 | 49 | 61 | 154 |
| 3 | 59 | 72 | 158 |
| 4 | 57 | 55 | 150 |
| 5 | 47 | 50 | 154 |

**Table F3** The percentage of Maximum stability obtained from Sensory Organization Test (SOT) of five females with symptomatic osteoarthritis

| Subjects | Trial | Eyes Open | Eyes Closed | Sway-ref vision | Eyes Open and Sway-ref support | Eyes Closed and Sway-ref support | Sway ref-vision and support |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 93 | 88 | 89 | 65 | 31 | 34 |
| | 2 | 95 | 88 | 88 | 69 | 64 | 44 |
| 2 | 1 | 94 | 88 | 91 | 65 | 61 | 54 |
| | 2 | 94 | 87 | 87 | 62 | 63 | 58 |
| 3 | 1 | 93 | 87 | 88 | 75 | 65 | 40 |
| | 2 | 92 | 89 | 90 | 71 | 52 | 52 |
| 4 | 1 | 96 | 92 | 90 | 57 | N/S | N/S |
| | 2 | 91 | 88 | 85 | 60 | 27 | 36 |
| 5 | 1 | 95 | 91 | 82 | 91 | 58 | 52 |
| | 2 | 95 | 87 | 84 | 67 | 61 | 63 |

**Table F4** The percentage of Maximum stability obtained from Sensory Organization Test (SOT) of five females without symptomatic osteoarthritis

| Subjects | Trial | Eyes Open | Eyes Closed | Sway-ref vision | Eyes Open and Sway-ref support | Eyes Closed and Sway-ref support | Sway ref-vision and support |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 95 | 93 | 85 | 77 | 57 | N/S |
| | 2 | 95 | 94 | 85 | 87 | 59 | 77 |
| 2 | 1 | 96 | 93 | 93 | 89 | 50 | 40 |
| | 2 | 93 | 94 | 87 | 63 | 57 | 53 |
| 3 | 1 | 95 | 79 | 87 | 76 | 66 | 48 |
| | 2 | 91 | 88 | 91 | 84 | 73 | 65 |
| 4 | 1 | 90 | 93 | 90 | 84 | 46 | 33 |
| | 2 | 96 | 90 | 92 | 93 | 78 | 75 |
| 5 | 1 | 97 | 93 | 84 | 85 | 52 | 62 |
| | 2 | 96 | 94 | 92 | 86 | 65 | 50 |

**Table F5** Sway velocity from Sensory Organization Test (SOT) of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Eyes Open | Eyes Closed | Sway-ref vision | Eyes Open and Sway-ref support | Eyes Closed and Sway-ref support | Sway ref-vision and support |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.4 | 0.5 | 0.7 | 0.8 | 1.6 | 1.7 |
| | 2 | 0.3 | 0.6 | 0.9 | 0.6 | 1.5 | 1.3 |
| 2 | 1 | 0.2 | 0.3 | 0.3 | 0.7 | 1.0 | 0.8 |
| | 2 | 0.3 | 0.5 | 0.7 | 0.8 | 0.9 | 0.7 |
| 3 | 1 | 0.4 | 0.6 | 0.6 | 1.1 | 1.4 | 2.0 |
| | 2 | 0.4 | 0.6 | 0.4 | 0.7 | 1.8 | 1.3 |
| 4 | 1 | 0.2 | 0.4 | 0.3 | 1.0 | N/S | N/S |
| | 2 | 0.3 | 0.8 | 0.5 | 2.0 | 3.0 | 3.7 |
| 5 | 1 | 0.2 | 0.4 | 0.5 | 0.4 | 1.2 | 1.3 |
| | 2 | 0.3 | 0.6 | 0.5 | 0.8 | 1.4 | 0.8 |

**Table F6** Sway velocity from Sensory Organization Test (SOT) of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Eyes Open | Eyes Closed | Sway-ref vision | Eyes Open and Sway-ref support | Eyes Closed and Sway-ref support | Sway ref-vision and support |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.2 | 0.3 | 0.4 | 0.6 | 1.1 | N/S |
| | 2 | 0.2 | 0.3 | 0.5 | 0.4 | 1.0 | 0.7 |
| 2 | 1 | 0.2 | 0.4 | 0.3 | 0.4 | 0.8 | 1.6 |
| | 2 | 0.2 | 0.4 | 0.5 | 1.5 | 1.0 | 1.2 |
| 3 | 1 | 0.2 | 0.7 | 0.4 | 0.5 | 0.9 | 1.1 |
| | 2 | 0.4 | 0.8 | 0.4 | 0.5 | 1.0 | 0.9 |
| 4 | 1 | 0.3 | 0.3 | 0.4 | 0.4 | 1.1 | 1.0 |
| | 2 | 0.2 | 0.6 | 0.3 | 0.3 | 0.6 | 0.5 |
| 5 | 1 | 0.2 | 0.4 | 0.4 | 0.6 | 1.3 | 0.7 |
| | 2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.9 | 1.0 |

**Table F7** Center Target of five females with symptomatic knee osteoarthritis: Sway velocity

| Subjects | Trial | Sway velocity (degree/second) |
|---|---|---|
| 1 | 1 | 0.3 |
| | 2 | 0.3 |
| 2 | 1 | 0.3 |
| | 2 | 0.2 |
| 3 | 1 | 0.4 |
| | 2 | 0.5 |
| 4 | 1 | 0.3 |
| | 2 | 0.4 |
| 5 | 1 | 0.3 |
| | 2 | 0.5 |

**Table F8** Center Target of five females without symptomatic knee osteoarthritis: Sway velocity

| Subjects | Trial | Sway velocity (degree/second) |
|---|---|---|
| 1 | 1 | 0.3 |
| | 2 | 0.2 |
| 2 | 1 | 0.4 |
| | 2 | 0.5 |
| 3 | 1 | 0.4 |
| | 2 | 0.2 |
| 4 | 1 | 0.5 |
| | 2 | 0.5 |
| 5 | 1 | 0.3 |
| | 2 | 0.2 |

**Table F9** Dynamic balance test : Rhythmic Weight Shift Left-Right of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Rhythmic Weight Shift Left-Right | | | | | |
|---|---|---|---|---|---|---|---|
| | | On axis velocity(degree/second) | | | Directional control (%) | | |
| | | slow | moderate | fast | slow | Moderate | fast |
| 1 | 1 | 2.2 | 3.7 | 8.6 | 69 | 84 | 92 |
| | 2 | 2.4 | 4.1 | 7.3 | 68 | 88 | 87 |
| 2 | 1 | 3.2 | 5.2 | 8.7 | 79 | 80 | 89 |
| | 2 | 2.5 | 4.8 | 11.6 | 74 | 83 | 88 |
| 3 | 1 | 2.5 | 4.4 | 7.7 | 81 | 85 | 86 |
| | 2 | 3.3 | 4.3 | 8.5 | 85 | 87 | 85 |
| 4 | 1 | 2.8 | 5.6 | 10.4 | 78 | 87 | 90 |
| | 2 | 3.0 | 4.2 | 9.0 | 78 | 86 | 85 |
| 5 | 1 | 2.7 | 4.3 | 7.0 | 76 | 82 | 84 |
| | 2 | 2.5 | 4.0 | 7.4 | 79 | 83 | 87 |

**Table F10** Dynamic balance test : Rhythmic Weight Shift Left-Right of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Rhythmic Weight Shift Left-Right | | | | | |
|---|---|---|---|---|---|---|---|
| | | On axis velocity(degree/second) | | | Directional control (%) | | |
| | | slow | moderate | fast | slow | moderate | fast |
| 1 | 1 | 2.6 | 4.0 | 7.6 | 81 | 87 | 89 |
| | 2 | 2.8 | 4.5 | 8.6 | 72 | 80 | 82 |
| 2 | 1 | 2.8 | 4.8 | 10 | 78 | 88 | 92 |
| | 2 | 2.8 | 4.6 | 9.3 | 78 | 84 | 84 |
| 3 | 1 | 2.8 | 4.8 | 9.4 | 83 | 85 | 92 |
| | 2 | 2.7 | 5.0 | 8.2 | 75 | 85 | 85 |
| 4 | 1 | 3.9 | 5.4 | 11.2 | 83 | 89 | 92 |
| | 2 | 3.8 | 5.3 | 9.7 | 81 | 89 | 92 |
| 5 | 1 | 2.6 | 5.0 | 10.5 | 86 | 89 | 86 |
| | 2 | 3.3 | 5.0 | 10.3 | 84 | 85 | 91 |

**Table F11** Limits of Stability: Reaction Time of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Reaction Time (second) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 1.36 | 1.28 | 1.08 | 0.72 | 0.42 | 0.96 | 0.66 | 1.08 |
| | 2 | 0.32 | 1.18 | 0.64 | 0.52 | 0.92 | 0.70 | 0.60 | 0.88 |
| 2 | 1 | 1.00 | 1.34 | 1.50 | 2.02 | 1.82 | 1.78 | 1.68 | 2.16 |
| | 2 | 1.44 | 1.72 | 1.40 | 1.78 | 2.20 | 1.08 | 1.46 | 1.28 |
| 3 | 1 | 3.14 | 0.54 | 0.78 | N/S | N/S | N/S | 0.50 | 1.60 |
| | 2 | 0.50 | 0.72 | 0.76 | 1.22 | 0.42 | 1.10 | 1.04 | 1.62 |
| 4 | 1 | 0.56 | 0.70 | 0.98 | 1.16 | 0.74 | 0.68 | 1.22 | 1.24 |
| | 2 | 0.78 | 0.46 | 0.84 | 0.62 | N/S | 0.60 | 1.22 | 0.74 |
| 5 | 1 | 3.30 | 2.80 | 0.56 | 0.50 | 0.20 | 0.60 | 0.44 | 1.02 |
| | 2 | 0.64 | 0.48 | 0.60 | 1.18 | 1.20 | 0.66 | 1.06 | 1.24 |

**Table F12** Limits of Stability: Reaction Time of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Reaction Time (second) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 1.6 | 0.82 | 0.64 | 0.72 | 1.02 | 0.7 | 0.84 | 0.7 |
| | 2 | 0.76 | 0.58 | 0.68 | 0.72 | 1.22 | 1.16 | 0.7 | 0.8 |
| 2 | 1 | 0.52 | 1.24 | 1.02 | 1.04 | 0.80 | 0.76 | 0.74 | 0.62 |
| | 2 | 0.78 | 0.52 | 0.58 | 0.52 | 0.56 | 1.14 | 0.54 | 1.28 |
| 3 | 1 | 1.74 | 1.46 | 0.56 | 0.92 | 1.16 | 1.26 | 0.66 | 0.68 |
| | 2 | 0.98 | 0.7 | 0.64 | 0.44 | N/S | N/S | 0.48 | 1.28 |
| 4 | 1 | 0.92 | 0.82 | 0.76 | 1.12 | 0.88 | 0.66 | 0.58 | 0.48 |
| | 2 | 1.18 | 0.44 | 0.62 | 0.46 | 0.52 | 0.64 | 0.44 | 0.54 |
| 5 | 1 | 1.04 | 0.92 | 0.54 | 0.46 | 0.32 | 0.80 | 0.70 | 0.64 |
| | 2 | 0.72 | 0.50 | 0.48 | 0.70 | N/S | 1.12 | 0.80 | 0.64 |

**Table F13** Limits of Stability: Movement Velocity of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Movement Velocity(degree/second) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 8.1 | 2.5 | 9.9 | 6.0 | 3.9 | 7.0 | 8.3 | 4.4 |
| | 2 | 4.0 | 3.8 | 9.3 | 8.7 | 4.6 | 5.6 | 7.6 | 5.2 |
| 2 | 1 | 2.3 | 3.0 | 1.8 | 1.4 | 1.8 | 1.6 | 1.8 | 1.6 |
| | 2 | 2.2 | 3.0 | 2.4 | 1.6 | 3.2 | 1.8 | 2.8 | 3.0 |
| 3 | 1 | 6.2 | 3.2 | 3.5 | N/S | N/S | N/S | 2.5 | 8.6 |
| | 2 | 6.1 | 4.5 | 4.1 | 2.2 | 2.2 | 3.6 | 4.2 | 4.3 |
| 4 | 1 | 10.8 | 4.1 | 2.6 | 2.5 | 2.0 | 2.5 | 2.2 | 3.0 |
| | 2 | 2.2 | 6.4 | 2.2 | 2.8 | N/S | 3.8 | 4.6 | 2.5 |
| 5 | 1 | 4.1 | 4.7 | 7.1 | 6.6 | 3.7 | 6.0 | 6.7 | 5.3 |
| | 2 | 5.2 | 4.4 | 2.8 | 2.6 | 1.6 | 3.2 | 4.4 | 3.0 |

**Table F14** Limits of Stability: Movement Velocity of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Movement Velocity(degree/second) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 5.4 | 4.1 | 5.1 | 2.4 | 1.4 | 2.3 | 7.0 | 5.6 |
| | 2 | 5.4 | 6.1 | 6.6 | 2.9 | 2.9 | 3.7 | 6.7 | 4.0 |
| 2 | 1 | 3.5 | 4.2 | 3.3 | 1.5 | 2.3 | 4.1 | 5.5 | 2.4 |
| | 2 | 2.5 | 3.6 | 3.3 | 4.5 | 3.8 | 1.9 | 3.3 | 3.2 |
| 3 | 1 | 5.7 | 5.0 | 7.6 | 8.2 | 7.4 | 4.0 | 9.2 | 4.1 |
| | 2 | 2.1 | 5.4 | 6.9 | 6.5 | N/S | N/S | 10.0 | 2.7 |
| 4 | 1 | 7.0 | 3.9 | 7.6 | 3.3 | 3.6 | 4.1 | 7.9 | 5.2 |
| | 2 | 3.0 | 8.8 | 4.9 | 5.9 | 3.9 | 3.0 | 4.3 | 6.1 |
| 5 | 1 | 2.9 | 5.5 | 4.0 | 3.1 | 3.4 | 3.3 | 4.1 | 3.2 |
| | 2 | 3.3 | 8.8 | 8.3 | 5.5 | N/S | 2.7 | 5.6 | 5.0 |

**Table F15** Limits of Stability: End Point Excursion of five females with symptomatic knee osteoarthritis

| Subjects | Trial | End Point Excursion (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 16 | 57 | 62 | 96 | 56 | 65 | 70 | 58 |
| | 2 | 32 | 73 | 64 | 82 | 56 | 84 | 59 | 76 |
| 2 | 1 | 72 | 72 | 68 | 62 | 55 | 55 | 58 | 77 |
| | 2 | 69 | 71 | 55 | 57 | 49 | 63 | 62 | 74 |
| 3 | 1 | 56 | 90 | 50 | N/S | N/S | N/S | 68 | 64 |
| | 2 | 55 | 82 | 69 | 53 | 74 | 69 | 67 | 71 |
| 4 | 1 | 68 | 61 | 55 | 52 | 55 | 81 | 77 | 65 |
| | 2 | 45 | 60 | 75 | 59 | N/S | 66 | 72 | 73 |
| 5 | 1 | 65 | 65 | 66 | 67 | 45 | 59 | 53 | 63 |
| | 2 | 48 | 46 | 70 | 70 | 63 | 60 | 50 | 67 |

**Table F16** Limits of Stability: End Point Excursion of five females without symptomatic knee osteoarthritis

| Subjects | Trial | End Point Excursion (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 64 | 59 | 51 | 67 | 51 | 43 | 50 | 59 |
| | 2 | 56 | 67 | 55 | 66 | 57 | 53 | 69 | 76 |
| 2 | 1 | 73 | 81 | 65 | 76 | 47 | 83 | 56 | 68 |
| | 2 | 62 | 75 | 65 | 56 | 42 | 74 | 75 | 80 |
| 3 | 1 | 54 | 79 | 84 | 89 | 56 | 77 | 77 | 58 |
| | 2 | 57 | 90 | 55 | 64 | N/S | N/S | 75 | 50 |
| 4 | 1 | 59 | 92 | 73 | 90 | 41 | 44 | 55 | 48 |
| | 2 | 64 | 86 | 68 | 60 | 48 | 40 | 88 | 77 |
| 5 | 1 | 52 | 92 | 69 | 40 | 24 | 70 | 67 | 74 |
| | 2 | 49 | 64 | 64 | 46 | N/S | 81 | 60 | 55 |

**Table F17** Limits of Stability: Maximum Excursion of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Maximum Excursion (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 24 | 75 | 82 | 96 | 64 | 84 | 76 | 58 |
| | 2 | 51 | 73 | 80 | 82 | 60 | 93 | 79 | 83 |
| 2 | 1 | 79 | 78 | 72 | 70 | 55 | 62 | 74 | 77 |
| | 2 | 75 | 72 | 71 | 69 | 73 | 87 | 71 | 75 |
| 3 | 1 | 87 | 90 | 68 | N/S | N/S | N/S | 74 | 91 |
| | 2 | 88 | 90 | 69 | 71 | 74 | 69 | 74 | 79 |
| 4 | 1 | 77 | 75 | 71 | 77 | 55 | 90 | 77 | 77 |
| | 2 | 79 | 83 | 75 | 94 | N/S | 74 | 80 | 75 |
| 5 | 1 | 65 | 87 | 77 | 81 | 78 | 71 | 75 | 84 |
| | 2 | 75 | 74 | 75 | 79 | 77 | 72 | 77 | 84 |

**Table F18** Limits of Stability: Maximum Excursion of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Maximum Excursion (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 85 | 76 | 72 | 88 | 80 | 55 | 74 | 89 |
| | 2 | 83 | 80 | 84 | 84 | 57 | 53 | 74 | 76 |
| 2 | 1 | 76 | 81 | 75 | 76 | 58 | 83 | 73 | 75 |
| | 2 | 76 | 77 | 71 | 74 | 57 | 79 | 75 | 80 |
| 3 | 1 | 77 | 79 | 84 | 89 | 56 | 77 | 77 | 84 |
| | 2 | 73 | 90 | 73 | 73 | N/S | N/S | 77 | 76 |
| 4 | 1 | 79 | 92 | 81 | 90 | 68 | 81 | 77 | 90 |
| | 2 | 77 | 86 | 78 | 78 | 65 | 77 | 88 | 83 |
| 5 | 1 | 55 | 92 | 78 | 57 | 48 | 78 | 76 | 74 |
| | 2 | 83 | 87 | 74 | 65 | N/S | 81 | 81 | 78 |

**Table F19** Limits of Stability: Directional Control of five females with symptomatic knee osteoarthritis

| Subjects | Trial | Directional Control (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | -337 | 49 | 88 | 45 | 10 | 21 | 83 | 29 |
| | 2 | -36 | 69 | 77 | 28 | -70 | 39 | 79 | 79 |
| 2 | 1 | 93 | 87 | 77 | 58 | 86 | 35 | 76 | 93 |
| | 2 | 85 | 77 | 64 | 61 | 75 | 59 | 91 | 88 |
| 3 | 1 | 78 | 81 | 49 | N/S | N/S | N/S | 61 | 84 |
| | 2 | 81 | 63 | 63 | 20 | 59 | -11 | 55 | 86 |
| 4 | 1 | 86 | 70 | 79 | 71 | 60 | 70 | 81 | 63 |
| | 2 | 93 | 74 | 92 | 78 | N/S | 6 | 84 | 86 |
| 5 | 1 | -1 | 83 | 65 | 27 | 87 | 31 | 80 | 79 |
| | 2 | 93 | 80 | 75 | 56 | 83 | 57 | 90 | 69 |

**Table F20** Limits of Stability: Directional Control of five females without symptomatic knee osteoarthritis

| Subjects | Trial | Directional Control (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | F | RF | R | RB | B | LB | L | LF |
| 1 | 1 | 96 | 85 | 81 | 85 | 51 | -0 | 68 | 87 |
| | 2 | 88 | 89 | 88 | 70 | 53 | 31 | 88 | 92 |
| 2 | 1 | 85 | 85 | 94 | 79 | 51 | 67 | 88 | 90 |
| | 2 | 92 | 96 | 92 | 66 | 48 | 72 | 91 | 90 |
| 3 | 1 | 89 | 65 | 90 | 40 | 43 | 15 | 92 | 61 |
| | 2 | 79 | 60 | 90 | 40 | N/S | N/S | 93 | 76 |
| 4 | 1 | 86 | 89 | 77 | 63 | 67 | 69 | 68 | 70 |
| | 2 | 95 | 79 | 82 | 69 | 75 | 26 | 92 | 66 |
| 5 | 1 | 13 | 50 | 67 | 11 | -8 | 55 | 83 | 80 |
| | 2 | 74 | 63 | 76 | 1 | N/S | 63 | 83 | 82 |

**Table F21** Proprioception at 50° of five females with symptomatic knee osteoarthritis

| Subjects | Proprioception at 50°(degree) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Right | | | | Left | | | |
| | Measured angle | | Mean angle | Error angle* | Measured angle | | Mean angle | Error angle* |
| | Trial 1 | Trial 2 | | | Trial 1 | Trial 2 | | |
| 1 | 47 | 48 | 47.50 | 2.50 | 43 | 43 | 43.00 | 7.00 |
| 2 | 55 | 53 | 54.00 | 4.00 | 54 | 51.5 | 52.75 | 2.75 |
| 3 | 49.5 | 51 | 50.25 | 0.75 | 50 | 49 | 49.50 | 0.50 |
| 4 | 49 | 50.5 | 50.25 | 0.75 | 50 | 50 | 50.00 | 0.00 |
| 5 | 43 | 45 | 44.00 | 6.00 | 42 | 49 | 45.50 | 4.50 |
| mean±SD | 48.7± 4.35 | 49.5± 3.08 | 49.2± 3.71 | 2.80±2.25 | 47.8± 5.12 | 48.5± 3.24 | 48.2± 3.87 | 2.95±2.89 |

*Error angle = $\frac{|\text{measured angle from trial1} - \text{referenced angle}| + |\text{measured angle from trial1} - \text{referenced angle}|}{2}$

**Table F22** Proprioception at 50° of five females without symptomatic knee osteoarthritis

| Subjects | Proprioception at 50°(degree) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Right | | | | Left | | | |
| | Measured angle | | Mean angle | Error angle* | Measured angle | | Mean angle | Error angle* |
| | Trial1 | Trial2 | | | Trial1 | Trial2 | | |
| 1 | 49 | 42 | 45.50 | 4.50 | 49 | 48 | 48.50 | 1.50 |
| 2 | 53.5 | 46 | 49.75 | 3.75 | 44.5 | 43.5 | 44.00 | 6.00 |
| 3 | 48 | 47.5 | 47.75 | 2.25 | 49 | 49.5 | 49.25 | 0.75 |
| 4 | 51 | 49 | 50.00 | 1.00 | 55.5 | 50.0 | 52.75 | 2.75 |
| 5 | 48 | 47 | 47.50 | 2.50 | 47 | 52.5 | 49.75 | 2.75 |
| mean±SD | 49.9± 2.35 | 46.3± 2.63 | 48.1± 1.84 | 2.80±1.36 | 49.0± 4.08 | 48.7± 3.33 | 48.85± 3.16 | 2.75±2.09 |

*Error angle = $\frac{|\text{measured angle from trial1} - \text{referenced angle}| + |\text{measured angle from trial1} - \text{referenced angle}|}{2}$

**Table F23** Proprioception at 60° of five females with symptomatic knee osteoarthritis

| Subjects | Proprioception at 60°(degree) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Right | | | | Left | | | |
| | Measured angle | | Mean angle | Error angle* | Measured angle | | Mean angle | Error angle* |
| | Trial 1 | Trial 2 | | | Trial 1 | Trial 2 | | |
| 1 | 55 | 57 | 56.0 | 4.00 | 48 | 52 | 50.0 | 10.0 |
| 2 | 58 | 62 | 60.0 | 2.00 | 64 | 61 | 62.5 | 2.50 |
| 3 | 55 | 59 | 57.0 | 3.00 | 55.5 | 56.5 | 56.0 | 4.00 |
| 4 | 57 | 56 | 56.5 | 3.50 | 61 | 64 | 62.5 | 2.50 |
| 5 | 56.5 | 51 | 53.75 | 6.25 | 51.5 | 56.5 | 54.0 | 6.00 |
| mean±SD | 56.3± 1.30 | 57.0± 4.06 | 56.7± 2.25 | 3.75±1.58 | 56.0± 6.59 | 58.0± 4.62 | 57.0± 5.47 | 5.00±3.14 |

*Error angle = |measured angle from trial1 – referenced angle|+| measured angle from trial1 – referenced angle|
2

**Table F24** Proprioception at 60° of five females without symptomatic knee osteoarthritis

| Subjects | Proprioception at 60°(degree) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Right | | | | Left | | | |
| | Measured angle | | Mean angle | Error angle* | Measured angle | | Mean angle | Error angle* |
| | Trial 1 | Trial 2 | | | Trial 1 | Trial 2 | | |
| 1 | 60 | 58 | 59.00 | 1.00 | 62 | 57 | 59.5 | 2.50 |
| 2 | 57.5 | 58 | 57.75 | 2.25 | 55 | 57 | 56.0 | 4.00 |
| 3 | 60 | 52 | 56.00 | 4.00 | 56 | 60 | 58.0 | 2.00 |
| 4 | 59 | 57 | 58.00 | 2.00 | 59 | 58 | 58.5 | 1.50 |
| 5 | 59 | 58.5 | 58.75 | 1.25 | 62 | 58 | 60.0 | 2.00 |
| mean±SD | 59.1± 1.02 | 56.7± 2.68 | 57.9± 1.18 | 2.10±1.18 | 58.8± 3.27 | 58.0± 1.23 | 58.4± 1.56 | 2.40±0.96 |

*Error angle = |measured angle from trial1 – referenced angle|+| measured angle from trial1 – referenced angle|
2

**Table F25** Muscle Strength of knee flexion of five females with symptomatic knee osteoarthritis

| Subjects | Muscle Strength of knee flexion (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Right | | | Left | | |
| | Trial1 | Trial2 | mean | Trial1 | Trial2 | mean |
| 1 | 6.3 | 5.4 | 5.85 | 5.3 | 5.7 | 5.50 |
| 2 | 8.9 | 8.9 | 8.90 | 9.5 | 9.2 | 9.35 |
| 3 | 5.4 | 5.6 | 5.50 | 8.1 | 9.2 | 8.65 |
| 4 | 5.1 | 5.9 | 5.50 | 9.1 | 9.0 | 9.05 |
| 5 | 13.5 | 13.6 | 13.55 | 14.0 | 14.6 | 14.3 |

**Table F26** Muscle Strength of knee flexion of five females without symptomatic knee osteoarthritis

| Subjects | Muscle Strength of knee flexion (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Right | | | Left | | |
| | Trial1 | Trial2 | mean | Trial1 | Trial2 | mean |
| 1 | 13.7 | 12.2 | 12.93 | 13.1 | 13.0 | 13.05 |
| 2 | 13.1 | 11.6 | 12.35 | 12.4 | 12.0 | 12.20 |
| 3 | 12.5 | 12.7 | 12.60 | 10.4 | 13.5 | 11.95 |
| 4 | 12.4 | 12.4 | 12.40 | 12.2 | 11.7 | 11.95 |
| 5 | 11.5 | 11.9 | 11.70 | 11.5 | 12.9 | 12.20 |

**Table F27** Muscle Strength of knee extension of five females with symptomatic knee osteoarthritis

| Subjects | Muscle Strength of knee extension (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Right | | | Left | | |
| | Trial1 | Trial2 | Mean | Trial1 | Trial2 | mean |
| 1 | 13.1 | 12.4 | 12.75 | 12.2 | 13.9 | 13.05 |
| 2 | 23.4 | 23.3 | 23.35 | 22.0 | 24.4 | 23.20 |
| 3 | 17.1 | 14.4 | 15.75 | 15.2 | 14.8 | 15.00 |
| 4 | 13.5 | 12.1 | 12.80 | 17.5 | 15.8 | 16.65 |
| 5 | 18.0 | 20.4 | 19.20 | 19.2 | 21.8 | 20.50 |

**Table F28** Muscle Strength of knee extension of five females without symptomatic knee osteoarthritis

| Subjects | Muscle Strength of knee extension (kg) | | | | | |
|---|---|---|---|---|---|---|
| | Right | | | Left | | |
| | Trial1 | Trial2 | Mean | Trial1 | Trial2 | mean |
| 1 | 24.1 | 24.7 | 24.40 | 28.0 | 28.3 | 28.15 |
| 2 | 24.0 | 22.2 | 23.10 | 23.7 | 24.9 | 24.30 |
| 3 | 23.4 | 21.8 | 22.60 | 19.6 | 23.3 | 21.45 |
| 4 | 25.1 | 26.1 | 25.60 | 20.4 | 22.9 | 21.65 |
| 5 | 21.3 | 21.4 | 21.35 | 21.9 | 21.0 | 21.45 |

# APPENDIX G

# RESULTS OF TEST-RETEST RELIABILITY

The test-retest reliability was determined for each of the following tests: the laboratory balance test, proprioception and muscle strength measurement test. Two different groups of 10 healthy females, aged 16-30 years were included in the test-retest reliability studies of the proprioception test and muscle strength measurements. For the laboratory balance test, 10 patients with osteoarthritic knee, aged ranging from 40 to 60 years were studied. Characteristics of all subjects are presented in Table G1, G2, and G15. The data of all tests were analyzed by SPSS for Window Release 7.5. Intraclass Correlation Coefficients (ICC3,1) was used to determine the test-retest reliability.

$$ICC(3,1) = \frac{BMS - EMS}{BMS + (k-1)\,EMS}$$

BMS = between – targets mean square

EMS = residual mean square

k= number of session

## 1. Laboratory balance test

Ten patients with osteoarthritic knee performed 3 trials of both static and dynamic balance tests. Since the first trial was used as the practice trial, only the scores of the second and the third trials were used for the calculation of ICC (3,1). The raw data of this study are presented in Table G2-G11.

- The percentage of maximum stability from Sensory Organization Test

The result showed that the test-retest reliabilities of 4 testing conditions were satisfactory (ICC (3,1) ranged from 0.5726-0.8797). For the other two testing conditions (Condition 2,6), the reliabilities were not satisfactory.

- Sway velocity of Sensory Organization Test

The results showed that the test-retest reliabilities of 4 testing conditions were satisfactory (ICC (3,1) ranged from 0.52-0.7940) while the other two were not.

-Center target and on axis velocity, directional control from Rhythmic Weight Shift.

For Rhythmic Weight Shift left /right, most of the ICC (3,1) values showed satisfactory results (ICC (3,1) ranged from 0.5691-0.7139). In contrast, the test-retest reliability was not satisfactory for all parameters in Rhythmic Weight Shift front/back.

-Limits of Stability

The results showed that 55% of the values were satisfactory (ICC (3,1) ranged from 0.5043-0.9243).

**2. Proprioception test of the knee**

Ten subjects underwent 3 sessions of proprioception test of both knees at the angle of 30°, 40°, 50°, 60° knee flexion. In each session, the subject performed 2 trials of the test at each angle. The mean values of 2 trials were used for the calculation of ICC (3,1). The raw data of the study are presented in Table G13-G16.

The results of this study revealed a moderately high to high test-retest reliabilities for the proprioception test at the knee flexion angle of 50° and 60° of both knees (ICC (3,1) ranged from 0.64-0.92). For the other angles tested (30° of both knees and 40° of right knee), the reliabilities were not satisfactory.

**3. Muscle Strength Measurement**

Ten subjects performed 3 trials of muscle strength measurement of both knees (flexor and extensor muscles). The mean values of 2 trials were used for the calculation of ICC (3,1). The raw data of this study are presented in Table G18 and G19.

The results of this study revealed a moderately high to high test-retest reliabilities for the muscle strength measurement of both knees (ICC (3,1) ranged from 0.6752-0.8942).

**Table G1.** Intraclass correlation coefficients of the percentage of maximum stability of the Sensory Organization Test (SOT) in ten females with osteoarthritis

| SOT condition | ICC (3,1) |
|---|---|
| 1.Eyes Open | 0.7427 |
| 2.Eyes Closed | 0.2901 |
| 3.Sway-ref vision | 0.8395 |
| 4.Eyes Open and Sway-ref support | 0.8797 |
| 5.Eyes Closed and Sway-ref support | 0.5726 |
| 6.Sway-ref vision and support | -0.4005 |

**Table G2.** Intraclass correlation coefficients of sway velocity of the Sensory Organization Test (SOT) in ten females with osteoarthritis

| SOT condition | ICC (3,1) |
|---|---|
| 1.Eyes Open | 0.6760 |
| 2.Eyes Closed | 0.5200 |
| 3.Sway-ref vision | 0.7746 |
| 4.Eyes Open and Sway-ref support | 0.7940 |
| 5.Eyes Closed and Sway-ref support | 0.3242 |
| 6.Sway-ref vision and support | -0.1012 |

**Table G3.** Intraclass Correlation Coefficients of center target and on-axis velocity, directional control from Rhythmic Weight Shift test

| Test | ICC (3,1) |
|---|---|
| Center Target | 0.1905 |
| Rhythmic Weight Shift Left/Right | |
| On-axis velocity | |
| Slow | 0.5691 |
| Moderate | 0.3859 |
| Fast | 0.5976 |
| Directional Control | |
| Slow | 0.2794 |
| Moderate | 0.5285 |
| Fast | 0.7139 |
| Rhythmic Weight Shift Front/Back | |
| On-axis velocity | |
| Slow | -0.1801 |
| Moderate | 0.1676 |
| Fast | 0.1732 |
| Directional Control | |
| Slow | 0.2051 |
| Moderate | 0.3329 |
| Fast | 0.1738 |

**Table G4.** Intraclass Correlation Coefficients of Limits of Stability test

| Limits of Stability test | ICC (3,1) |
|---|---|
| Reaction Time (second) | |
| front | -0.0893 |
| right-front | 0.3853 |
| right | 0.7510 |
| right-back | 0.1305 |
| back | 0.6388 |
| left-back | 0.5507 |
| left | 0.3371 |
| left-front | 0.2569 |
| Movement Velocity (degree/second) | |
| front | 0.9243 |
| right-front | 0.2085 |
| right | 0.5679 |
| right-back | 0.5971 |
| back | 0.5043 |
| left-back | 0.6720 |
| left | 0.4862 |
| left-front | 0.2656 |
| End Point Excursion (%) | |
| front | -0.0944 |
| right-front | 0.7185 |
| right | 0.4285 |
| right-back | 0.8534 |
| back | 0.4158 |
| left-back | 0.6399 |
| left | -0.2453 |
| left-front | 0.3818 |
| Maximum Excursion (%) | |
| front | 0.5714 |
| right-front | 0.2097 |
| right | 0.7611 |
| right-back | 0.8647 |
| back | 0.2553 |
| left-back | 0.7759 |
| left | 0.7062 |
| left-front | 0.8143 |
| Directional Control (%) | |
| front | 0.7330 |
| right-front | 0.5523 |
| right | 0.8135 |
| right-back | 0.6347 |
| back | -0.1273 |
| left-back | 0.4685 |
| left | 0.7304 |
| left-front | 0.3857 |

**Table G5.** Intraclass Correlation Coefficients of proprioception test of the knee

| Angle (degree) | ICC (3,1) of right knee | ICC(3,1) of left knee |
|---|---|---|
| 30 | 0.5002 | 0.5988 |
| 40 | 0.7855 | 0.4751 |
| 50 | 0.9203 | 0.6357 |
| 60 | 0.7872 | 0.6913 |

**Table G6.** Intraclass Correlation Coefficients of muscle strength test of the knee

| Groups of Muscle work | ICC(3,1) of right knee | ICC(3,1) of left knee |
|---|---|---|
| Flexor group | 0.8433 | 0.8942 |
| Extensor group | 0.6752 | 0.8228 |

# APPENDIX H

## RAW DATA OF TEST-RETEST RELIABILITY

**Table H1.** Characteristics of ten female subjects with osteoarthritis of the knee for static and dynamic balance tests

| Subjects | Age (years) | Weight (kg.) | Height (cm.) |
|---|---|---|---|
| 1 | 52 | 65 | 153 |
| 2 | 60 | 46.7 | 146 |
| 3 | 57 | 55.8 | 158.8 |
| 4 | 48 | 64.5 | 164 |
| 5 | 41 | 63.6 | 156 |
| 6 | 57 | 62 | 153 |
| 7 | 60 | 55 | 144 |
| 8 | 47 | 50 | 150 |
| 9 | 57 | 57 | 155 |
| 10 | 46 | 61 | 153 |
| Mean | 52.50 | 153.28 | 58.06 |
| SD | 6.6542 | 5.8296 | 6.2726 |

**Table H2.** Static balance test: The percentage of Maximum stability obtained from the Sensory Organization Test

| Subjects | Eye Open | | | Eye Closed | | | Sway-referenced vision | | | Eye Open and Sway-referenced Support | | | Eye Closed and Sway-referenced Support | | | Sway-referenced vision and support | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 |
| 1 | 93 | 94 | 94 | 91 | 90 | 89 | 84 | 84 | 83 | 77 | 69 | 69 | 61 | 53 | 65 | 55 | 56 | 74 |
| 2 | 95 | 92 | 93 | 91 | 88 | 91 | 82 | 91 | 90 | 82 | 68 | 69 | 51 | 74 | 81 | 70 | 56 | 50 |
| 3 | 91 | 91 | 88 | 88 | 81 | 85 | 89 | 89 | 89 | 40 | 72 | 63 | N/S | 47 | 35 | 51 | 46 | 62 |
| 4 | 97 | 94 | 92 | 91 | 81 | 91 | 78 | 85 | 82 | 53 | 32 | 31 | N/S | N/S | 40 | N/S | 38 | N/S |
| 5 | 93 | 97 | 96 | 90 | 87 | 93 | 88 | 87 | 91 | 79 | 82 | 85 | 44 | 60 | 73 | N/S | 28 | 77 |
| 6 | 93 | 90 | 93 | 89 | 85 | 89 | 77 | 91 | 85 | 52 | 77 | 75 | 70 | 73 | 60 | 52 | N/S | 37 |
| 7 | 95 | 94 | 96 | 95 | 92 | 92 | 91 | 94 | 94 | 74 | 75 | 83 | N/S | 58 | 69 | N/S | 62 | 55 |
| 8 | 96 | 95 | 93 | 93 | 93 | 91 | 92 | 93 | 95 | 83 | 84 | 87 | 65 | 60 | 60 | 54 | 80 | 66 |
| 9 | 90 | 88 | 83 | 82 | 88 | 83 | 80 | 74 | 78 | 54 | 56 | 75 | 17 | 51 | N/S | N/S | N/S | 55 |
| 10 | 96 | 94 | 94 | 92 | 92 | 90 | 95 | 86 | 89 | 60 | 68 | 78 | 76 | 60 | 53 | 51 | 63 | 48 |

**Table H3.** Static balance test: Sway Velocity from the Sensory Organization Test

| Subjects | Eye Open | | | Eye Closed | | | Sway-referenced vision | | | Eye Open and Sway-referenced Support | | | Eye Closed and Sway-referenced Support | | | Sway-referenced vision and support | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 |
| 1 | 0.2 | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.4 | 0.9 | 0.6 | 0.8 | 1.1 | 1.2 | 1.3 | 1.3 | 1.3 | 1.2 | 1.0 | 1.4 |
| 2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.4 | 0.3 | 0.4 | 0.5 | 0.5 | 0.6 | 1.0 | 1.2 | 0.7 | 0.8 | 0.6 | 1.0 | 0.9 |
| 3 | 0.3 | 0.5 | 0.8 | 0.4 | 0.6 | 0.9 | 0.5 | 0.7 | 0.7 | 1.2 | 0.8 | 1.2 | N/S | 1.6 | 1.4 | 1.1 | 1.4 | 1.4 |
| 4 | 0.2 | 0.3 | 0.3 | 0.4 | 0.6 | 0.5 | 0.5 | 0.4 | 0.7 | 0.5 | 1.1 | 1.0 | N/S | N/S | 1.5 | N/S | 1.4 | N/S |
| 5 | 0.2 | 0.2 | 0.3 | 0.4 | 0.6 | 0.5 | 0.4 | 0.3 | 0.3 | 0.5 | 0.7 | 0.6 | 1.9 | 1.4 | 1.0 | N/S | 2.0 | 0.6 |
| 6 | 0.3 | 0.4 | 0.3 | 0.4 | 0.5 | 0.3 | 0.5 | 0.3 | 0.4 | 1.1 | 0.5 | 0.6 | 1.2 | 0.7 | 1.0 | 1.0 | N/S | 1.0 |
| 7 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.6 | 0.6 | 0.5 | N/S | 1.4 | 1.2 | N/S | 1.4 | 1.1 |
| 8 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.4 | 0.3 | 0.6 | 0.4 | 0.5 | 1.2 | 1.6 | 0.8 | 1.3 | 0.6 | 1.1 |
| 9 | 0.3 | 0.4 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.9 | 1.1 | 2.0 | 1.9 | 1.5 | 1.8 | 1.8 | N/S | N/S | N/S | 1.8 |
| 10 | 0.1 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.3 | 0.8 | 0.6 | 0.9 | 1.3 | 1.4 | 2.2 | 1.0 | 0.9 | 1.2 |

**Table H4.** Dynamic balance test: Center Target: Sway Velocity (degree/second)

| Subjects | Center Target (degree/second) | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 |
| 1 | 0.3 | 0.4 | 0.3 |
| 2 | 0.6 | 0.4 | 0.3 |
| 3 | 0.5 | 0.5 | 0.3 |
| 4 | 0.3 | 0.3 | 0.4 |
| 5 | 0.6 | 0.4 | 0.3 |
| 6 | 0.3 | 0.2 | 0.2 |
| 7 | 0.5 | 0.4 | 0.3 |
| 8 | 0.3 | 0.3 | 0.3 |
| 9 | 0.3 | 0.2 | 0.3 |
| 10 | 0.3 | 0.4 | 0.3 |

**Table H5.** Dynamic balance: Rhythmic Weight Shift L/R (degree/second)

| Subject NO. | On axis velocity (degree/second) | | | | | | | | | Directional Control (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | slow | | | moderate | | | fast | | | slow | | | moderate | | | fast | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 2.1 | 2.9 | 2.3 | 3.6 | 4.1 | 3.8 | 4.8 | 5.7 | 4.6 | 74 | 79 | 63 | 84 | 77 | 80 | 82 | 84 | 88 |
| 2 | 2.5 | 2.8 | 2.8 | 4.0 | 3.7 | 4.5 | 5.5 | 6.3 | 7.4 | 84 | 76 | 80 | 90 | 87 | 87 | 89 | 85 | 88 |
| 3 | 3.0 | 2.9 | 2.8 | 4.7 | 4.7 | 3.9 | 9.6 | 9.0 | 10 | 79 | 77 | 77 | 82 | 84 | 86 | 75 | 83 | 84 |
| 4 | 3.0 | 3.0 | 3.1 | 4.5 | 4.9 | 4.9 | 5.5 | 9.8 | 7.8 | 78 | 79 | 84 | 84 | 87 | 92 | 83 | 90 | 92 |
| 5 | 3.1 | 2.9 | 2.7 | 5.1 | 5.2 | 4.7 | 8.2 | 7.2 | 10.3 | 87 | 86 | 79 | 88 | 88 | 86 | 92 | 92 | 93 |
| 6 | 2.4 | 2.6 | 2.6 | 3.7 | 4.3 | 4.5 | 6.7 | 8.3 | 7.5 | 72 | 75 | 70 | 69 | 81 | 81 | 85 | 88 | 91 |
| 7 | 2.9 | 3.0 | 3.1 | 4.6 | 4.6 | 4.8 | 9.6 | 11.2 | 12.5 | 81 | 68 | 76 | 86 | 79 | 86 | 87 | 92 | 92 |
| 8 | 3.3 | 3.0 | 2.7 | 6.0 | 4.6 | 4.5 | 12.2 | 9.7 | 9.8 | 71 | 84 | 84 | 90 | 89 | 86 | 95 | 89 | 91 |
| 9 | 1.1 | 3.2 | 3.1 | 5.9 | 3.7 | 4.3 | 5.7 | 8.8 | 6.9 | 59 | 74 | 75 | 83 | 77 | 87 | 86 | 85 | 91 |
| 10 | 2.6 | 2.7 | 2.4 | 4.1 | 4.2 | 4.2 | 6.5 | 10.0 | 7.5 | 80 | 79 | 77 | 83 | 88 | 89 | 90 | 93 | 90 |

**Table H6.** Dynamic balance: Rhythmic Weight Shift F/B (degree/second)

| Subjects | On axis velocity (degree/second) | | | | | | | | | Directional Control (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | slow | | | moderate | | | fast | | | slow | | | moderate | | | fast | | |
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 1.4 | 2.1 | 1.5 | 2.9 | 2.7 | 2.4 | 4.5 | 5.0 | 3.4 | 76 | 79 | 76 | 86 | 80 | 82 | 91 | 86 | 82 |
| 2 | 1.6 | 1.6 | 2.2 | 2.9 | 3.0 | 2.8 | 3.9 | 5.9 | 3.4 | 83 | 72 | 82 | 90 | 85 | 89 | 90 | 91 | 91 |
| 3 | 2.2 | 1.8 | 2.0 | 3.4 | 3.4 | 3.0 | 5.5 | 5.4 | 7.3 | 69 | 77 | 67 | 80 | 81 | 77 | 81 | 83 | 82 |
| 4 | 1.7 | 1.7 | 1.9 | 2.5 | 2.5 | 2.9 | 4.1 | 4.4 | 7.4 | 78 | 80 | 79 | 90 | 85 | 86 | 88 | 82 | 93 |
| 5 | 1.9 | 2.0 | 1.8 | 3.3 | 2.9 | 3.3 | 6.1 | 6.9 | 5.0 | 81 | 81 | 85 | 90 | 86 | 85 | 93 | 92 | 90 |
| 6 | 1.7 | 1.8 | 1.8 | 2.4 | 3.0 | 2.6 | 3.7 | 4.1 | 3.7 | 76 | 55 | 70 | 77 | 75 | 70 | 81 | 87 | 84 |
| 7 | 1.9 | 1.8 | 1.9 | 2.7 | 2.6 | 3.3 | 5.7 | 6.3 | 7.4 | 68 | 77 | 75 | 77 | 84 | 83 | 82 | 89 | 84 |
| 8 | 2.6 | 2.1 | 2.0 | 3.7 | 3.2 | 3.3 | 6.8 | 6.5 | 6.4 | 85 | 67 | 87 | 89 | 87 | 91 | 83 | 88 | 89 |
| 9 | 2.2 | 1.9 | 2.9 | 2.5 | 2.9 | 1.7 | 5.1 | 5.2 | 4.7 | 59 | 72 | 80 | 87 | 72 | 82 | 86 | 85 | 87 |
| 10 | 1.8 | 1.8 | 2.0 | 2.6 | 3.2 | 3.4 | 6.7 | 5.9 | 6.6 | 75 | 79 | 81 | 74 | 71 | 90 | 84 | 82 | 87 |

**Table H7.** Limits of Stability: Reaction Time (second)

| Subject | front | | | right-front | | | right | | | right-back | | | back | | | left-back | | | left | | | left-front | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 0.92 | 0.42 | 0.36 | 0.30 | N/S | 0.62 | N/S | 1.12 | 0.72 | N/S | N/S | 0.82 | 0.20 | 0.60 | 0.34 | N/S | 0.38 | 0.52 | N/S | N/S | 1.06 | N/S | 1.50 | 0.20 |
| 2 | 1.70 | N/S | 0.16 | 1.10 | 0.64 | 0.42 | 0.68 | 0.50 | 0.68 | 0.94 | 1.12 | 0.38 | 0.84 | 1.96 | 0.98 | 0.78 | 1.24 | 0.94 | 0.96 | 0.16 | 0.52 | 1.12 | 1.14 | 1.04 |
| 3 | 0.68 | 1.00 | 0.48 | 0.86 | 1.34 | 0.68 | 0.20 | 1.20 | 0.84 | 0.46 | 1.14 | 0.48 | 1.00 | 1.14 | 1.10 | 0.76 | 1.38 | 0.58 | 0.54 | 0.94 | 0.52 | 1.30 | 1.24 | 1.12 |
| 4 | 1.02 | 0.32 | 1.32 | 1.14 | 1.28 | 0.92 | 0.70 | 1.20 | 1.16 | 1.34 | 1.42 | 1.02 | 0.68 | 1.30 | 1.22 | 1.44 | 1.68 | 1.52 | 1.26 | 0.36 | 1.56 | 1.56 | 1.78 | 0.58 |
| 5 | 1.56 | 0.98 | 0.58 | 0.50 | 0.64 | 0.56 | 0.96 | 0.36 | 0.56 | 0.48 | 0.72 | 0.38 | 1.02 | 0.54 | 0.46 | 0.46 | 0.56 | 0.58 | 0.58 | 0.72 | 0.74 | 0.92 | 0.58 | 0.68 |
| 6 | 0.86 | 1.16 | 0.66 | 0.62 | 1.10 | 0.82 | 1.00 | 1.32 | 0.76 | 1.10 | 1.16 | N/S | N/S | N/S | N/S | 1.02 | 1.58 | 0.92 | 1.22 | 1.38 | 1.38 | 1.82 | 2.68 | 1.20 |
| 7 | 0.28 | 0.38 | 0.62 | 1.34 | 0.40 | 1.22 | 0.58 | 0.40 | 0.52 | 0.52 | 1.00 | 0.52 | 0.76 | 0.36 | 0.84 | 0.98 | 0.82 | 1.06 | 0.50 | 0.60 | 0.50 | 1.04 | 0.64 | 0.52 |
| 8 | 0.60 | 0.46 | 0.48 | 0.58 | 0.48 | 0.56 | 0.48 | 0.40 | 0.52 | 0.48 | 0.52 | 0.58 | 0.38 | 0.50 | 0.50 | 0.42 | 0.48 | 0.58 | 0.54 | 0.56 | 0.56 | 0.76 | 0.64 | 0.58 |
| 9 | 0.76 | 0.90 | 1.22 | 1.50 | 1.42 | 1.48 | 1.58 | 1.58 | 1.52 | 0.58 | 0.4 | 0.50 | 1.34 | 0.24 | 0.28 | 1.60 | 1.12 | 1.44 | 1.62 | 1.24 | 1.50 | 1.46 | 0.62 | 0.70 |
| 10 | 1.62 | 0.72 | 0.76 | 1.04 | 0.72 | 0.72 | 0.90 | 0.98 | 0.68 | 1.22 | 0.66 | 1.18 | 0.74 | 1.20 | 0.78 | 0.68 | 0.88 | 1.18 | 1.52 | 1.32 | 0.74 | 1.46 | 0.74 | 0.86 |

**Table H8.** Limits of Stability: Movement Velocity (degree/second)

| Subject | front | | | right-front | | | right | | | right-back | | | back | | | left-back | | | left | | | left-front | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 2.3 | 1.8 | 2.4 | 5.0 | N/S | 3.6 | N/S | 3.3 | 3.0 | N/S | N/S | 2.6 | 2.4 | 3.7 | 7.9 | N/S | 5.7 | 3.8 | N/S | N/S | 4.7 | N/S | 4.4 | 2.5 |
| 2 | 0.9 | N/S | 2.4 | 3.1 | 3.2 | 3.2 | 3.8 | 5.3 | 2.8 | 2.8 | 2.7 | 2.4 | 1.1 | 1.2 | 1.5 | 2.2 | 2.1 | 2.5 | 3.4 | 3.5 | 3.1 | 2.8 | 2.9 | 2.4 |
| 3 | 7.2 | 2.2 | 4.1 | 5.5 | 1.7 | 5.5 | 6.6 | 3.6 | 4.6 | 6.8 | 5.2 | 4.8 | 1.5 | 1.1 | 1.7 | 6.6 | 2.6 | 3.1 | 5.8 | 4.9 | 3.8 | 2.1 | 1.7 | 4.5 |
| 4 | 1.7 | 1.7 | 2.2 | 3.1 | 1.7 | 2.1 | 1.9 | 1.8 | 2.4 | 2.5 | 1.0 | 1.9 | 1.5 | 1.6 | 1.2 | 2.4 | 2.0 | 1.3 | 2.8 | 2.2 | 2.0 | 2.1 | 2.7 | 2.9 |
| 5 | 3.5 | 3.6 | 2.5 | 5.5 | 4.1 | 4.1 | 5.2 | 5.2 | 5.3 | 2.6 | 3.1 | 3.7 | 2.3 | 2.3 | 1.6 | 5.9 | 4.0 | 5.6 | 6.3 | 4.6 | 7.0 | 4.1 | 4.8 | 4.0 |
| 6 | 3.2 | 1.6 | 2.4 | 2.4 | 2.5 | 3.3 | 2.6 | 2.4 | 2.0 | 3.2 | 1.5 | N/S | N/S | N/S | N/S | 0.9 | 2.0 | 1.9 | 1.8 | 2.0 | 2.5 | 2.4 | 2.0 | 2.2 |
| 7 | 6.4 | 9.4 | 10.3 | 7.0 | 5.2 | 4.9 | 3.2 | 8.2 | 5.0 | 2.2 | 3.0 | 3.6 | 2.0 | 2.7 | 2.7 | 2.1 | 4.6 | 2.3 | 2.9 | 3.7 | 4.9 | 3.2 | 6.9 | 4.0 |
| 8 | 7.8 | 6.7 | 5.5 | 3.7 | 2.9 | 5.8 | 5.9 | 6.8 | 3.8 | 3.8 | 3.1 | 3.0 | 4.7 | 5.3 | 3.4 | 4.7 | 7.8 | 7.0 | 4.4 | 6.0 | 4.2 | 2.7 | 4.2 | 6.7 |
| 9 | 4.0 | 1.1 | 2.3 | 4.0 | 3.5 | 3.3 | 2.7 | 3.7 | 3.0 | 5.9 | 1.6 | 4.2 | 1.6 | 2.9 | 1.3 | 5.0 | 6.5 | 3.6 | 4.3 | 3.9 | 2.7 | 2.6 | 4.3 | 3.8 |
| 10 | 2.9 | 3.8 | 3.3 | 5.0 | 3.4 | 4.0 | 5.4 | 4.6 | 4.2 | 2.5 | 2.7 | 2.3 | 1.3 | 2.0 | 1.7 | 2.4 | 2.1 | 3.8 | 3.4 | 3.8 | 6.0 | 3.8 | 4.0 | 4.8 |

**Table H9.** Limits of Stability: End Point of Excursion (%)

| Subject | front | | | right-front | | | right | | | right-back | | | back | | | left-back | | | left | | | left-front | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 47 | 78 | 71 | 51 | N/S | 82 | N/S | 63 | 77 | N/S | N/S | 60 | 87 | 59 | 44 | N/S | 52 | 60 | N/S | N/S | 48 | N/S | 51 | 73 |
| 2 | 23 | N/S | 46 | 52 | 70 | 73 | 49 | 52 | 71 | 56 | 53 | 44 | 55 | 47 | 41 | 78 | 49 | 57 | 74 | 76 | 58 | 40 | 42 | 38 |
| 3 | 47 | 52 | 52 | 76 | 79 | 91 | 67 | 65 | 64 | 57 | 66 | 66 | 54 | 42 | 56 | 52 | 77 | 58 | 81 | 65 | 80 | 71 | 80 | 61 |
| 4 | 75 | 63 | 41 | 49 | 64 | 54 | 69 | 57 | 54 | 58 | 52 | 62 | 37 | 38 | 66 | 75 | 70 | 74 | 60 | 69 | 66 | 74 | 75 | 68 |
| 5 | 59 | 49 | 57 | 77 | 66 | 65 | 78 | 67 | 72 | 47 | 73 | 67 | 52 | 57 | 51 | 52 | 80 | 66 | 76 | 80 | 71 | 70 | 62 | 50 |
| 6 | 39 | 71 | 39 | 72 | 60 | 65 | 54 | 58 | 55 | 39 | 29 | N/S | N/S | N/S | N/S | 45 | 32 | 33 | 55 | 63 | 64 | 60 | 70 | 52 |
| 7 | 59 | 67 | 65 | 73 | 92 | 82 | 57 | 61 | 81 | 67 | 72 | 69 | 38 | 70 | 74 | 75 | 45 | 69 | 80 | 71 | 72 | 55 | 55 | 92 |
| 8 | 60 | 55 | 49 | 76 | 85 | 77 | 76 | 79 | 75 | 80 | 86 | 84 | 54 | 64 | 57 | 83 | 82 | 82 | 74 | 72 | 71 | 78 | 72 | 71 |
| 9 | 38 | 39 | 59 | 68 | 78 | 76 | 75 | 66 | 62 | 79 | 46 | 51 | 70 | 43 | 50 | 43 | 69 | 57 | 61 | 69 | 78 | 65 | 78 | 74 |
| 10 | 77 | 42 | 67 | 53 | 64 | 73 | 64 | 74 | 80 | 67 | 57 | 66 | 48 | 67 | 76 | 76 | 61 | 53 | 75 | 72 | 60 | 81 | 87 | 90 |

**Table H10.** Limits of Stability: Maximum Excursion (%)

| Subject | front | | | right-front | | | right | | | right-back | | | back | | | left-back | | | left | | | left-front | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 81 | 78 | 83 | 71 | N/S | 82 | N/S | 72 | 77 | N/S | N/S | 74 | 87 | 59 | 83 | N/S | 75 | 91 | N/S | N/S | 71 | N/S | 87 | 78 |
| 2 | 28 | N/S | 74 | 72 | 73 | 80 | 77 | 77 | 72 | 73 | 75 | 77 | 79 | 76 | 75 | 81 | 86 | 74 | 76 | 76 | 78 | 56 | 42 | 61 |
| 3 | 84 | 80 | 81 | 82 | 79 | 91 | 79 | 84 | 79 | 91 | 85 | 85 | 75 | 76 | 102 | 90 | 98 | 96 | 81 | 77 | 80 | 89 | 80 | 84 |
| 4 | 75 | 74 | 77 | 75 | 80 | 84 | 69 | 74 | 74 | 71 | 68 | 72 | 71 | 65 | 72 | 75 | 91 | 81 | 75 | 78 | 74 | 76 | 83 | 82 |
| 5 | 89 | 79 | 82 | 86 | 81 | 81 | 79 | 78 | 79 | 82 | 81 | 88 | 81 | 76 | 81 | 81 | 80 | 82 | 76 | 80 | 73 | 86 | 87 | 86 |
| 6 | 71 | 73 | 76 | 72 | 73 | 75 | 69 | 67 | 60 | 58 | 32 | N/S | N/S | N/S | N/S | 45 | 55 | 51 | 59 | 67 | 66 | 72 | 75 | 80 |
| 7 | 72 | 91 | 74 | 84 | 92 | 82 | 82 | 85 | 81 | 87 | 87 | 84 | 46 | 83 | 83 | 80 | 81 | 81 | 80 | 88 | 80 | 74 | 90 | 92 |
| 8 | 81 | 76 | 80 | 77 | 85 | 78 | 76 | 79 | 78 | 80 | 86 | 84 | 72 | 84 | 87 | 88 | 89 | 86 | 80 | 77 | 75 | 78 | 76 | 80 |
| 9 | 74 | 63 | 59 | 81 | 78 | 76 | 75 | 78 | 83 | 79 | 66 | 73 | 78 | 71 | 50 | 57 | 69 | 66 | 79 | 83 | 78 | 74 | 78 | 82 |
| 10 | 83 | 80 | 84 | 80 | 81 | 84 | 78 | 80 | 80 | 67 | 74 | 75 | 72 | 67 | 76 | 77 | 61 | 74 | 89 | 80 | 82 | 86 | 87 | 90 |

**Table H11.** Limits of Stability: Directional Control (%)

| Subject | front | | | right-front | | | right | | | right-back | | | back | | | left-back | | | left | | | left-front | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 89 | 92 | 88 | 73 | N/S | 84 | N/S | 46 | 61 | N/S | N/S | 26 | 53 | 29 | 78 | N/S | 12 | 54 | N/S | N/S | 39 | N/S | 69 | 74 |
| 2 | 53 | N/S | 83 | 76 | 78 | 90 | 84 | 93 | 87 | 83 | 65 | 70 | 90 | 88 | 88 | 69 | 76 | 86 | 89 | 83 | 86 | 82 | 65 | 52 |
| 3 | 89 | 90 | 90 | 81 | 93 | 86 | 59 | 86 | 79 | 41 | 64 | 81 | 50 | 72 | 81 | 28 | 63 | 78 | 90 | 91 | 93 | 76 | 88 | 88 |
| 4 | 91 | 91 | 91 | 86 | 84 | 87 | 82 | 68 | 73 | 53 | 49 | 56 | 84 | 77 | 81 | 65 | 39 | 72 | 87 | 95 | 93 | 76 | 87 | 87 |
| 5 | 85 | 92 | 94 | 82 | 89 | 80 | 91 | 94 | 94 | 70 | 72 | 72 | 77 | 71 | 86 | 38 | 64 | 30 | 90 | 91 | 88 | 83 | 87 | 88 |
| 6 | 81 | 96 | 92 | 90 | 85 | 83 | 80 | 78 | 77 | 32 | 12 | N/S | N/S | N/S | N/S | 38 | 24 | 37 | 83 | 83 | 83 | 80 | 91 | 77 |
| 7 | 71 | 91 | 87 | 48 | 71 | 70 | 86 | 83 | 88 | 78 | 69 | 80 | 48 | 79 | 69 | 82 | 58 | 90 | 87 | 83 | 90 | 35 | 79 | 90 |
| 8 | 93 | 89 | 93 | 71 | 89 | 95 | 85 | 93 | 89 | 61 | 75 | 74 | 69 | 59 | 71 | 51 | 52 | 61 | 92 | 96 | 88 | 90 | 77 | 83 |
| 9 | 94 | 85 | 80 | 54 | 67 | 80 | 79 | 90 | 77 | 25 | 54 | 72 | 78 | 81 | 28 | 35 | 29 | 40 | 88 | 89 | 88 | 59 | 52 | 85 |
| 10 | 88 | 84 | 78 | 93 | 87 | 89 | 81 | 94 | 89 | 75 | 63 | 72 | 75 | 47 | 72 | 66 | 54 | 51 | 69 | 75 | 78 | 79 | 80 | 85 |

**Table H12.** Characteristics of ten normal subjects for proprioception test

| Subjects | Age | Weight | Height |
|---|---|---|---|
| 1 | 23 | 49 | 156 |
| 2 | 24 | 47 | 165 |
| 3 | 24 | 52 | 166 |
| 4 | 22 | 45 | 157 |
| 5 | 23 | 46 | 152 |
| 6 | 23 | 60 | 162 |
| 7 | 22 | 48 | 162 |
| 8 | 23 | 48 | 158 |
| 9 | 22 | 52 | 160 |
| 10 | 16 | 43 | 157 |

**Table H13.** Proprioception at 30°

| Subjects | Right knee | | | | | | | | | Left knee | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | | Session2 | | | Session3 | | | Session 1 | | | Session2 | | | Session3 | | |
| | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean |
| 1 | 34.0 | 26.0 | 30.00 | 31.0 | 26.0 | 28.50 | 30.0 | 30.0 | 30.00 | 30.0 | 22.0 | 26.00 | 24.0 | 28.0 | 26.00 | 31.0 | 24.0 | 27.50 |
| 2 | 29.0 | 30.0 | 29.50 | 29.0 | 28.5 | 28.75 | 26.5 | 27.0 | 26.75 | 28.0 | 28.0 | 28.00 | 30.0 | 30.0 | 30.00 | 28.0 | 29.0 | 28.50 |
| 3 | 32.0 | 30.0 | 31.00 | 31.0 | 30.0 | 30.50 | 32.5 | 30.0 | 31.25 | 30.0 | 33.0 | 31.50 | 31.0 | 29.0 | 30.00 | 31.0 | 29.0 | 30.00 |
| 4 | 27.5 | 27.5 | 27.50 | 28.0 | 31.5 | 29.75 | 31.5 | 32.0 | 31.75 | 31.0 | 29.0 | 30.00 | 33.0 | 30.0 | 31.50 | 34.0 | 30.0 | 31.50 |
| 5 | 31.0 | 29.0 | 30.00 | 23.0 | 24.0 | 23.50 | 30.0 | 30.0 | 30.00 | 26.0 | 30.0 | 28.00 | 30.0 | 30.0 | 30.00 | 29.0 | 29.0 | 28.00 |
| 6 | 29.0 | 29.0 | 29.00 | 28.0 | 29.0 | 28.50 | 29.0 | 27.0 | 28.00 | 26.0 | 30.0 | 28.00 | 30.0 | 30.0 | 30.00 | 28.0 | 28.0 | 28.00 |
| 7 | 25.0 | 22.0 | 23.50 | 23.0 | 24.0 | 23.50 | 25.0 | 24.0 | 24.50 | 24.0 | 26.0 | 25.00 | 27.0 | 30.0 | 29.00 | 27.0 | 26.0 | 26.50 |
| 8 | 26.0 | 29.0 | 27.50 | 31.0 | 30.0 | 30.50 | 29.0 | 30.0 | 29.50 | 29.0 | 30.0 | 29.50 | 30.0 | 28.0 | 29.00 | 30.0 | 29.0 | 30.00 |
| 9 | 31.0 | 29.0 | 30.00 | 31.0 | 29.0 | 29.50 | 30.0 | 31.0 | 30.50 | 28.5 | 29.5 | 29.00 | 28.0 | 26.5 | 27.25 | 31.5 | 28.5 | 30.00 |
| 10 | 30.5 | 29.0 | 29.75 | 28.5 | 28.0 | 28.25 | 29.0 | 25.0 | 27.00 | 33.0 | 29.0 | 31.00 | 29.0 | 31.0 | 30.00 | 30.0 | 31.0 | 30.50 |

**Table H14.** proprioception at 40°

| Subjects | Right knee | | | | | | | | | Left knee | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | | Session2 | | | Session3 | | | Session 1 | | | Session2 | | | Session3 | | |
| | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean |
| 1 | 40.0 | 35.0 | 37.50 | 39.0 | 36.0 | 37.50 | 34.0 | 40.0 | 37.00 | 38.0 | 40.0 | 39.00 | 40.0 | 41.0 | 40.50 | 39.0 | 44.5 | 41.75 |
| 2 | 37.0 | 36.5 | 36.75 | 36.0 | 36.0 | 36.00 | 36.0 | 35.0 | 35.50 | 39.0 | 38.5 | 38.75 | 37.0 | 38.0 | 37.50 | 38.0 | 39.0 | 38.50 |
| 3 | 38.0 | 39.0 | 38.50 | 37.0 | 38.0 | 37.50 | 38.0 | 37.5 | 37.75 | 39.0 | 40.0 | 39.50 | 40.0 | 39.0 | 39.50 | 39.5 | 39.5 | 39.50 |
| 4 | 40.0 | 40.0 | 40.00 | 42.0 | 41.0 | 41.50 | 41.0 | 40.0 | 40.50 | 40.0 | 37.0 | 38.50 | 39.0 | 36.0 | 37.50 | 37.0 | 39.0 | 38.00 |
| 5 | 36.0 | 39.0 | 37.50 | 39.0 | 41.0 | 40.00 | 40.0 | 39.0 | 39.50 | 36.0 | 40.0 | 38.00 | 37.5 | 40.0 | 38.75 | 37.0 | 37.0 | 37.00 |
| 6 | 37.0 | 34.0 | 35.50 | 35.0 | 40.0 | 37.50 | 38.0 | 39.5 | 38.75 | 38.0 | 39.0 | 38.50 | 36.0 | 39.0 | 37.50 | 39.0 | 39.0 | 39.00 |
| 7 | 35.5 | 35.0 | 35.25 | 33.0 | 35.0 | 34.00 | 35.0 | 36.5 | 35.75 | 32.0 | 31.0 | 31.50 | 35.0 | 36.0 | 35.50 | 38.0 | 38.0 | 38.00 |
| 8 | 41.0 | 41.0 | 41.00 | 40.0 | 40.0 | 40.00 | 40.0 | 40.0 | 40.00 | 39.0 | 42.0 | 40.50 | 40.0 | 39.5 | 39.75 | 39.0 | 40.0 | 39.50 |
| 9 | 44.0 | 41.0 | 42.50 | 43.0 | 41.0 | 40.50 | 40.0 | 41.0 | 40.50 | 41.0 | 42.0 | 41.50 | 38.0 | 39.0 | 38.50 | 39.0 | 39.0 | 39.00 |
| 10 | 38.0 | 39.0 | 38.50 | 38.0 | 41.0 | 41.00 | 41.0 | 39.0 | 40.00 | 41.0 | 40.0 | 40.50 | 40.0 | 37.0 | 38.50 | 41.0 | 38.0 | 39.50 |

**Table H15.** Proprioception at 50°

| Subjects | Right knee | | | | | | | | | Left knee | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | | Session2 | | | Session3 | | | Session 1 | | | Session2 | | | Session3 | | |
| | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | Mean |
| 1 | 50.0 | 48.0 | 49.00 | 44.0 | 51.0 | 47.50 | 45.0 | 47.0 | 46.00 | 49.0 | 50.0 | 49.50 | 49.0 | 48.0 | 48.50 | 50.0 | 49.0 | 49.50 |
| 2 | 50.0 | 50.0 | 50.00 | 50.0 | 50.0 | 50.00 | 49.0 | 49.0 | 49.00 | 45.5 | 47.0 | 46.25 | 45.0 | 44.0 | 44.50 | 43.0 | 46.0 | 44.50 |
| 3 | 49.0 | 50.0 | 49.50 | 50.0 | 50.5 | 50.25 | 50.0 | 48.5 | 49.25 | 52.0 | 49.0 | 50.50 | 51.0 | 50.5 | 50.75 | 50.0 | 48.0 | 49.00 |
| 4 | 50.0 | 54.0 | 52.00 | 55.0 | 51.0 | 53.00 | 52.0 | 51.5 | 51.75 | 49.0 | 48.5 | 48.75 | 44.0 | 51.0 | 47.50 | 50.0 | 50.0 | 50.00 |
| 5 | 43.0 | 44.0 | 43.50 | 45.0 | 43.0 | 44.00 | 46.0 | 45.0 | 45.50 | 44.0 | 45.0 | 44.50 | 50.0 | 48.0 | 49.00 | 46.0 | 48.0 | 47.00 |
| 6 | 47.0 | 48.0 | 47.50 | 48.0 | 47.0 | 47.50 | 46.0 | 45.0 | 45.50 | 43.0 | 48.0 | 45.50 | 49.0 | 49.0 | 49.00 | 46.0 | 43.0 | 49.00 |
| 7 | 38.0 | 41.0 | 39.50 | 40.0 | 43.0 | 41.50 | 40.0 | 42.0 | 41.00 | 44.0 | 47.0 | 45.50 | 45.0 | 45.0 | 45.00 | 43.0 | 48.0 | 45.50 |
| 8 | 50.0 | 51.0 | 50.50 | 50.0 | 49.0 | 49.50 | 50.0 | 50.0 | 50.00 | 50.0 | 49.0 | 49.50 | 46.0 | 50.0 | 48.00 | 49.0 | 49.0 | 49.00 |
| 9 | 53.0 | 46.5 | 49.75 | 48.0 | 49.0 | 48.50 | 50.0 | 47.0 | 48.50 | 51.0 | 51.5 | 51.25 | 50.0 | 48.5 | 49.25 | 50.0 | 48.0 | 49.00 |
| 10 | 46.0 | 48.0 | 47.00 | 50.0 | 49.0 | 49.50 | 48.0 | 49.0 | 48.50 | 49.5 | 50.0 | 49.75 | 48.0 | 51.0 | 49.50 | 50.0 | 50.0 | 50.00 |

**Table H16.** Proprioception at 60°

| Subjects | Right knee | | | | | | | | | Left knee | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Session 1 | | | Session2 | | | Session3 | | | Session 1 | | | Session2 | | | Session3 | | |
| | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean | 1 | 2 | mean |
| 1 | 57.0 | 61.0 | 59.00 | 56.0 | 59.0 | 57.50 | 60.0 | 59.0 | 59.50 | 59.0 | 58.0 | 58.50 | 59.0 | 57.5 | 58.25 | 60.0 | 61.0 | 60.50 |
| 2 | 58.0 | 60.0 | 59.00 | 60.0 | 58.5 | 59.25 | 56.0 | 55.0 | 55.50 | 53.0 | 56.0 | 54.50 | 57.0 | 54.0 | 55.50 | 55.0 | 60.0 | 57.50 |
| 3 | 60.0 | 59.0 | 59.50 | 57.5 | 59.0 | 58.25 | 60.0 | 58.0 | 59.00 | 59.0 | 61.0 | 60.00 | 58.0 | 60.0 | 59.00 | 59.0 | 59.0 | 59.00 |
| 4 | 61.5 | 60.0 | 60.75 | 59.0 | 58.5 | 58.75 | 61.5 | 60.0 | 60.75 | 60.0 | 61.0 | 60.50 | 62.0 | 60.5 | 61.25 | 60.0 | 61.5 | 60.75 |
| 5 | 57.0 | 58.0 | 57.50 | 58.0 | 59.0 | 58.50 | 57.0 | 57.0 | 57.00 | 58.0 | 57.0 | 57.50 | 55.0 | 55.0 | 55.00 | 53.0 | 60.0 | 56.50 |
| 6 | 59.0 | 60.0 | 59.50 | 59.0 | 59.0 | 59.00 | 55.0 | 56.0 | 55.50 | 61.0 | 59.0 | 60.00 | 59.0 | 58.0 | 58.50 | 60.0 | 60.0 | 60.00 |
| 7 | 50.0 | 55.5 | 52.75 | 51.0 | 54.0 | 52.50 | 49.0 | 50.0 | 49.50 | 52.0 | 56.0 | 54.00 | 57.0 | 59.0 | 58.00 | 57.0 | 59.0 | 58.00 |
| 8 | 61.0 | 60.0 | 60.50 | 58.0 | 60.0 | 59.00 | 56.0 | 59.0 | 57.50 | 58.0 | 59.0 | 58.50 | 59.0 | 60.0 | 59.50 | 61.0 | 60.0 | 60.50 |
| 9 | 61.0 | 60.0 | 60.50 | 61.5 | 59.0 | 60.25 | 60.0 | 60.5 | 60.25 | 56.5 | 56.0 | 56.25 | 57.5 | 57.5 | 57.50 | 59.0 | 58.0 | 58.50 |
| 10 | 60.0 | 60.5 | 60.25 | 56.0 | 60.0 | 58.00 | 60.0 | 59.0 | 59.50 | 59.5 | 60.0 | 59.75 | 58.5 | 60.0 | 59.25 | 60.0 | 61.5 | 60.75 |

**Table H17.** Characteristics of ten normal subjects for muscle strength test of the knee

| Subjects | Age | Weight | Height |
|---|---|---|---|
| 1 | 21 | 47 | 150 |
| 2 | 22 | 52 | 164 |
| 3 | 20 | 45 | 155 |
| 4 | 30 | 42 | 162 |
| 5 | 22 | 45 | 155 |
| 6 | 23 | 60 | 162 |
| 7 | 22 | 48 | 153 |
| 8 | 24 | 52 | 166 |
| 9 | 22 | 48 | 157 |
| 10 | 21 | 52 | 155 |

**Table H18.** Muscle Strength: Knee Extensor (kg.)

| Subjects | Right | | | Left | | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 |
| 1 | 12.1 | 12.9 | 11.9 | 11.9 | 12.1 | 15.1 |
| 2 | 18.8 | 17.4 | 17.2 | 17.0 | 16.0 | 16.2 |
| 3 | 21.8 | 23.1 | 21.6 | 18.5 | 19.0 | 17.0 |
| 4 | 18.5 | 17.3 | 17.4 | 17.8 | 18.7 | 17.5 |
| 5 | 19.9 | 23.5 | 22.5 | 15.9 | 18.6 | 17.1 |
| 6 | 20.4 | 20.6 | 23.2 | 21.1 | 20.1 | 22.5 |
| 7 | 20.0 | 26.1 | 26.7 | 18.5 | 19.9 | 19.7 |
| 8 | 20.1 | 27.2 | 30.9 | 22.2 | 21.4 | 18.3 |
| 9 | 23.6 | 20.1 | 30.9 | 21.6 | 24.0 | 20.4 |
| 10 | 21.0 | 27.3 | 25.6 | 22.2 | 23.0 | 24.0 |

**Table H19.** Muscle Strength: Knee Flexor (kg.)

| Subjects | Right | | | Left | | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Trial 1 | Trial 2 | Trial 3 |
| 1 | 6.9 | 6.0 | 5.9 | 9.1 | 8.3 | 9.7 |
| 2 | 7.8 | 10.1 | 9.4 | 9.1 | 8.8 | 9.4 |
| 3 | 12.3 | 11.1 | 12.0 | 10.8 | 10.9 | 11.6 |
| 4 | 8.0 | 8.1 | 8.5 | 7.9 | 7.7 | 8.7 |
| 5 | 10.7 | 13.5 | 11.7 | 10.7 | 9.4 | 10.2 |
| 6 | 7.5 | 7.3 | 6.1 | 7.4 | 8.1 | 8.9 |
| 7 | 7.1 | 9.6 | 9.8 | 11.6 | 11.9 | 11.2 |
| 8 | 8.5 | 7.6 | 10.5 | 7.0 | 7.2 | 7.3 |
| 9 | 8.8 | 8.9 | 10.9 | 7.1 | 9.7 | 9.6 |
| 10 | 15.4 | 13.7 | 15.2 | 14.4 | 12.8 | 15.4 |

# APPENDIX I

# SAMPLE SIZE

**Table I1.** Sample size of the study in each parameter

| Parameter | n1 | n2 | $S_1$ | $S_2$ | $Sp^2$ | $\mu_1$ | $\mu_2$ | N |
|---|---|---|---|---|---|---|---|---|
| **%maximum stability** | | | | | | | | |
| 1.Eye Open | 5 | 5 | 2.1679 | 1.8166 | 3.9999 | 94.2 | 93.4 | 131.9471 |
| 2.Eye Closed | 5 | 5 | 2.8284 | 0.8367 | 4.3499 | 92.0 | 87.8 | 5.2061 |
| 3.Sway-ref vision | 5 | 5 | 3.2094 | 2.3875 | 8.0002 | 89.4 | 86.8 | 24.9852 |
| 4. Eye Open and sway-ref support | 5 | 5 | 11.4586 | 4.6583 | 76.4996 | 82.6 | 65.8 | 5.7223 |
| 5. Eye Closed and sway -ref support | 5 | 5 | 8.9889 | 15.5016 | 160.5500 | 66.4 | 53.4 | 20.0564 |
| 6. Sway-ref vision and support | 5 | 5 | 12.3288 | 10.8074 | 134.3996 | 64.0 | 50.6 | 15.8022 |
| **Sway Velocity** | | | | | | | | |
| 1.Eye Open | 5 | 5 | 0.0894 | 0.0450 | 0.0050 | 0.24 | 0.32 | 16.5333 |
| 2.Eye Closed | 5 | 5 | 0.2408 | 0.1095 | 0.0295 | 0.46 | 0.62 | 31.7717 |
| 3.Sway-ref vision | 5 | 5 | 0.0837 | 0.2000 | 0.0235 | 0.42 | 0.60 | 15.3129 |
| 4. Eye Open and sway-ref support | 5 | 5 | 0.4879 | 0.5762 | 0.2850 | 0.64 | 0.98 | 52.0543 |
| 5. Eye Closed and sway -ref support | 5 | 5 | 0.1732 | 0.7855 | 0.3235 | 0.90 | 1.72 | 10.1574 |
| 6. Sway-ref vision and support | 5 | 5 | 0.2702 | 1.2280 | 0.7905 | 0.86 | 1.56 | 34.0590 |
| **Center Target** | 5 | 5 | 0.1643 | 0.1304 | 0.0220 | 0.32 | 0.38 | 129.0138 |
| **Rhythmic Weight Shift L/R** | | | | | | | | |
| -On axis velocity | | | | | | | | |
| Slow | 5 | 5 | 0.4658 | 0.3912 | 0.1850 | 3.08 | 2.74 | 33.7872 |
| Moderate | 5 | 5 | 0.3271 | 0.3114 | 0.1020 | 4.88 | 4.28 | 5.9807 |
| Fast | 5 | 5 | 0.8408 | 1.7444 | 1.8749 | 9.22 | 8.76 | 187.0685 |
| -Directional control | | | | | | | | |
| Slow | 5 | 5 | 4.7434 | 6.3008 | 31.0999 | 78.0 | 76.8 | 455.96 |
| Moderate | 5 | 5 | 3.2094 | 2.3022 | 7.8002 | 84.6 | 85.4 | 257.3087 |

| Parameter | n1 | n2 | $S_1$ | $S_2$ | $Sp^2$ | $\mu_1$ | $\mu_2$ | N |
|---|---|---|---|---|---|---|---|---|
| Fast | 5 | 5 | 4.4385 | 1.3416 | 10.7501 | 86.8 | 86.4 | 1418.4740 |
| **Limits of stability** | | | | | | | | |
| 1. Reaction Time | | | | | | | | |
| front | 5 | 4 | 0.1903 | 0.4288 | 0.1002 | 0.88 | 0.74 | 96.5952 |
| right-front | 5 | 5 | 0.0986 | 0.5368 | 0.1489 | 0.55 | 9.12 | 0.0428 |
| right | 5 | 5 | 0.0761 | 0.3230 | 0.0551 | 0.60 | 0.85 | 18.9016 |
| right-back | 5 | 4 | 0.1331 | 0.5108 | 0.1219 | 0.57 | 1.06 | 10.4648 |
| back | 3 | 3 | 0.3931 | 0.7496 | 0.3582 | 0.77 | 1.19 | 43.2211 |
| left-back | 4 | 4 | 0.2505 | 0.2419 | 0.0606 | 1.02 | 0.83 | 36.6062 |
| left | 5 | 5 | 0.1527 | 0.3148 | 0.0612 | 0.59 | 1.08 | 5.5163 |
| left-front | 5 | 5 | 0.3520 | 0.3489 | 0.1228 | 0.91 | 1.15 | 43.5522 |
| 2.Movement Velocity | | | | | | | | |
| front | 5 | 5 | 1.2818 | 1.7544 | 2.3604 | 3.26 | 3.94 | 107.7728 |
| right-front | 5 | 5 | 2.2557 | 1.2578 | 3.3351 | 6.54 | 4.42 | 15.6664 |
| right | 5 | 5 | 1.9339 | 2.9670 | 6.2715 | 6.00 | 4.16 | 39.1081 |
| right-back | 5 | 5 | 1.4100 | 2.8986 | 5.1950 | 5.06 | 3.58 | 50.0715 |
| back | 3 | 4 | 0.5508 | 1.3115 | 1.1534 | 3.53 | 2.90 | 60.7127 |
| left-back | 4 | 5 | 0.7455 | 1.3638 | 1.3010 | 2.83 | 3.60 | 45.7308 |
| left | 5 | 5 | 2.5898 | 1.7584 | 4.8995 | 5.98 | 4.72 | 65.1541 |
| left-front | 5 | 5 | 1.3730 | 1.1158 | 1.5650 | 4.20 | 3.60 | 91.7826 |
| 3.End Point Excursion | | | | | | | | |
| front | 5 | 5 | 5.8566 | 13.5904 | 109.4994 | 57.6 | 49.8 | 37.9972 |
| right-front | 5 | 5 | 11.4149 | 13.8311 | 160.7996 | 76.4 | 66.4 | 33.9480 |
| right | 5 | 5 | 6.0249 | 7.5697 | 46.7999 | 61.4 | 66.6 | 36.5399 |
| right-back | 5 | 5 | 7.9246 | 11.7771 | 100.7497 | 58.4 | 64.2 | 63.2291 |
| back | 3 | 4 | 7.5498 | 10.6615 | 91.0003 | 49.0 | 60.5 | 14.5270 |
| left-back | 4 | 5 | 18.8856 | 9.3434 | 202.7420 | 62.0 | 68.4 | 104.4993 |
| left | 5 | 5 | 10.2127 | 8.3367 | 86.8999 | 73.4 | 62.0 | 14.11689 |
| left-front | 5 | 5 | 13.9750 | 3.4205 | 103.5002 | 67.6 | 72.2 | 103.2654 |

| Parameter | n1 | n2 | $S_1$ | $S_2$ | $Sp^2$ | $\mu_1$ | $\mu_2$ | N |
|---|---|---|---|---|---|---|---|---|
| 4.Maximum Excursion | | | | | | | | |
| front | 5 | 5 | 4.4497 | 13.704 | 103.7997 | 78.4 | 73.6 | 95.1137 |
| right-front | 5 | 5 | 5.3385 | 7.8294 | 44.8995 | 84.0 | 78.4 | 30.2270 |
| right | 5 | 5 | 5.1478 | 4.2426 | 22.2498 | 76.0 | 74.0 | 117.4342 |
| right-back | 5 | 5 | 6.9785 | 9.9750 | 74.1000 | 74.8 | 79.0 | 88.6848 |
| back | 3 | 4 | 4.6188 | 7.5277 | 42.5331 | 59.7 | 71.0 | 6.9911 |
| left-back | 4 | 5 | 13.1022 | 10.4163 | 135.5715 | 72.5 | 79.0 | 67.7440 |
| left | 5 | 5 | 5.7009 | 3.7014 | 23.1003 | 79.0 | 76.2 | 62.2058 |
| left-front | 5 | 5 | 2.9665 | 4.2661 | 13.4999 | 78.6 | 79.2 | 791.6922 |
| 5.Directional Control | | | | | | | | |
| front | 5 | 5 | 8.8487 | 39.6963 | 827.0479 | 85.6 | 70.4 | 75.5740 |
| right-front | 5 | 5 | 15.7575 | 6.7305 | 146.7992 | 77.4 | 72.6 | 134.5150 |
| right | 5 | 5 | 6.5422 | 11.7771 | 90.7502 | 85.6 | 74.2 | 14.7424 |
| right-back | 5 | 5 | 29.6429 | 24.0583 | 728.7517 | 49.2 | 48.6 | 42737.24 |
| back | 3 | 4 | 14.3643 | 37.5178 | 927.0844 | 58.7 | 54.3 | 1003.3510 |
| left-back | 4 | 5 | 22.9056 | 27.8514 | 668.1145 | 48.0 | 32.2 | 56.5023 |
| left | 5 | 5 | 4.0373 | 14.6867 | 115.9995 | 89.4 | 79.8 | 26.5732 |
| left-front | 5 | 5 | 10.6395 | 7.8294 | 87.2492 | 81.2 | 81.6 | 11512.54 |
| **Proprioception** | | | | | | | | |
| 1.Right knee at 50° | 5 | 5 | 1.8422 | 2.42113 | 4.6281 | 1.90 | 2.65 | 172.7465 |
| 2.Left knee at 50° | 5 | 5 | 2.2981 | 3.2384 | 7.8842 | 2.25 | 3.65 | 84.4548 |
| 3.Right knee at 60° | 5 | 5 | 1.1806 | 2.2472 | 3.2219 | 2.10 | 3.35 | 43.2919 |
| 4.Left knee at 60° | 5 | 5 | 1.5572 | 3.1425 | 6.1501 | 1.60 | 5.00 | 51.3782 |
| **Muscle Strength** | | | | | | | | |
| 1.Extensor of left knee | 5 | 5 | 2.9172 | 4.1262 | 12.7678 | 23.40 | 17.68 | 8.2386 |
| 2.Flexor of left knee | 5 | 5 | 0.4536 | 3.1584 | 5.0906 | 12.27 | 9.37 | 12.7792 |
| 3.Extensor of right knee | 5 | 5 | 1.6410 | 4.5322 | 11.6169 | 23.41 | 16.77 | 5.5627 |
| 4.Flexor of right knee | 5 | 5 | 0.4569 | 3.4870 | 6.1839 | 12.40 | 7.86 | 6.3341 |

# APPENDIX J

# INTRA-TESTER RELIABILITY AND VALIDITY OF A MODIFIED GONIOMETER

This intra-tester reliability study aimed to prove the consistency of a tester in using a modified goniometer for measuring angles. Ten referenced angles were drawn on a A4 paper. All angles were measured for 3 trials. In each trial, ten angles were measured randomly. The raw data of three trials are shown in Table J1. Intraclass Correlation Coefficient (ICC (3,1)) of 3 trials showed high reliability (ICC(3,1) = 0.9999) indicating excellent intratester reliability.

**Table J1.** Raw data of Intra-tester reliability by using standard goniometer

| Reference Angle(degree) | Measured Angle (degree) | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 |
| 22 | 23 | 23 | 22 |
| 68 | 67 | 68 | 68 |
| 94 | 93 | 93 | 93 |
| 131 | 130 | 129 | 131 |
| 169 | 169 | 169 | 169 |
| 193 | 192 | 194 | 193 |
| 226 | 226 | 226 | 226 |
| 285 | 286 | 286 | 287 |
| 317 | 319 | 318 | 318 |
| 351 | 352 | 351 | 351 |

The validity of a modified goniometer was tested against the referenced angles. The ICC (3,1) was determined from the average angles measured by the modified goniometer in trials1 & 2 and the referenced angles. The result revealed high validity with ICC(3,1) equaled 0.9999.

**Table J2.** Validity of a modified goniometer

| Reference Angle(degree) | Mean value of trial1 & 2 | Error Angle |
|---|---|---|
| 22 | 23.0 | 1.0 |
| 68 | 67.5 | 0.5 |
| 94 | 93.0 | 1.0 |
| 131 | 129.5 | 1.5 |
| 169 | 169.0 | 0.0 |
| 193 | 193.0 | 0.0 |
| 226 | 226.0 | 0.0 |
| 285 | 286.0 | 1.0 |
| 317 | 318.5 | 1.5 |
| 351 | 351.5 | 0.5 |
| Average error angle | | 0.7 |

# BIOGRAPHY

| | |
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