ผลของการกระโดดซ้ำต่อความสามารถในการทรงท่าในวัยรุ่นตอนต้นที่มีภาวะเท้าแบนชนิด
ยืดหยุ่น

EFFECT OF REPETITIVE HOPPING ON POSTURAL BALANCE IN YOUNG ADOLESCENCE WITH FLEXIBLE FLATFOOT

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2018

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# EFFECT OF REPETITIVE HOPPING ON POSTURAL BALANCE IN YOUNG ADOLESCENCE WITH FLEXIBLE FLATFOOT

THITIYA KLAIKAEW

A Thesis Submitted in partial Fulfillment of Requirements

for MASTER OF SCIENCE (Physical Therapy)

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THE THESIS TITLED

EFFECT OF REPETITIVE HOPPING ON POSTURAL BALANCE IN YOUNG ADOLESCENCE WITH FLEXIBLE FLATFOOT

BY

THITIYA KLAIKAEW

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Background: Flexible flatfoot(FFF) is usually found in the abnormal development of the medial longitudinal arch(MLA) in childhood. FFF can disturb postural balance and physical activities. Objective: The study compared the effects of repetitive hopping on navicular drop(ND), single leg standing(SLS) and Y balance test(YBT) within and between groups of people with normal foot and FFF. Methodology: Thirty-eight participants, aged between thirteen and fourteen were separated into groups of those with FFF and normal foot. All of the participants were measured with ND test, SLS in four conditions of eyes open, eyes closed on firm and foam surfaces, and YBT before and after repetitive hopping. The Wilcoxon Signed-Rank and the The Mann-Whitney U test employed statistical analysis to calculate the differences within and between groups. Results and Discussion: The present study found a dropping down of navicular bone and a flattening of MLA after repetitive hopping. The FFF group showed flatter foot after repetitive hopping and less SLS times in the eyes open on a firm surface when compared to a normal group. Moreover, the FFF group had less distance of YBT in the postero-lateral and postero-medial directions after repetitive hopping. The results of SLS and YBT in FFF may represent instability after repetitive hopping and changing weight distribution at the plantar foot. However, some conditions did not show differences that might be explained as other factors or the immature development of sensory systems.

Keyword : Flexible flatfoot, Navicular drop test, Repetitive hopping, Single leg standing, Y balance test

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THITIYA KLAIKAEW

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1.3 Objectives

1.4 Hypotheses of the study

1.5 Advantages of the study

1.6 Key words

1.7 Conceptual framework of this study

## 1.1 Background

The common problem of foot in children related with development of supported structures of arch of foot.(1) The structures which supported arch of foot could be classified in 2 groups of the dynamic and the passive supports.(2) The dynamic supports are muscles in the foot that help to support the medial longitudinal arch (MLA) and the passive supports are ligaments that provide stability of foot arch. In addition, weight bearing on foot during standing was a supplementary factor for developing arch of foot.(1) Normally, children could developed their arches of foot progressively until they grow up in adolescent aged between 11 and 18 years old.(3) However, Adolescent aged between 10 and 13 years old had highly progressive increase of MLA and there were no more visible change of MLA afterward. Consequently, the navicular bone had developed to stable height in 13 - 14 years old as well.(4,5) If adolescent have less development of foot arches in childhood, they would have been risk of flatfeet constantly in the future.(6-8) Abnormal arch of foot was usually classified in two types of high and low arch of foot. Low arch of foot had incident approximately 13.88 percent in age of preschool and adolescent that might lead to impair of some functional ability or injuries of lower limb throughout of lifetime.(9-11)

Consequently, the appropriate age for early detecting of flat foot should be lately childhood or adolescent age between 13 and 14 years old for preventing permanently flat foot. Moreover, two general types of flatfoot were classified in flexible and rigid flatfoot.(12) The flexible flat foot (FFF) was generally seen in children that could be occurred one or both feet with and without pain or functional disturbance.(13) Diagnoses of FFF have applied in many techniques such as clinical diagnosis(14), x-ray, foot print analysis(15-17) and navicular drop (ND) test. Brody in 1982 described the ND test and noted that it was a helpful technique for evaluating the amount of foot mobility, it was easy and specific test for diagnosing the FFF.(18) The ND test showed moderate to good validity when compared with x-ray examination.(19-21) The range of ND test was 5 to 9 millimeters in normal arch of foot and 10-15 millimeters and over in low arch of foot.(18)

The main problem of FFF were hypermobility of ankle or foot joints and abnormal muscle activities in the lower extremity. The tibialis posterior and intrinsic muscles of foot were key muscles for maintaining normal MLA, damaging or overloading within muscles resulted in collapse the MLA and flatfeet respectively.(4,22) Moreover, pain symptoms could be developed by tension of soft tissues, calcaneonavicular ligament or plantar fascia.(23,24) FFF can changes weight distribution on plantar and sole leading to reduce body balance.(25,26) In addition, FFF can alter normal weight bearing on ankle, knee and hip joints.(27) Children with FFF approximately 10–60% and up to 63% had functional impairment or abnormal movement patterns during stance phase support.(24) Although, some of children with FFF have no pain symptoms initially, the FFF emerged reducing of ability to control postural equilibrium in widely physical activities such as standing, running, jumping, and balance in one leg standing.(28)

The single leg standing (SLS) was a favorite test in research laboratory and clinical test. The clinical test of SLS have 4 various conditions of eye open, eye closed firm and foam surface.(29) Dynamic single leg balance test have two favor test such as the star excursion balance test and Y balance test (YBT). The YBT was developed from star excursion balance test. The YBT had similar protocol as the star excursion balance test, but it had only 3 directions for saving time and preventing muscle fatigue or injury after finishing protocol.(30,31) Kim et al in 2015 studied static and dynamic standing balance in subjects with and without flatfeet by standing one leg on force plate and YBT. The result showed significant difference in static balance between normal and flatfoot groups, but dynamic balance showed no difference between groups.(32)

The general activities in daily young adolescent school-life were enthusiastic lifestyles and more loading activity such as walking, running and jumping.(33) The hopping activity is higher impact loading activity in lower extremity structure. Boozari et al in 2013 studied effect of repetitive lateral hopping protocol in participants with FFF and normal arch. They founded that participants with FFF increase vertical ground-reaction force of single leg support during walking after intervention protocol. Increasing of vertical ground reaction force was hypothesized that FFF group lost ability for controlling the medial arch alignment.(34) Consequently, early detecting of FFF in young adolescent should be an important thing to concern before inducing of pain and functional ability problems in the future.

In summary, previous studies have been questionable about effect of loading of physical activities such as standing, walking and hopping on FFF and balance control. The ability of postural control after loading of physical activities interest in this study especially adolescent. Therefore, the aim of this study was balance ability in young adolescent with and without FFF after loading of physical activities that was induced by repetitive hopping. Advantages of the study are represented as a guideline to suggest risk of flatfeet to impact functional ability in young adolescent and early detecting of FFF before pain and functional ability problems in the future.

## 1.2 Research question

How does repetitive hopping affect to balance ability in adolescence with and without flexible flatfoot?

### 1.3 Objectives

General objective of the study was measurement of balance ability in young adolescent with and without flexible flatfoot before and after repetitive hopping.

Specific objectives of the study were:

1. Comparing of single leg standing in participants with normal arch before and after repetitive hopping.

2. Comparing of single leg standing in participants with flexible flatfoot before and after repetitive hopping.

3. Comparing of single leg standing between participants with normal arch and flexible flatfoot before repetitive hopping.

4. Comparing of single leg standing between participants with normal arch and flexible flatfoot after repetitive hopping.

5. Comparing of Y balance test in participant with normal arch before and after repetitive hopping.

6. Comparing of Y balance test in participant with flexible flatfoot before and after repetitive hopping.

7. Comparing of Y balance test in between participants with normal arch and flexible flatfoot before repetitive hopping.

8. Comparing of Y balance test in between participants with normal arch and flexible flatfoot after repetitive hopping.

### 1.4 Hypotheses of the study

1. There will be differences of balance ability between groups of normal arch and flexible flatfoot.

2. There will be differences of balance ability before and after repetitive hopping in participants with flexible flatfoot.

1.5 Advantages of the study

The study will be a guideline to suggest risk of flatfeet that impact physical activities in young adolescent and early detecting of FFF before pain and physical activities problems in the future.

1.6 Key words

Flexible flatfoot, Navicular drop test, Repetitive hopping, Single leg standing, Y balance test.

1.7 Conceptual framework of this study

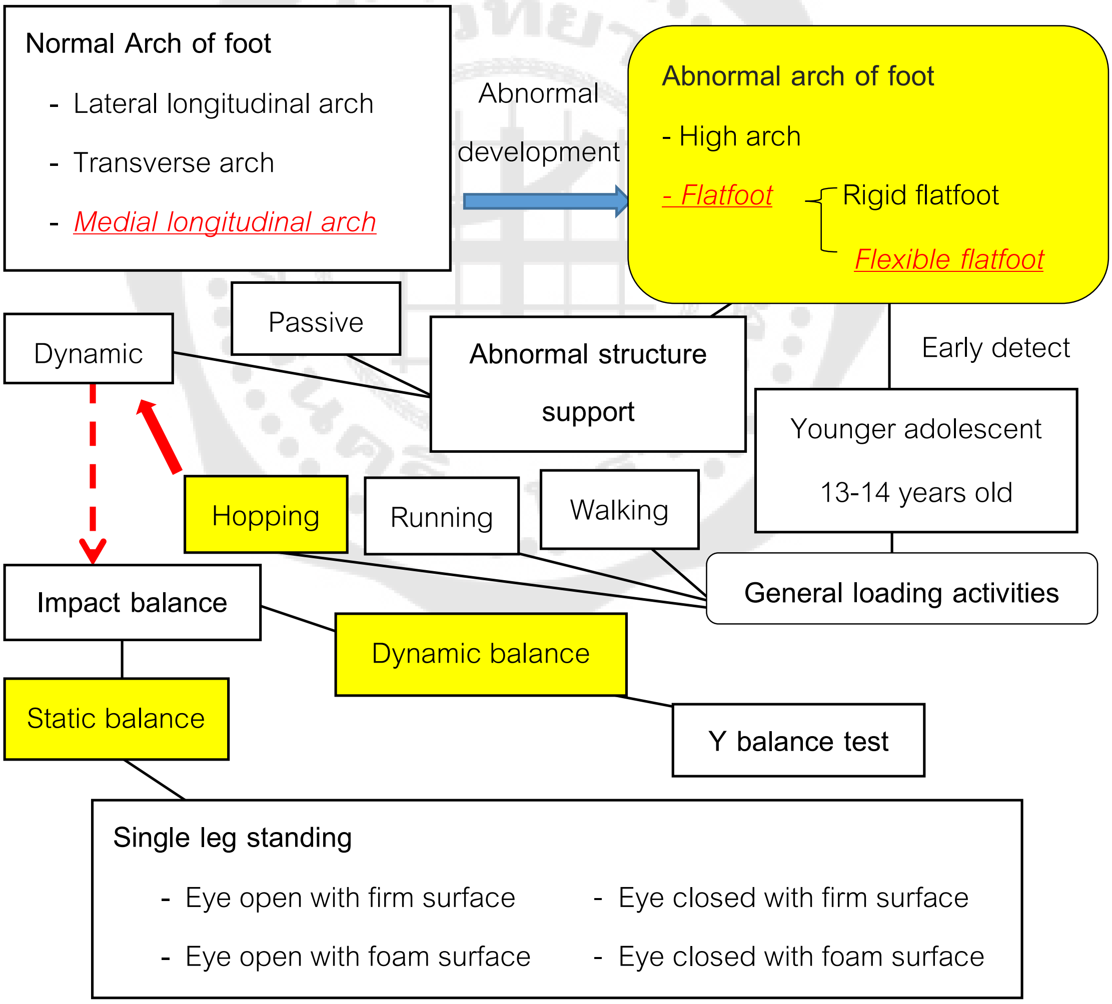



Figure 1 : Flowchart of conceptual framework

# CHAPTER 2
# LITERATURE REVIEWS

This study, the researcher has content of literature review as follows:

2.1 Arch of foot

2.2 Function of arches in human

2.3 The development of foot in pediatric

2.4 Abnormal development of arch

2.5 Problem from flatfoot

2.6 The arch of foot examination

## 2.1 Arch of foot

Foot is a region of the body distal to the leg and consists of 28 pieces of bone. Bones are arranged into longitudinal and transverse arches with the support of various muscles and ligaments. Arches of foot support body weight in the erect posture.(35-37) There are three arches of foot in medial longitudinal arch, lateral longitudinal arch and transverse arch.

### Medial Longitudinal Arch

The Medial longitudinal arch (MLA) is mainly arch of foot in human. The MLA has visible between the heel of the foot proximally and the medial three metatarsophalangeal joints distally. The bones that participate in the formation of the MLA are including (Figure 2):

a) The medial three metatarsals up to their heads.

b) Sesamoid bone: within tendon at behind of head of 1$^{st}$ metatarsal bone.

c) The three cuneiforms.

d) The navicular.

e) The talus.

f) The calcaneus.

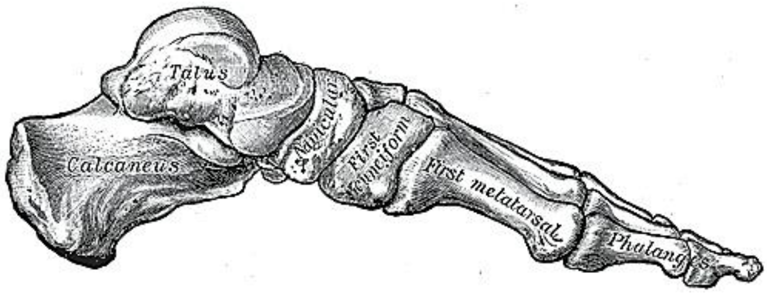



Figure 2 : Skeleton of foot at medial aspect area.

Source: Bartleby.com T. Gray's Anatomy of the Human Body. 20, editor. New York: Bartleby.com; 2000.(38)

The supported structures of the MLA separate in 2 types of passive and dynamic supporting. The passive supporting are ligaments that provide stability of foot arch with in four layers, as follows (Figure 3)

a) The plantar aponeurosis acts as a supporting beam between the two pillars.

b) Long plantar ligament works as supporting between first metatarsal and calcaneus bone.

c) Short plantar ligament works as supporting between cuneiform to calcaneus bone.

d) The spring ligament (Plantar calcaneonavicular ligament) supports the head of the talus.

The dynamic supporting are muscles in the foot that help to support the MLA, as follows:

a) Tibialis posterior muscles is the most important muscle for maintaining MLA. Damaging of tibialis posterior results in collapse of the arch.

b) Tibialis anterior muscles.

c) Flexor hallucis longus muscles.

d) Fibularis longus muscles.

e) Intrinsic plantar muscles.

The tibialis posterior and tibialis anterior muscles help to raise the medial border of the arch whilst the flexor hallucis longus acts as a bowstring

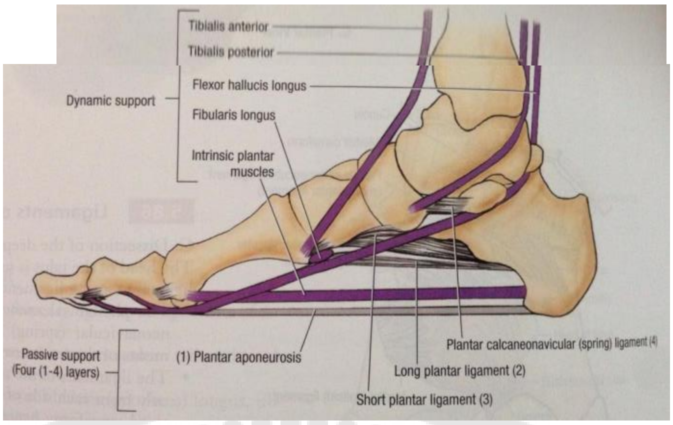



Figure 3 : Dynamic and passive support at medial part of foot.

Source: Anne MR, Arthur F. Grant's Atlas of Anatomy. China: C&C Offset Printing; 2009.(2)

## 2.2 Function of arches in human

### Weight Bearing and chock absorption

The arch of the foot has an important role in weight bearing. During standing, the body weight is loaded throughout arch of foot. The weight is transmitted from tibia to the talus, before transmitted posteriorly to the calcaneus. It is also transmitted anteriorly to the navicular, cuneiforms and metatarsals. The lateral longitudinal arch is involved in transmitting this weight and makes more contact with the ground than the medial longitudinal arch.

The MLA has an important role in shock absorption and propulsion during walking, running and jumping. The arch acts like a springboard, as its anterior pillar is the point of take-off during these activities. The process of walking is referred to gait cycle and this consists of two phases: a stance phase and a swing phase. During the stance phase, the forefoot pronates which flattens the MLA and the transverse arch. During the swing phase, the hind foot supinates which causes the MLA to elevate.

**2.3 The development of foot in pediatric**

The lower limb development appears in three to five weeks of embryonic. The position of lower limb was placed slightly lateral to the lumbar sacral myotomes. The foot develops from condensed mesenchyme which projects through the adjacent estoderm to form the foot template or anlage. Much differentiation of the embryonic tissues occurs to form the cartilaginous, osseous, vascular and neural components of the infant foot. The average length of the foot at term gestation is 7.6 centimeters (range 7.1-8.7 centimeters). Foot develops rapidly until five years of age and continues slowly to skeletal maturity of the feet at age approximately 12 years in girls and 14 years in boys.

From birth until approximately eight years of age, there are a number of changes in alignment and mobility of foot which occur due to osseous modeling and growth. The primary bony attribute of the young child's foot which causes to become flat when weight-bearing is the varus position of the heel. Flat foot in young child is allied of ligament laxity, muscle strength and muscle tone. Infants were born with flat feet, and the MLA develops naturally during the first decade of life. Most of children are born with flat foot, but they can develop their arch of foot when they begin to walk. However, there ere many factors that relate with developing of foot arch such as healthy posterior tibial tendon and muscle, firming of plantar aponeurosis, deltoid ligament, properly placed of inferior-calcaneonavicular ligament and tendoachilles.(1)

Waseda et al in 2013 studied normal growth of foot and standard values of the foot length and arch height in childhood and adolescence. The result of foot length in boys and girl showed a significant extension from age of 6 to 14 and 6 to 13 years old (Figure 4).(3,4) Moreover, the navicular height had significantly increase in nearby from the age of child foot. Although, there were no significant difference for boys and girls over 13 and 14 years old respectively. The growth speed of the navicular height was lower in girls when compared with boys after 13 years old. The Children in 13 - 14 years old are classified in adolescent ages from developmental stages (Figure 5).

The arch height ratio was normalized by foot length. In boys, the arch height ratio was almost flat until 11 years old, but was significantly elevated in the 11–13 years period. The elevation of navicular bone was gentle slope up after the age of 14–18 years old. In girls was almost flat until 10 years old, but was significantly elevated in the 10–12 years.(4) However, variations in arch of foot associated with the development of lower limb including injuries throughout lifetime.(10)

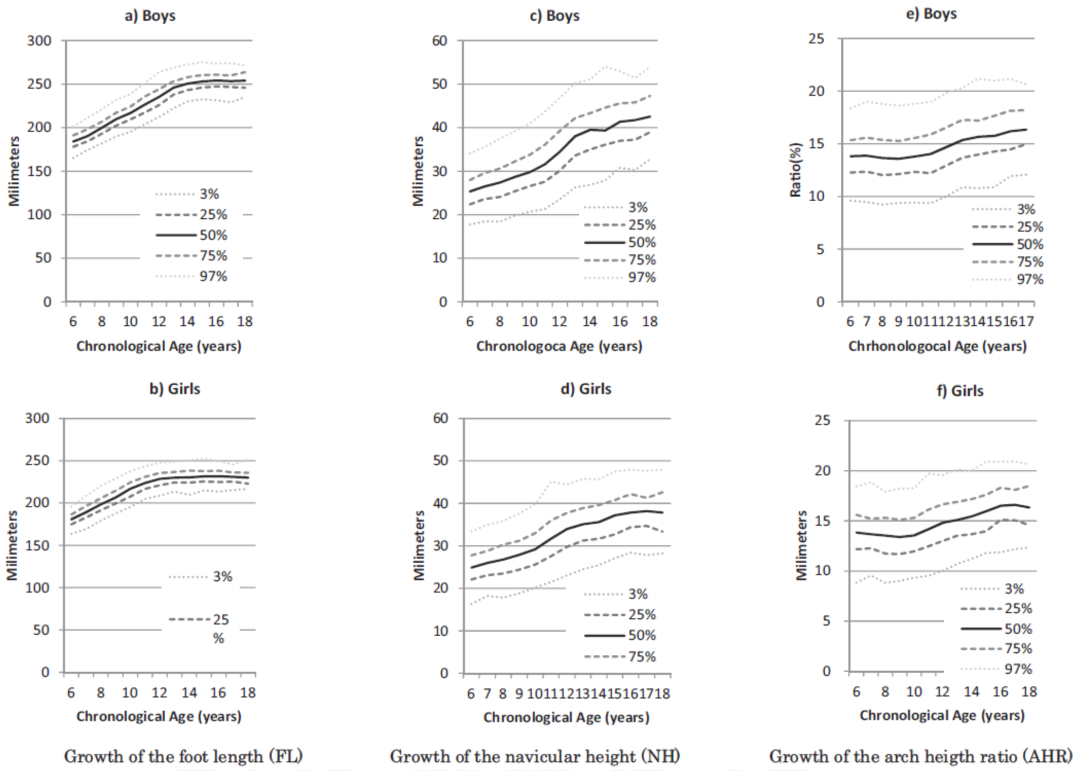



Figure 4 : Growth of the foot, 6–18 years of age.

Growth of the foot length: (a) boys, (b) girls. Growth of the navicular height: (c) boys, (d) girls. Growth of the arch height ratio: (e) boys, (f) girls. The result had shown age of 10 to13 years old to peak increased of all graft.

Source: Waseda A, Suda Y, Inokuchi S, Nishiwaki Y, Toyama Y. Standard Growth of the Foot Arch in Childhood and Adolescence--Derived from the Measurement Results of 10,155 Children. Foot Ankle Surg. 2014; 20(3): 208-214.(4)

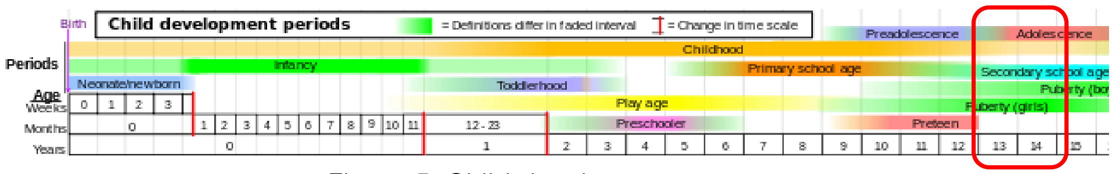



Figure 5: Child development stages.

Source: Häggström M. Approximate Outline of Development Periods in Postnatal Human Development Until What Generally is Regarded as Adulthood. 2009.(39)

## 2.4 Abnormal development of arch

Mostly, children have developed arches of foot to normal arches when they grow up. However, abnormal MLA of foot would be happened if child cannot develop their structures.(6-8) Nevertheless, controversy exists about the clinical characterization of the FFF, the degree of disability it causes in adulthood, and the requirement and choice of treatment.(40,41) Some studies suggested that the FFF is not a reveal problem as it is asymptomatic and rarely causes disability.(42-44) Conversely, others studies suggested that the FFF may cause gait disorders in adulthood.(45) Other conditions such as hallux valgus/rigidus, metatarsalgia, subtalar osteoarthritis, tunnel tarsal syndrome, Morton's neuroma, and posterior tibialis tendon dysfunction are often reported as consequences of a the FFF deformity. Most forefoot deformities are considered a consequence of abnormal subtalar pronation during propulsion.(46) The children with FFF can develop symptoms of mild pain in foot which is generally related to soft tissue tension of the plantar calcaneonavicular ligament or plantar fascia.(23)

The abnormal arch of foot had influence by the anomaly of structural function in foot support. When the structures of arch of foot was failed, the arch of foot could change of structural alignment and supportive function. The abnormal MLA was frequently founded in 2 forms of Pes Planus (Flatfoot) and Pes Cavus (High arch). Flatfoot had incident in children approximately 13.88 percentage that might lead to impair some of functional ability or injuries of lower limb throughout lifetime.(9-11) Previous study found that the children with FFF approximately 10–60% and up to 63% had functional impairment or abnormal movement patterns during walking and playing sports in stance phase support.(24)

### Pes Planus (Flatfoot)

Progressive flatfoot deformity in adults is a common entity that is encountered by orthopedic surgeons. A deformity that develops after skeletal maturity is commonly referred to flatfoot deformity. Flatfoot deformity should be differentiated from constitutional flatfoot, which is common congenital nonpathological foot morphology.(28,47) Foot deformity is still explained in variable pathophysiology. The biomechanics and anatomical contributions of foot deformity are the important factors into its etiology. The failure of one anatomical or biomechanical factor alone may not explain the clinical presentation of flatfoot deformity.

**a) Flexible flatfoot**

Infants are usually born with flexible flatfoot (FFF). At the time of birth, a foot pad is the dominant visible structure in the region of the MLA. During the first decade of life, the MLA develops along with the bones, muscles, and ligaments within the foot. By the age of 2, a child usually develops a medial arch that is visible when sitting. This arch may collapse with weight bearing, producing the appearance of flat feet. The FFF usually resolves by the age of 10. However, some of children would persist flatfeet into adolescent and adulthood. FFF should be considered because it may lead to deformity or deformity in the future. Previous studies suggested that FFF without symptoms could had variant foot shape throughout life.(48,49)

**b) Rigid flatfoot**

Multiple causes of rigid flatfeet in children and adolescents have been identified, with tarsal coalitions being the most common. Investigation into the underlying cause of rigid flatfoot is important in order to rule out neoplastic, neurologic, infectious and rheumatologic etiologies. In addition, treatment of the rigid flatfoot can be highly dependent on its etiology. Most patients with a rigid flatfoot have an identifiable etiology for their foot deformity. The rigid flatfoot type has alternated contraction of the muscles around joint. (50) Occasionally, adolescent and young adult patients present with a stiff, painful flatfoot deformity.(51,52)

### 2.4.1 Causes of flatfoot

#### 2.4.1.1 Insufficiency of posterior tibial tendon

The most common cause of flatfoot deformity is posterior tibial tendon dysfunction. The etiology of posterior tibial tendon dysfunction is varied such as degenerative, inflammatory, and traumatic causes. The most frequently affected dynamic stabilizer in flatfoot deformity is the posterior tibial tendon. This structure is the most powerful invertor of the foot and serves as an important dynamic arch stabilizer.(53) At heel rise, posterior tibial tendon initiates adduction of transverse tarsal joint with resultant of subtalar inversion that causes the talonavicular and calcaneocuboid joint axes to diverge and the transverse tarsal joint (Chopart joint) to become locked. This process converts the foot into a rigid lever arm against which the powerful gastrocnemius-soleus complex acts to propel the body forward.(54)

Insufficiency or dysfunction of the posterior tibial tendon has historically been thought to be the most common cause of flatfoot deformity.(55) The posterior tibial muscle and the corresponding tendon are crucial to hindfoot position and foot flexibility during the gait cycle. The posterior tibial muscle originates from the posterior aspect of the tibia, intraosseous membrane, and fibula, the posterior tibial muscle and the posterior tibial tendon pass postero-medially behind the medial malleolus and then insert via multiple bands into the navicular, the cuneiforms, the second through fourth metatarsal bases, and the sustentaculum tali. Ankle plantarflexion and forefoot adduction-supination with resultant subtalar inversion are key functions of the posterior tibial tendon because of its posteromedial position.

Patients with posterior tibial tendon insufficiency demonstrated extensive involvement of ligaments, particularly the spring-ligament complex, the talocalcaneal interosseous ligament, and the deltoid ligament.(56,57) Ligament pathology is nearly as common as posterior tibial pathology. The spring-ligament complex is the most frequently affected static stabilizer in symptomatic flatfoot deformity. Loss of posterior tibial function due to stretching or rupture of the posterior tibial tendon removes the primary inverter of the foot and leaves the primary and secondary everters of the foot, the peroneus brevis and the peroneus longus are relatively unopposed. Thus, posterior tibial dysfunction leads to flattening of the MLA, forefoot abduction, and hindfoot valgus.

#### 2.4.1.2 Pathophysiology

The deformity of foot arch involved with lateral subluxation of navicular on the talar head.(58) Three-dimensional computed tomography of patients with flatfoot deformity have documented subluxation of the subtalar joint with less contact between three facets of the calcaneus and talus as compared with control subjects. Clinical flatfoot showed the arch flattening, the forefoot abduction, and heel valgus occurring. This abnormal foot position has a profound negative impact on the gait cycle. Patients with flatfoot lack ability to lock the transverse tarsal joints. Patients will be unable to perform a single-leg heel rise. This inability to invert the heel results in chronic heel valgus and subsequent contracture of Achilles tendon. Furthermore, excessive forefoot abduction will stress the static stabilizers of the midfoot. The static and dynamic stabilizers of the arch are overloaded and develops painful sensation to patients subsequently.(59,60)

#### 2.4.1.3 Others

Although most cases of flatfoot deformity are attributable to posterior tibial tendon insufficiency, it is still necessary to evaluate patients for other possible causes to ensure optimal treatment.(61) Younger patients who present with rigid flatfoot should be screened for tarsal coalition, congenital vertical talus, or other forms of congenital hind foot pathology. It is theorized that patients with asymptomatic flatfeet may eventually progress to symptomatic disease as ongoing degenerative processes turn flexible deformities into rigid ones.(62,63)

Certain conditions that well known and documented were the incidence of posterior tibial tendon pathology.(64-66) Other clinical features that have been found to contribute to the development of posterior tibial tendon dysfunction include diabetes mellitus, hypertension, steroid exposure, or previous trauma or surgery in the medial foot region. Holmes and Mann in 1992 studied in 67 patients with posterior tibial tendon rupture(67), and noted that almost 60% of their patients had a history of at least one of the above-noted conditions. Biomechanical studies confirm that elevated gliding resistance and trauma to the posterior tibial tendon surface can simulate flatfoot model.(68) Moreover, trauma to bone, soft tissue can lead to the development of flatfoot deformity. Fracture-dislocation that involves the medial column (navicular and first metatarsal), and calcaneal fractures have been noted to cause flatfoot deformity, usually because of malunion or chronic joint subluxation. There has also been increasing interest in soft-tissue injury as a cause of flatfoot deformity. Ruptures of either the spring ligament or the plantar fascia have been reported to lead to progressive collapse of the MLA.(68,69)

Arthritis, both inflammatory and degenerative, have also been examined as a possible underlying cause of flatfoot deformity. Degenerative arthritis typically give rise to signs and symptoms in and around the midfoot region with accompanying pain and exostosis. Rheumatoid arthritis and other inflammatory arthritis (e.g., seronegative spondyloarthropathies and gout) have a deformity progression that is primarily dependent upon disease control. In one study found that 11% of 99 Rheumatoid arthritis patients have posterior tibial tendon pathology.(70)

Neuropathy-induced pes planus is perhaps the most concerning etiology. Diabetes mellitus induced Charcot neuroarthropathy to spinal cord injuries. Midfoot collapses secondary to Charcot neuroarthropathy which was completely different intervention and treatment from patients with posterior tibial tendon-insufficiency disease.(71) Many vascular and degenerative etiologies have also been proposed to explain posterior tibial tendon failure. Clinical evidence indicates that ruptures are common in the high-stress region where the tendon curves around the medial malleolus. A zone of tendon hypovascularity is 1-1.5 cm distally to the medial malleolus. Poor blood supply in this area of the tendon, where it takes a sharply curving course around the medial malleolus, could result in tendon degeneration and may explain a mechanical cause for tendon rupture. Nontraumatic tears usually occur in this hypovascular location, suggesting a possible etiology of ischemia and subsequent tendinosis.

### 2.4.2 Prognosis

If patient with flatfoot earns proper treatment regarding to foot biomechanics and etiology specially. A continuous of treatment options must be considered to gain the best functional outcome for the individual patient. Demonstrated significant improvement of all outcome measures such as high patient satisfaction.(72) The flatfoot patients who have mild changes of the dynamic structures, they are the best prognosis for returning to full function. These patients are most tolerant of non-operative treatment modalities and, if surgery is necessary, can reasonably expect a return to near-normal function.

### 2.5 Problem from flatfoot

The FFF had many according problems. The main problems were hypermobility and higher muscle activities in the lower extremity. Change on arch of foot affected to abnormal weight distribution on plantar and sole.(26) Because of flatfoot have been altered to the point that structures not designed to consistently accept greater loads, weight bearing was dispersed inappropriately to ankle, knee and hip joints.(27)

Children with FFF approximately 10–60% and up to 63% had functional impairment or abnormal movement patterns during stance phase support, but most of children with FFF are have no pain symptoms.(24) No single factor has been identified as the root cause of pediatric with FFF. One theory suggested that the FFF is the result of decreasing of muscle strength.(73)

#### Balance ability

The normal neuromotor developmental processes is essential to all professionals working with children whose development is normal or disturbed. Postural stability is the skill that underlies all motor actions.(74) Every motor action has destabilizing consequences that require age-adequate postural control.(75) Postural actions depend highly on contextual demands and therefore, in order to gain effective postural stability situational limits of equilibrium need to be learned.(76) The learning process continues throughout the life-span, but is most evident during infancy and early childhood. Posture utilizes information from the various senses that inform the brain about, for example, the position and movement of the body in space. Therefore, the development of postural control is tightly coupled with both the maturation and development of the sensory and motor systems as well as the integration of sensory information.(77) When the complexity of a system increases, the underlying components that affect development are much harder to disentangle.(78)

In infancy, postural control is manifested at the behavioral level as a progression of new motor milestones. The infant first learns to control the neck muscles and hence becomes able to coordinate head movements. Trunk control then develops during the emergence of independent sitting.(79) Attaining an independent upright posture poses new challenges to postural control. The support surface is reduced and new body segments are added, complicating the demands on the postural control system. Finally, cruising improves trunk control and enables a shift towards independent walking. Advanced postural control is reflected in the increasing number of participating muscles. As a function of development and experience, change will take place in the order in which muscles become activated and in the ability to adapt to perturbations.

Postural control appears to play an important role in the development of reaching and manipulation skills. Developmental changes in manipulation skills in 4-12 years old children can be seen as a more straightened hand trajectory, as well as increased coordination between hand transport and grip formation, and decreased dependence on visual control of the movement.(80) However, for a new movement children have to use visual information in main variable. The development of postural control continues after the achievement of an independent stance, although it is less apparent and not as fast as earlier in development. For example, the postural requirements for walking take at least 4-5 years of practice before a level comparable with that of adults is reached. The time window from 4 to 6 years of age seems to be a transition phase in other domains connected to postural control. At this age, the child learns to resolve intersensory conflict, and vision dominant mediator of postural responses. Later (> 7 years), children are able to choose the most relevant information source required for postural control. Also the anticipatory responses, which are considered to be a link between postural control and volitional movement, seem to be in a turning-point at age of 4-5 years when anticipatory postural adjustments appear to be consistently similar to adults.(81)

### 2.5.1 Static balance in one leg standing

When the arches have been descended or completely lost leading to structural or functional deformation, the ability to absorb impacts will decrease and the sense of balance will be lost stability during walking or running. Decreasing of stability during walking and running lead to reduce muscle strength and endurance.(82) Consequently, children with flatfoot emerged reducing of ability to control postural equilibrium in widely physical activities such as standing, running, jumping, and one leg standing.(28) Ability of balance in one leg standing presented as a problem in FFF even in static and dynamic standing.

Standing on one leg requires using of many body's systems such as muscle strength, sensory integration, vestibular and proprioception. There are tests of single leg standing in static and dynamic standing as follows;

**Static single leg standing test**

The Single leg standing (SLS) test was the easiest test for static standing balance. In the one-leg stand test, assessors instructed patients to stand with one foot and the other foot lift off the ground approximately six inches and count aloud by thousands (one thousand-one, one thousand-two, etc.) until patients put the foot down or until patients done completely 30 seconds.(73) The SLS protocol test have included with eye open, eye closed and foam surface. In the SLS with eye open, the subjects stand on their test leg side on a tape fixed to the ground, with hands on hips and non-weight bearing flexed knee to 90 degrees at the hip at 0 degree. The test was stopped when the foot’s subject moved from the mark or put the other leg down and some hand out of the hip, and the SLS with eyes closed was the same protocols.(83)

The SLS with foam surface protocols, subjects were asked to stand on their test leg on a 6-inchs foam cushion with medium density that fixed on the ground. Subjects were instructed to stand on one leg with their hands-on hips and non-weight bearing flexed knee to 90 degrees at the hip at 0 degree. Birmingham in 2000 has been reported that the reliability of the SLS test is 0.89 and 0.86 with eyes opened and closed.(84) Condon et at in 2013, studied one leg standing’s time in normal children and adolescence. The researcher founded that the adolescence childhood (more than 12 years old) controlled balance more than 120 seconds in eye open, 60 seconds in eyes closed and 10 to 30 seconds on unstable/foam surface (Figure 6).(85)

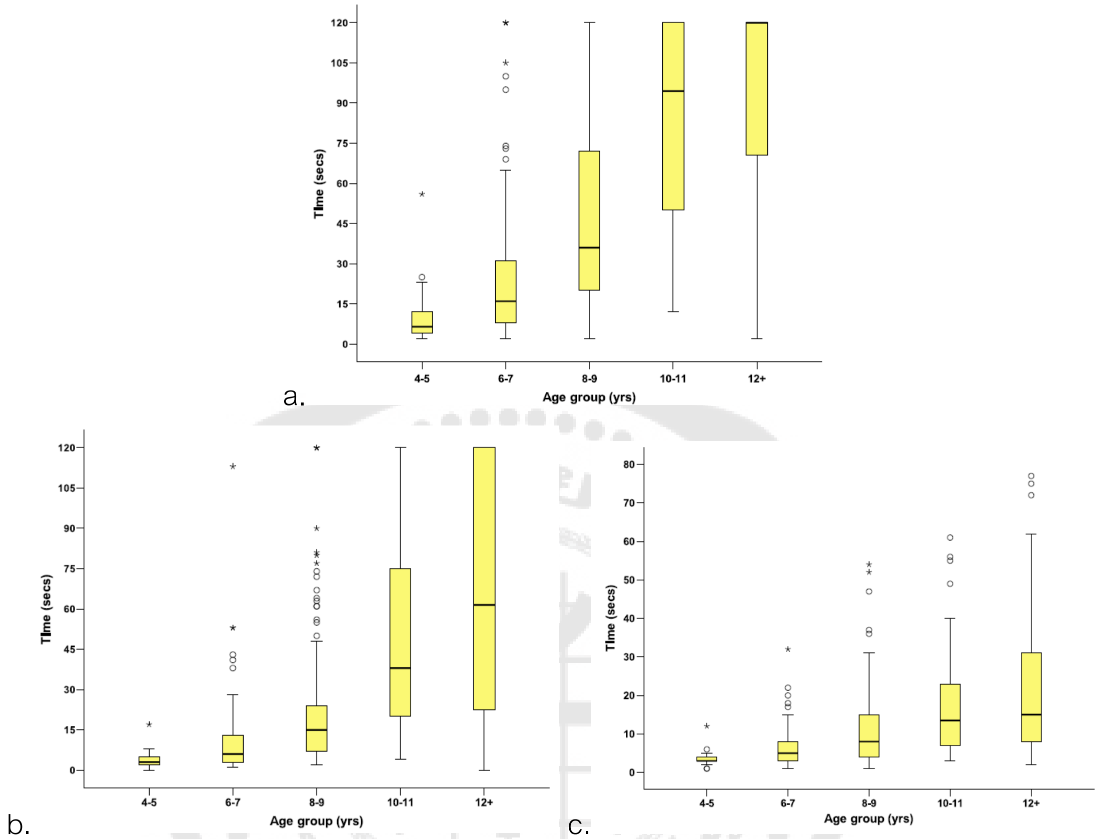



Figure 6 : Single leg balance.

a: Single leg balance on stable surface with eyes open, b: Single leg balance on stable surface with eyes closed, and c: Single leg balance on foam surface with eyes open.

Source: Condon C, Cremin K. Static Balance Norms in Children. Physiother Res Int. 2014; 19(1): 1-7.(85)

2.5.2 Dynamic balance in one leg standing

Dynamic Balance is more challenge than static balance. Dynamic balance is the ability to transfer the vertical projection of the center of gravity around the base of support. Dynamic balance is the ability to maintain postural stability and orientation with center of mass over the base of support while the body parts are in motion.(86) Therefore, valid and reliable assessment of dynamic postural control is necessary to determine if it represents a limiting factor in a person's movement skill performance.(87)

The dynamic balance test during single leg standing in this study was represented as star excursion balance test and Y balance test.

The star excursion balance test was developed to Y balance test. In the study of Plisky et al in 2009 they discussed in difference between the star excursion balance test and Y balance test for clinical use and screening purposes. In the direction of the anterior, posteromedial, and posterolateral directions appear to be important to identify individuals with chronic ankle instability and greater risk of lower extremity injury. While the subject touching down with the reach foot introduces error by making amount of support gained from that touchdown. If touchdown is not allowed, marking of the farthest reach point was used as variable.(88)

**The Y Balance Test**

The Y balance test (YBT) had the same protocol as the star excursion balance test, but it had only three directions of movement in anterior, postero-medial and postero-lateral directions (Figure 7). YBT protected fatigue and injury after protocols and reduced examination time significantly.(89) The device consisted of a single central plastic plate and three attached tubes that arranged in anterior, posteromedial and posterolateral positions.(31,89) A measurement was position on each of the tubes, with an interval of 0.5 centimeters. Subjects stand on one leg (barefoot) in a central location on the YBT instrument, with hands placed on the wing of ilium. They were asked to move the box on the tube as far as possible by using the lower limb opposite to the support limb, in three directions of anterior, posteromedial, posterolateral. YBT were performed in the same order of anterior, posterolateral and posteromedial directions respectively, subjects always started moving the box with their dominant leg.(90)

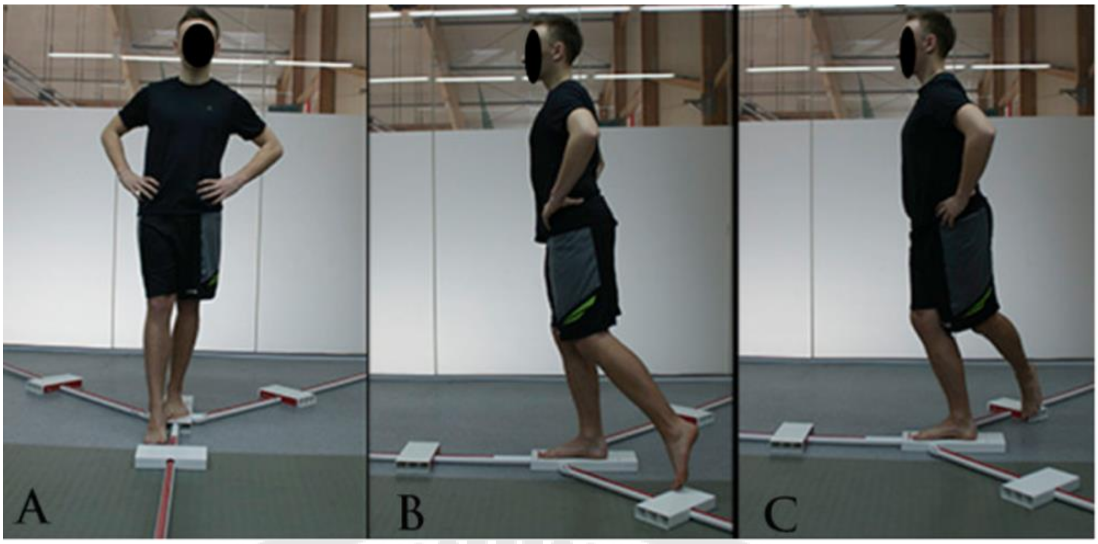



Figure 7 : Y balance test.

A: anterior direction; B: poterolateral direction and C: posteromedial direction.

Source: Linek P, Sikora D, Wolny T, Saulicz E. Reliability and Number of Trials of Y Balance Test in Adolescent Athletes. Musculoskelet Sci Pract. 2017.(90)

The setting area of YBT must not have slope (0° of sea level) and rough. The positions of YBT in antero-medial, antero-lateral are set 45° between them and posterior will be set as 135° respectively. Three lines on the floor was created as groove over the ground for putting a rectangular block. Subjects were instructed to push a rectangular block by one foot as far as possible. Before the testing, participant's leg length was assessed in supine lying position by physical therapy. Coughlan et al in 2012, studied difference between the star excursion balance test and the YBT, they suggested that the YBT test can be instead test with time saving of the star excursion test.(31) Kim et al in 2015 studied static balance on single leg standing by using forceplate and dynamic balance by using YBT in groups of flatfoot and normal foot. The result of standing balance with eyes open and closed in group of flatfoot showed less control of balance when compared with group of normal foot.(32)

## 2.6 The arch of foot examination

The clinical diagnosis of flatfoot have been applied in many techniques such as physical examination(14,91), Jack test(92,93), foot print analysis(94) and navicular drop test.

### 2.6.1 The computers examination

Computer techniques can classify foot arch types that derived from radiographs. Radiographic techniques are regarded as the gold-standard for assessing skeletal alignment of the foot in a static weight bearing position.(95) Therefore, angular foot measurements derived from x-rays are often used to validate clinical measures of foot posture.(96) It would be useful to have clinical measurements that accurately predict angular measurements derived from radiographs. The computers examination have many x-ray techniques(97), Computed tomography(25), magnetic resonance imaging(98) and foot print by optical podoscope technique.(99) The x-ray techniques are direct analysis method to diagnosis pathology of bone problem on human.

### 2.6.2 Navicular Drop test

The navicular height can be test by Navicular drop (ND) test , the test was originated by Brody in 1982 as a means of quantifying the amount of foot pronation in runners.(18) It is intended to represent the sagittal plane displacement of the navicular tuberosity from a neutral position to a relaxed position in standing (Figure 8).

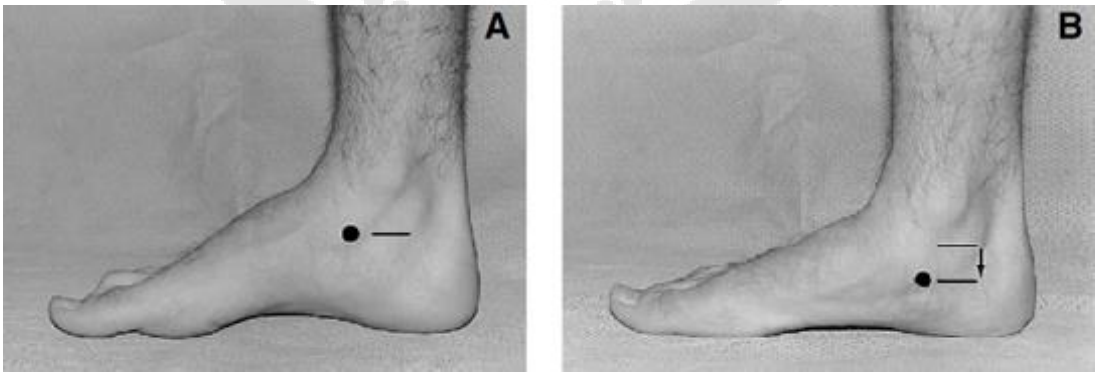



Figure 8 : Measurement of navicular drop.

A: The height of the navicular tuberosity is measured in neutral and relaxed B: Stance positions, and the amount of excursion is measured.

Source: Menz HB. Alternative Techniques for the Clinical Assessment of Foot Pronation. J Am Podiatr Med Assoc. 1998; 88(3): 119-129.(100)

The Navicular drop test was start by arranging subtalar joint to neutral in sitting position. After that an examiner marked Navicular tuberosity over skin and measured Navicular tuberosity height that related to the floor by ruler or Vernier caliper. Subjects were asked to stand with relaxed bilateral standing position, the level of the marker relative down to the floor was measured again. The distance between the two marks between the first and the second Navicular height was recorded.(18,26,100)

Static ND might be the most appropriate technique for the clinical assessment of foot pronation.(100) Mean values of navicular height among healthy adults range from 3.6 to 8.1 millimeters in the original version of the test(100-104) and from 7.3 to 9.0 millimeters in modified versions.(105,106) Brody's definition of ND test in 1982, the normal range for the ND showed between 5 to 9 millimeters. A drop more than 10 millimeters was considered as low arch and less than 4 millimeters was known as high arch foot.(18) The navicular drop test has shown moderate to good validity(21) when compared with x-ray examination.(19,20) The previous study showed moderately to good correlation between ND and x-ray technique (r = 0.61 - 0.89)(19-21,107)

# CHAPTER 3
# METHODOLOGY

This study has contents of methodology as follows:

3.1 Research design

3.2 Participants

3.3 Sample size

3.4 Equipment and research tools

3.5 Procedures

3.6 Statistical analysis

3.7 Summarize of the present study

## 3.1 Research design

The study was experimental study. Comparing of postural balance within and between groups of FFF and normal when they had repetitive hopping.

## 3.2 Participants

Subjects were recruited from secondary schools. They were adolescent ages between 13 and 14 years old. They were separated into groups of FFF and normal arch of foot. The group of FFF were classified by ND test. Participants were screened by inclusion and exclusion criteria:

### 3.2.1 Inclusion criteria

3.2.1.1 Participants could understand Thai Language and can perform following instructions.

3.2.1.2 Parent or caregiver of participants consented to include their adolescent in the study.

3.2.1.3 Participants have been FFF in dominant leg.

### 3.2.2 Exclusion criteria

3.2.2.1 Participants have rigid flatfoot or deformity of foot and ankle joint.

3.2.2.2 Participants have open wound around area of foot and sole.

3.2.2.3 Participants have leg length discrepancy more than 2 centimeter.

3.2.2.4 Participants have history of musculoskeletal problem that effect to postural control such as scoliosis.

3.2.2.5 Participants have lower extremity injury that effect standing and hopping.

3.2.2.6 Participants have history of surgery at lower extremities that effect standing and hopping.

3.2.2.7 Participants have history of underlying diseases that effect to physical activities such as Asthma.

3.2.2.8 Participants have history of neuromuscular problem that effect to postural control.

3.2.2.9 Participants have more weight and height than 2 standard deviation of normal criteria of ages 5 to 18 years in Thailand (Figure 9).

3.2.2.10 Participants have history of vestibular disorders.

3.2.2.11 Participants have visual problems that cannot correctable with lens.

3.2.2.12 Participants were athlete.

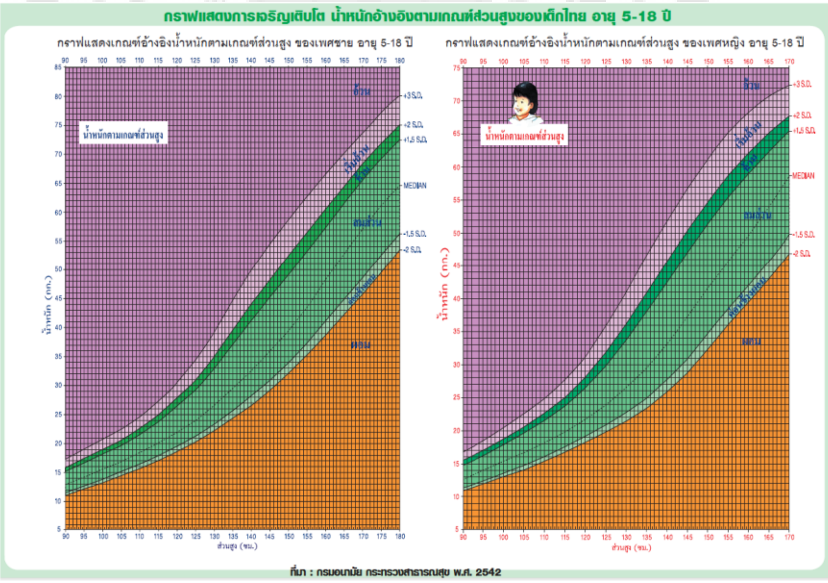



Figure 9 : Standard graft of criteria weight for height in Thailand children.

Source: สถาบันวิจัยและประเมินเทคโนโลยีทางการแพทย์กรมการแพทย์กระทรวงสาธารณสุข. แนวทางเวชปฏิบัติการป้องกันและดูแลรักษาโรคอ้วน. ชุมนุมสหกรณ์การเกษตรแห่งประเทศไทยจากัด 2542.(108)

### 3.3 Sample size

This study used purposive sampling. A purposive sample is a non-probability sample that is selected based on characteristics of a population and the objective of the study. GPower 3.1.9.2 was used to calculate the sample size in this study. The statistical analysis of this study was unpaired t – test for comparing between the FFF and normal groups. Program was set participants at two groups, 0.05 of alpha error and 80 percent of power. The effect size from previous study, static balance parameters was filled in the program. The sample size in each group was 18. This study included 20 percent of dropout. Thus, there were 4 participants adding in each group of participants. Therefore, this study was collected the data of 22 participants per groups of FFF and normal. Total participants were 44 persons. (Figure 10).

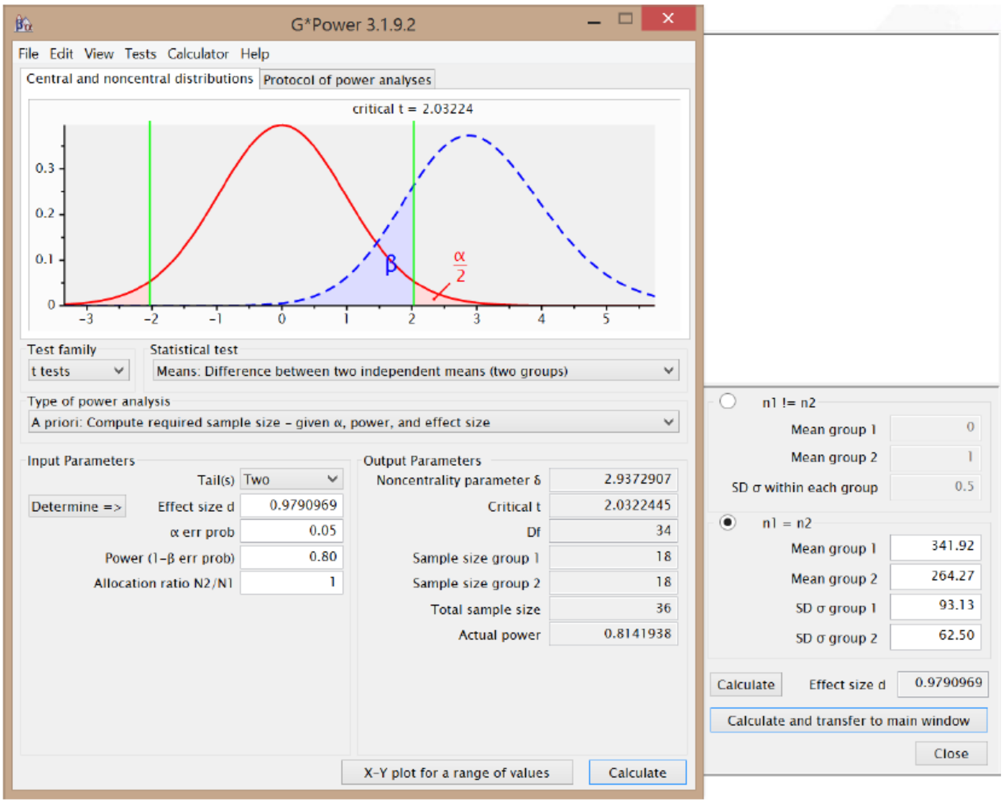



Figure 10 : Calculate sample size by GPower program.

Source: Kim JA, Lim OB, Yi CH. Difference in Static and Dynamic Stability Between Flexible Flatfeet and Neutral Feet. Gait Posture. 2015; 41(2): 546-550.(32)

### 3.4 Equipment and research tools

3.4.1 Standard Vernier caliper

3.4.2 Chair

3.4.3 Tape

3.4.4 Paper glue

3.4.5 Water level measure

3.4.6 Medium density foam: Ethylene Vinyl Acetate (EVA) foam

3.4.7 The Y Balance Test Kit™

3.4.8 Stopwatch

3.4.9 Computer program of metronome

3.4.10 Hand rail bar

3.4.11 Polar Heart rate monitor

3.4.12 The Baseline® hand held dynamometer

3.4.13 Blood pressure monitor

3.4.14 ball

### 3.5 Procedures

This study had 2 examiners, the first examiner was the examiner who measurer anthropometric data, set position of navicular bone and marked distance of navicular movement. The second examiner was the examiner who measured navicular drop and classified participants into groups of normal and flexible flatfoot.

Participants who align with inclusion criteria had invited in the study. Participants were asked about basic and health history. They had assessed anthropometric data such as leg length, muscle strength, dominant leg and physical examination as shown in Appendix A and B. Muscle strength test measured maximum force in eight groups of hip flexor, hip extensor, hip abductor, hip adductor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexor muscle by the Baseline® electronic push-pull dynamometer. The machine have maximum force capacity in 23 kilograms.

Hip flexors were measured in sitting position with hips and knees flexion at 90° dynamometer placed on the anterior aspect of the thigh, proximal to the knee joint. Knee extensors were also measured in sitting position with hips and knees flexion at 90°, dynamometer placed on the anterior aspect of the shank, proximal to the ankle joint. Ankle plantarflexors and dorsiflexor were measured in supine lying with ankle joints in neutral position, dynamometer placed over the plantar surface of metatarsal heads for measuring ankle plantarflexors and dorsal surface of metatarsal heads for measuring ankle dorsiflexor. Hip abductors and adductors were measure in supine lying, hip and knee joints were set in $0^o$, dynamometer placed on the lateral aspect of the shank, proximal to the ankle joint for measuring abductors and placed on the medial aspect for measuring hip adductors. Hip extensors were measured in prone lying, hip and knee joints were set in $0^o$, dynamometer placed on the posterior aspect of the shank, proximal to the ankle joint.(109) The dominant leg was tested by 3 protocols of kick a ball, step on bug and step forward, the dominant leg was chosen if participants used the same leg 2 of 3 protocols or over.(110)

The ND test was the test for measuring MLA in present study. The ND test began in the sitting position with bare feet on firm surface, knee flexes 90º and ankle set in neutral position (Figure 11a), the first examiner palpated on skin area of anterior inferior of medial malleolus and marked a dot on skin over the navicular tuberosity (Figure 11b). After that, the first examiner arranged subtalar joint in neutral position by the anterior line method. This method included 3 steps of 1) finding the depressions on either side of the talus head and mark the points. After that, center of marked points will be marked again for representing center of the ankle joint. 2) On the dorsal of the foot, draw a line from the 2nd metatarsal head to join a mark of center point of the ankle. 3) Draw a line on the apex of the anterior tibia crest (only concentrating on the lower one third of the tibia) and join a line to the center point of the ankle (Figure 11c).(111,112)

While examiner maintained subtalar joint in neutral position already, a ruler will be set vertically from the floor at the inner aspect of hind foot. Examiner used a paper for marking a height of navicular tuberosity from floor (Figure 12). After that, participants changed to standing position and distributed equal weight on feet without moving feet from sitting position, the level of navicular tuberosity moved relative down to the floor, the first examiner measured a height of navicular tuberosity from floor again. The second examiner was measured distance of navicular height between sitting and standing by standard Vernier caliper in unit of millimeter (Figure 13).(18,26,100)

a.  b.  c. 

Figure 11 : Setting for navicular drop test.

a: the participant relaxes in sitting position, b: Examiner marks dot on navicular tuberosity, and c: Examiner sets subtalar joint in neutral position.

Figure 12 : Examiner marked level of navicular tuberosity on paper glue.


Figure 13 : Distance of Navicular drop were measured by standard Vernier caliper.

Participants were classified to FFF and normal groups by the second examiner. If participants had distance from 10 millimeters and over more, they were classified in group of FFF. If participants had distance less than 10 millimeters, they were classified in group of normal arch of foot.(18) If participants had FFF both sides, They were collected data only on dominant foot. All of participants were randomly measured SLS and YBT before protocol of repetitive hopping.

Before protocol of repetitive hopping, participants had warm up phase for 5 minutes of free walking and self-stretching of lower extremity muscles, hip flexor, hip extensor, hip abductor, hip adductor, knee flexor, knee extensor, ankle dorsiflexion and ankle plantar flexor. The stretch slowly and hold for 20 to 30 seconds and Repeat 3 times.(113) After that, the repetitive hopping that modified from protocol of Boozari et al in 2013 (34) had beginning.

Participants had asked for hopping on a single dominant leg. During hopping, they were holding hand rail support which approximately adjusted in $90^{o}$ of elbow flexion in standing position, the level of hand rail could be adjusted from 85 - 150 centimeters from the ground (Figure 14). Participants hoped laterally side by side 60 times/minute/set and totally 3 sets by using metronome. Participants had asked for walking 30 seconds after finishing each set for resting. A set had terminated if participants fail to follow the metronome pace for 5 consecutive hops. Participants were monitored heart rate by polar and they will stop hopping if they have 70% of heart rate reserve(114) that identify vigorous intensity of participant's heart rate. If participants failed hopping and have more heart rate reserve than 70% in 2 sets, they were asked for discontinuing of protocol.

a. b.

Figure 14 : The modified repetitive impact loading activity.

After protocol of repetitive hopping, participants were randomly measured SLS, Y balance and ND test again. Finishing of repetitive hopping protocol, participants had stretch of muscles again. The protocols of SLS and YBT were explained in the next paragraph.

**3.5.1 Single leg standing (SLS) test**

Participants had stand on one leg in 4 conditions of eyes open, eyes closed on firm and foam surfaces.(115) Participants stood with barefoot on flatfoot side. An examiner marked foot position of participants on the ground for setting the same foot position in next condition. Participants stand on one leg with both hands-on hips and the other leg lifted over ground, angle of hip at 0 degrees and angle of knee at 90 degrees (Figure 15). SLS test had stopped when standing foot was moved on the ground, non-weight bearing foot moves down, or hands move out from hips. SLS test with eyes closed had similar protocol as the SLS with eyes open but add stopped criteria when participants open their eyes.

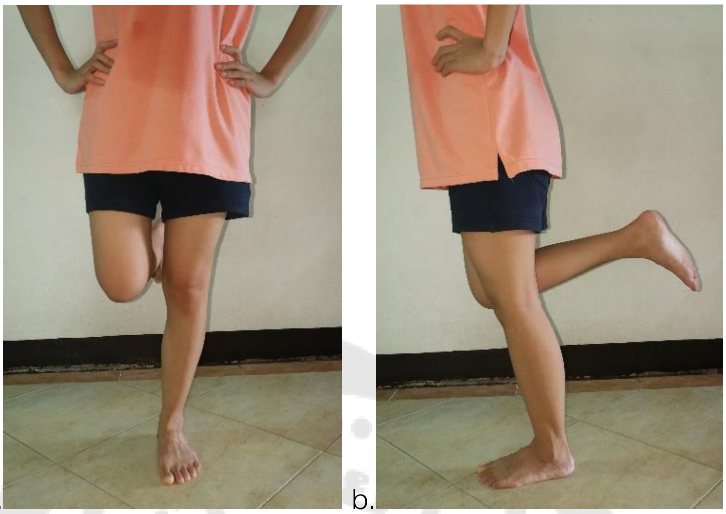
a.  b.

Figure 15 : Single leg standing test with eyes open and closed on firm surface a: front view and b: lateral view.

SLS test on foam surface, participant stand with one leg on Ethylene Vinyl Acetate (EVA) foam with the same protocol as stand on firm surface.(116) The EVA foam had fixed on the ground (Figure 16). SLS test stopped when participants move standing leg from stationary position, non-weight bearing leg down, hand out of the hips. SLS test had measured once in each condition with 10 seconds of resting time. The maximal time of test were 120 seconds.

a.  b. c.

Figure 16 : Single leg standing test with eyes open and closed on foam surface a. the EVA foam, b. front view and c. lateral view.

3.5.2 Y Balance test (YBT)

Before testing of YBT, participants had measured leg length in supine position (117), from the anterior superior iliac spine to the distal part of the medial malleolus by using tapeline.(89) YBT was a dynamic balance testing by standing on one leg and reaching the other leg as far as possible in 3 different directions.(30) The setting area must not had slope (0° of sea level) and rough.

YBT consisted of three direction lines of anterior, postero-medial and postero-lateral. Direction lines had set in angle of 135-degrees between anterior and postero-medial, and between anterior and postero-lateral. The last angle had set in angle of 90-degrees between postero-medial and postero-lateral (Figure 17). Three lines were arranged as groove on the ground for putting rectangular blocks over. Participants started by standing on the FFF at the center of three lines and reached the opposite foot to push rectangular block as far as possible on the setting directions (Figure 18) and then returned to a bilateral stable stance position.(31)

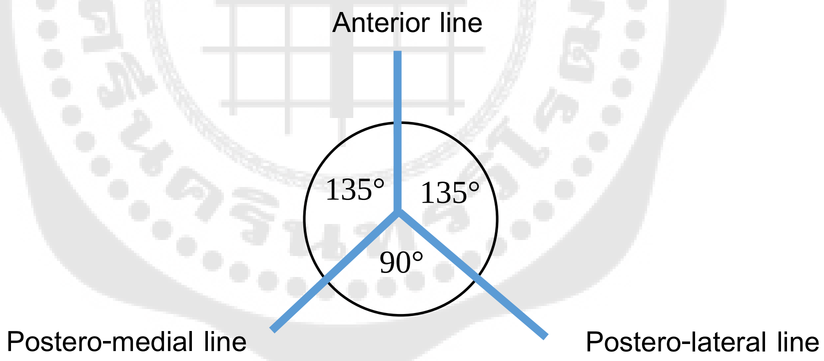



Figure 17 : Directions of Y balance test

a.  b.  c. 

Figure 18 : Participant reaching on Y balance test.

Participants tested only one trial for in each direction and then turn to next direction. The possible distances had recorded at the peak point of reaching. The important instructions of YBT that participants had to discard and repeat testing again were 1) touch on the block when you reaching or maintaining weight bearing on the reaching foot, 2) lift or move the stance foot from the center, 3) lost balance at any point during the trial and 4) cannot maintain balance, and return to first positions.(118,119) Peak distance of Y balance test had calculated to percentage by leg length. The formula is (Reaching distance / Leg Length) x 100 = Reach Percentage.(120,121)

### 3.6 Statistical analysis

Variables of the study were time of SLS (second) and distance of YBT (percentage) before and after hopping between FFF and normal groups. Variables had analyzed by SPSS version 23.0. Demographic data of participants such as age, weight, height and muscle strength will be analyzed by descriptive statistics. Shapiro-Wilk test (W test) had used for calculated normal distribution of data because data less than 50 unit. Statistical analysis in this study was two-way mixed ANOVA for normal distribution of data that variables compared within group of before and after hopping and between groups of FFF and normal. If data present as non-normal distribution Wilcoxon Signed-Rank test and The Mann-Whitney U test had used to calculated as dependent and independent groups. Significant differences for all test were set at $P < 0.05$.

3.7 Summarize of the present study

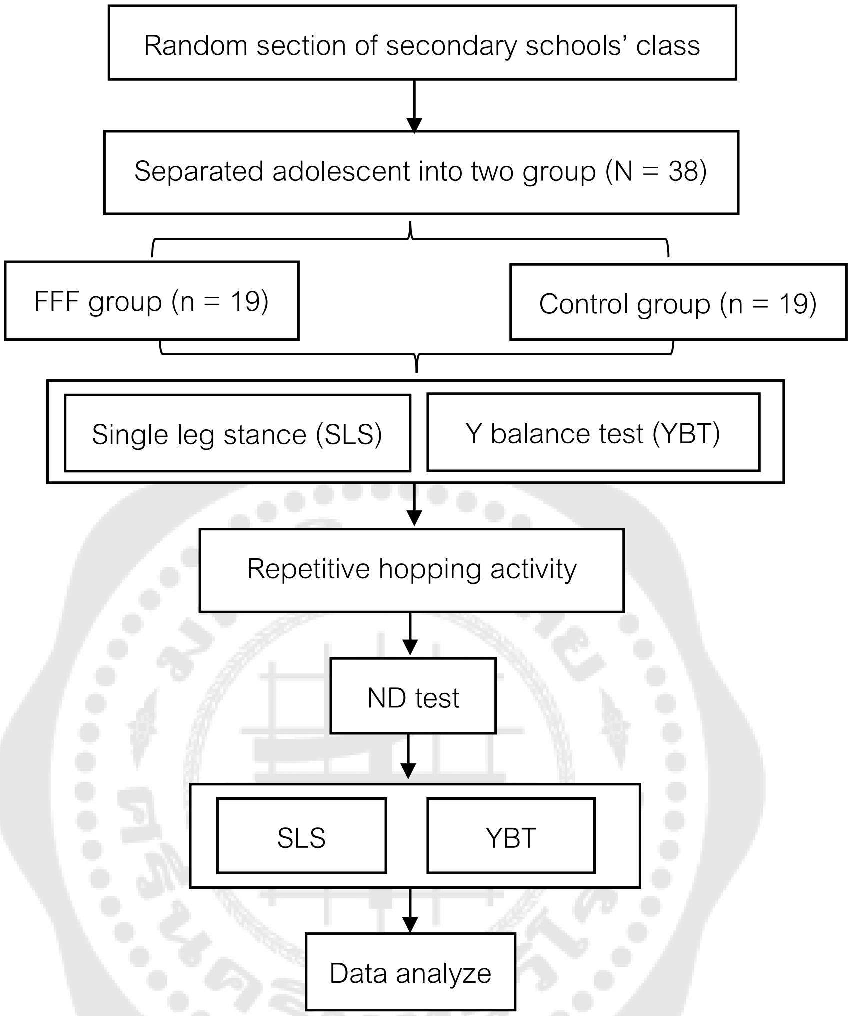



Figure 19 : Summarize of the present study

# CHAPTER 4
# RESULT

This study has contents of result as follows:

4.1 Summarize of participants

4.2 Data analysis

## 4.1 Summarize of participants

Participants in this study were adolescent ages between 13 and 14 years old from secondary school. Forty-four participants were recruited in the study. Six of all participants could not complete measuring of protocol because of unfollow the rhythm of metronome during hopping for 5 consecutively, had too exhausted and had pain at lower extremities. Finally, this study had 38 participants. Participants who had distance of ND between 5 to 9.99 millimeters were classified into normal group. The other group were FFF who had distance from 10 millimeters of ND. The demographic data of participants such as gender and dominant leg were show in percentile, another of age, weight, height, and muscle strength were shown as mean, standard deviation and percent in Table 1. The independent sample t-test was used for calculating significant difference between normal and FFF groups. The result showed no significant difference of demographic data between normal and FFF groups.

Table 1: Demographic data of participant.

| Demographic | FFF group (n=19) | Control group (n=19) | P value |
|---|---|---|---|
| Sex (n, %) | | | |
| Male | 12, 63.16 % | 9, 47.37 % | |
| Female | 7, 36.84 % | 10, 52.63 % | |
| Age (Mean ± SD) | 13.31 ± 0.73 | 13.64 ± 0.50 | 0.113 |
| Weight, kg (Mean ± SD) | 46.71 ± 6.03 | 47.96 ± 10.57 | 0.656 |
| Height, cm (Mean ± SD) | 158.74 ± 8.68 | 161.37 ± 8.29 | 0.346 |

| Demographic | FFF group (n=19) | Control group (n=19) | P value |
|---|---|---|---|
| Dominant leg (n, %) | | | |
| Right leg | 16, 84.21 % | 17, 89.47 % | |
| Left leg | 3, 15.79 % | 2, 10.53 % | |
| Muscle test (Mean ± SD) | | | |
| Hip flexors, kg | 12.65 ± 2.16 | 12.16 ± 2.12 | 0.490 |
| Hip extensors, kg | 11.38 ± 2.48 | 11.98 ± 2.49 | 0.458 |
| Hip abductors, kg | 11.89 ± 14.31 | 8.23 ± 1.50 | 0.275 |
| Hip adductors, kg | 7.55 ± 2.04 | 7.49 ± 1.42 | 0.920 |
| Knee flexors, kg | 11.48 ± 3.11 | 10.80 ± 2.27 | 0.447 |
| Knee extensors, kg | 11.53 ± 2.91 | 11.46 ± 2.88 | 0.942 |
| Dorsiflexors, kg | 7.76 ± 1.55 | 8.16 ± 1.76 | 0.468 |
| Plantar flexors, kg | 8.95 ± 2.03 | 8.46 ± 2.17 | 0.477 |

* Independent t-test showed statistically significant difference between FFF and control groups. ($p < 0.05$)

n = Number, FFF = Flexible flatfoot, SD = Standard deviation, %= Percent, kg = kilograms, cm = centimeter

### 4.2 Data analysis

Shapiro-Wilk test showed non-normal distribution of data in this study ($P < 0.05$). Therefore, the appropriate statistic in this study were Wilcoxon Signed-Rank test and The Mann-Whitney U test for calculating of difference within and between groups of normal and FFF.

The results of before and after repetitive hopping showed significant differences of the ND position in normal and FFF groups. For the SLS in FFF group, results showed significant differences in conditions of SLS on firm surface with eyes open ($P = 0.002$) and foam surface with eyes closed ($P = 0.025$). Normal group showed significant difference in condition of SLS on firm surface with eyes closed ($P = 0.044$). However, there were no significant differences in conditions of SLS on firm surface with eyes open, foam surface with eyes open and eyes closed (P = 0.114, 0.246, 0.717) in normal group. There were no significant differences in conditions of SLS on firm surface with eyes closed and foam surface with eyes open (P = 0.085, 0.122) in FFF group.

For YBT, results showed significant differences in directions of postero-medial line in both groups (P = 0.014, 0.023) and postero-lateral line in FFF group (P = 0.008). There were no significant differences in directions of anterior line in both groups and postero-lateral line in normal group (Table 2).

The results between groups showed significant differences of navicular drop position either before or after repetitive hopping. There was significant difference between groups in condition of SLS on firm surface with eyes open either before or after repetitive hopping (P = 0.000). Other conditions of SLS had no significant differences. For YBT, there were no significant differences of all directions between both groups.

Table 2: Before and after repetitive hopping of both groups of single leg stance and Y balance test

| Test | | Group | Before activity Mean ± SD | Before activity P value | After activity Mean ± SD | After activity P value | Before-After activity (P value) |
|---|---|---|---|---|---|---|---|
| ND | | FFF | 16.12 ± 4.47 | 0.000† | 18.32 ± 2.98 | 0.000† | 0.003* |
| | | Normal | 8.10 ± 1.48 | | 12.19 ± 3.79 | | 0.000* |
| SLS (s) | Eye open with firm surface | FFF | 78.89 ± 30.75 | 0.000† | 50.37 ± 33.04 | 0.000† | 0.002* |
| | | Normal | 112.35 ± 16.17 | | 102.09 ± 25.24 | | 0.114 |
| | Eye closed with firm surface | FFF | 21.39 ± 20.89 | 0.157 | 14.33 ± 14.84 | 0.267 | 0.085 |
| | | Normal | 29.69 ±20.95 | | 21.97 ±19.81 | | 0.044* |
| | Eye open with foam surface | FFF | 41.03 ± 31.66 | 0.199 | 28.97 ± 27.10 | 0.133 | 0.122 |
| | | Normal | 55.93 ± 35.83 | | 50.78 ± 43.47 | | 0.246 |
| | Eye closed with foam surface | FFF | 3.78 ± 2.19 | 0.255 | 3.12 ± 2.44 | 0.589 | 0.025* |
| | | Normal | 3.12 ± 1.91 | | 3.03 ±1.65 | | 0.717 |
| YBT (%) | Anterior line | FFF | 68.13 ± 10.09 | 0.872 | 66.55 ± 9.48 | 0.609 | 0.184 |
| | | Normal | 69.20 ± 9.69 | | 67.72 ± 8.93 | | 0.268 |
| | Postero-lateral line | FFF | 107.57 ± 14.30 | 0.474 | 99.73 ± 11.77 | 0.770 | 0.014* |
| | | Normal | 109.73 ± 23.20 | | 101.06 ± 12.72 | | 0.023* |

| Test | Group | Before activity | | After activity | | Before-After activity (P value) |
|---|---|---|---|---|---|---|
| | | Mean ± SD | P value | Mean ± SD | P value | |
| Postero-medial line | FFF | 102.63 ± 11.38 | 0.849 | 96.73 ± 13.62 | 0.737 | 0.008* |
| | Normal | 101.25 ± 15.65 | | 99.40 ± 12.54 | | 0.227 |

† Statistical significance between groups of FFF and normal ($P<0.05$)

* Statistical significance between before and after of repetitive hopping ($P<0.05$)

ND = Navicular drop, SLS = Single leg standing, YBT = Y balance test, FFF = Flexible flatfoot, s = Seconds, SD = Standard deviation,

% = Percent

# CHAPTER 5
# DISCUSSION

This study has contents of discussion as follows:

5.1 Discussion of this study

5.2 Conclusion of this study

## 5.1 Discussion of this study

This study presented balance abilities of young adolescent with and without flatfoot through SLS and YBT. Repetitive hopping was induced in participants both groups of flexible flatfoot and normal foot. After repetitive hopping, both groups showed more increased of navicular drop position than 10 millimeters (Table 2). Dropping of navicular bone and medial longitudinal arch may have cause from fatigue of supporting structures of medial longitudinal arch such as tibialis posterior, tibialis anterior, flexor hallucis longus, fibularis longus and intrinsic plantar muscles.(2,122) Functional fatigue during hopping may be explained by mechanism of stretch - shortening cycles.(123) The function of the stretch-shortening cycles was explained as muscle activation in 3 phases of pre-activation, stretch and shortening.(124) During hopping, leg and foot muscles have to work all the time of 3 phases and medial longitudinal arch was loaded by external force from gravity.(124) Pre-activation was a phase of pre-hopping, lower extremity contacts on the ground. Stretch phase was a phase of stretch and contract muscles as eccentric for preparing to the next movement. Shortening was a phase of extremity floating over the ground by concentric contraction. Moreover, this study was repetitive hopping to left and right direction that can stretch over plantar ligament lead to the excessive pronation of subtalar joint, valgus posture of rear foot away from the midline of calcaneus and depression of talus and navicular bones.(125) The fatigue cycle was showing an immediate reduction in performance during exercise, quick recovery within 1–2 hours, followed by a secondary reduction, which may often show the lowest values on the second day post-exercise when the symptoms of muscle soreness/damage are also greatest. The full recovery may take 4–8 days.(124)

Thus, result may imply that repetitive hopping or high impact of physical activities can increase flat foot in both groups by fatiguing of muscles and loading on medial longitudinal arch. From previous study of Robbins and Hanna in 1987 found that medial longitudinal arch could be affected after weight-bearing activity.(126) Gardin et al in 2013 showed changing of navicular height after fatigue of ankle invertor, tibialis posterior, tibialis anterior muscles.(122)

Before repetitive hopping, FFF group had average time of single leg standing with eye open on firm surface for 78 seconds and normal group for 112 seconds. After repetitive hopping, FFF group had average time of single leg standing with eye open on firm surface for 50 seconds and normal group for 102 seconds. Moreover, FFF was showed significant difference by reducing time after repetitive hopping on single leg standing with eyes open on firm surface. The results imply that the FFF group had less stability of balance than normal group especially after repetitive hopping. Because of the dynamic support such as tibialis posterior, tibialis anterior, flexor hallucis longus, fibularis longus and intrinsic plantar muscles of FFF cannot stabilize the MLA during SLS test.(127) Change of arch of foot after repetitive hopping could affected to abnormal weight distribution on plantar and sole. Lee et al in 2012 found that FFF had increased mid foot area in SLS with eye open on firm surface after fatigue of the plantar intrinsic muscle protocol.(128) The somatosensory system had disturbed by abnormal weight distribution after repetitive hopping.(129) Change of forefoot area after repetitive hopping would change position of joint, receptors and skin receptors. Other factors that may relate with instability of single leg standing in FFF is muscle endurance. Because of protocol of single leg standing in this study was used the maximum time at 120 seconds. Participants should have appropriate muscle strength and endurance for maintaining single leg standing for 120 seconds.(130) This study had measured muscle strength but not measured muscle endurance. Therefore, it is a suggestion of further study.

There were no significant differences in conditions of eyes closed with firm surface, eyes open with foam surface and eyes closed with foam surface between groups of FFF and normal. Alteration of sensory systems may induce inconsistency of static balance in both groups of adolescents. Therefore, if sensory systems had altered, ability of balance control may be reduced in both groups of FFF and normal. Because of the development of balance control from sensory systems in early adolescent are not consistency as adulthood.(85) Crowe et al in 1987 discussed that the proprioceptive accuracy had improvement continuously until age of 24 years old.(131) The visual information was the first necessary to control the body balance in young children to early adolescent. Previous studies found that children in 5-18 years old had more unstable balance with their eyes closed, the children in 8 – 10 years old had less proprioceptive accuracy than 16 – 18 years old approximately 50 percent.(132,133) Moreover, Tudor et al in 2009 found no significant difference between children aged 11 to 15 years in FFF and normal arch group in unstable surface test.(44)

In conditions of single leg standing on firm surface with eyes closed and foam surface with eyes closed, have significant differences between before and after repetitive hopping in groups of normal and FFF respectively. The result of single leg standing with eyes closed on firm surface in normal group showed standing time for 29 seconds and 21 seconds before and after repetitive hopping. Also, the SLS test with eyes closed on foam surface of FFF group showed standing time for 3.7 seconds and 3.1 seconds before and after repetitive hopping. A factor that can explain significant difference between before and after repetitive hopping was muscular fatigue after hopping as mention before. However, there were large amplitude of standard deviation in both conditions of eyes closed on firm surface and eyes closed on foam surface. Large amplitude of standard deviation represents variability of data even before and after repetitive hopping. The variability can represent as behavioral factors such as attention, motivation and muscle fatigue.(134,135) The other factor that related with variability of data was sensory development of adolescent. Presumptions of insufficient development of sensory systems and visual dependent for postural control in adolescent still be considered as a factor for increasing variation of body balance.(136)

All directions of Y balance test (YBT) in both groups of FFF and normal found no significant difference either before or after repetitive hopping. No difference between groups may be due to ability of body compensation during YBT. There was possible that FFF have adaptation of balance systems such as biomechanical constraints, and sensory systems for maintaining of dynamic balance.(137) From the demographic data showed that both groups of subjects had difference of foot types, but similarly characteristic of muscle strength, age, weight and height. Previous study of Kim et al in 2015 mentioned that the protocol of YBT was depended on visual input for maintaining of body balance and differences of foot types was a supplement factor.(32) Although visual system was the main factor of balance stability in adolescent, vestibular and proprioception also act as the main factors that would be improved further on dynamic balance testing.(138)

The study found significant difference of YBT in direction of postero-lateral before and after repetitive hopping in both groups. Moreover, in direction of postero-medial found significant different before and after repetitive hopping in FFF group. Medial longitudinal arch had flatter after repetitive hopping in both groups. Consequently, flatting of MLA can be induced foot pressure on midfoot area.(128) Increasing of contact area of plantar surface could be leading to reduce movement of center of mass (COM), especially in group of FFF that showed more drop of navicular bone than normal group.(139) A previous study suggested that an increase of foot flexibility in FFF had ability to use more available area for center of pressure (COP) excursion. However, increasing of available area of COP excursion might be a hypermobile of foot joints and may be less stable than normal and high arch of foot.(26) Therefore, participants who have FFF may reduce ability of dynamic balance when they are measured by YBT.

Regarding to direction of YBT, participants showed significant difference in postero-medial and postero-lateral and no significant difference in anterior direction. As mention previous, weight bearing on area of plantar foot may have increase after repetitive hopping. Change of weight bearing area may also alternate position of COP. Possible direction that COP might be deviated to medial direction after flatting of MLA Therefore, participant with flatting of MLA should change of dynamic stability and may be effect on body control in medial lateral direction.(26) Thus, the result implies that FFF subjects in this study had normal dynamic balance in anterior direction when they were measured by YBT. However, dynamic balance was consisted of many factors such as strength, flexibility, proprioception, concentration of motion, coordination between trunk, ankle, knee, and hip joints that a suggestion to concern in the further study.(138,140)

The present study founded that adolescent with and without FFF had flatter foot after repetitive lateral hopping. Changing of balance performance was showed in SLS with eye open on firm surface and YBT in postero-lateral and postero-medial direction. Because of repetitive hopping can effect to supportive structures of MLA and disturb weight distribution of mid-foot. (128) Alteration of weight distribution can engage in another joints of ankle, knee, hip and vertebral.(138,140,141) Consequently, FFF may also damage in another joints as mention previous. Therefore, this study has a suggestion of earlier exercise for treatment or rehabilitation of FFF in adolescent for preventing uncomfortable symptoms in the future.

Limitations of in this study should be mentioned. Firstly, the assessment of muscle property in this study had only muscle strength by using hand held dynamometer. The muscular endurance might be a necessary measurement for testing together with muscle strength that would be obviously explanation a changing of muscular properties. It should be suggesting in the further study. Secondly, the measurement of muscular strength in this study were performed by resistance of examiner which a factor of error in measurement. For the further study, constant setting of dynamometer would be a suggestion for reducing the error of measurement. Lastly, the measurement protocols could not control attention, motivation and concentration of participants that would be an important factor effecting to data. Therefore, the next study should have screening test of attention, motivation and concentration of participants as well.

Advantage of the study, the result of this study may be applied in adolescent with flexible flatfoot who have impairment of balance in static and dynamic. Training of static, single leg standing with different surfaces and visual inputs, or dynamic balance, Y balance test, may improve ability of postural balance in adolescent.

### 5.2 Conclusion of this study

The present study founded dropping down of navicular bone and flatting of MLA after repetitive hopping. Group of FFF showed flatter of foot after repetitive hopping and less SLS time in condition of eye open on firm surface when compared with normal group. Moreover, FFF group had less distance of YBT in postero-lateral and postero-medial direction after repetitive hopping. Results of SLS and YBT may represent static and dynamic balance on single leg standing of FFF that was reduced after repetitive hopping. After repetitive hopping, FFF was changed in weight distribution at plantar foot, ankle and excursion of COP. However, in conditions of SLS with eye closed and foam surface were not showed obviously differences after repetitive hopping because of variation of data that might explain as immature development of sensory systems in adolescent. Therefore, study of FFF and balance activities in adults or other factors that can relate with balance activities such as flexibility, proprioception, movement of trunk, ankle, knee, and hip joints would be a suggestion for further study.

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# VITA

| | |
|---|---|
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| DATE OF BIRTH | 21 March 1993 |
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# APPENDIXES

This study has contents of appendixes as follows:

a) Appendix A: The questionnaires information of subject

b) Appendix B: Physical examination

c) Appendix C: Pre-exercise, single leg standing and Y balance test

d) Appendix D: Post-exercise, navicular drop, single leg standing and Y balance test

วันที่ ............................... เลขที่ ................. 

Appendix A: The questionnaires information of subject

## แบบสอบถามคัดกรองข้อมูลทั่วไปของอาสาสมัคร
## คณะกายภาพบำบัด มหาวิทยาลัยศรีนครินทรวิโรฒ

---

**คำชี้แจง** แบบสอบถามนี้จัดทำขึ้นเพื่อบันทึกข้อมูลทั่วไปของอาสาสมัครในการดำเนินกระบวนการวิจัยในหัวข้อเรื่อง "ผลของการกระโดดซ้ำต่อความสามารถในการทรงท่าในวัยรุ่นตอนต้นที่มีภาวะเท้าแบนชนิดยืดหยุ่น"

**หมายเหตุ** เนื่องด้วยอาสาสมัครเป็นกลุ่มประชากรวัยรุ่น ที่ยังอยู่ในความดูแลของผู้ปกครองหรือผู้ดูแลดังนั้นในการให้ข้อมูลในแบบสอบถามนี้ผู้ปกครองควรเป็นคนให้ข้อมูลของอาสาสมัครด้วยตนเอง

โปรดทำเครื่องหมาย ✓ ลงในช่อง ☐ ที่ตรงกับความเป็นจริงมากที่สุด

1. ข้อมูลทั่วไป

ชื่อ เด็กหญิง/ เด็กชาย ....................................................................... อายุ ............ปี

เกิดวันที่ วัน/เดือน/ปี .............................

กำลังศึกษาอยู่ระดับชั้น ................... โรงเรียน ........................................................

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

อยู่ในเกณฑ์....................(อ้างอิงเกณฑ์ตามกรมอนามัย กระทรวงสาธารณสุข ปี 2542)

ความดันโลหิต.....................มิลลิเมตรปรอท อัตราการเต้นของหัวใจ..............ครั้ง/นาที

โรคประจำตัว: ☐ ไม่มี ☐ มี โปรดระบุ 1) ...................................................

2) ...................................................

3) ...................................................

4) ...................................................

* หากมีโรคประจำตัว โปรดระบุยาที่ได้รับ.......................................................................

ได้รับประทานยา/รักษา ต่อเนื่องหรือไม่ ☐ ต่อเนื่อง ☐ ไม่ต่อเนื่อง

2. ประวัติด้านสุขภาพ

2.1 ประวัติการผ่าตัดบริเวณสะโพก ขา และเท้า

☐ ไม่เคย ☐ เคย (โปรดระบุ) เมื่อใด .......................................................

ที่บริเวณ ....................................................

สาเหตุเกิดจาก ............................................

2.2 ประวัติการบาดเจ็บที่บริเวณสะโพก ขา และเท้า

☐ ไม่เคย ☐ เคย (โปรดระบุ) เมื่อใด .......................................................

ที่บริเวณ ....................................................

สาเหตุเกิดจาก ............................................

3. เป็นนักกีฬา ☐ ไม่ใช่ ☐ ใช่ กีฬาอะไร......................................................

4. สายตา ☐ ปกติ ☐ ผิดปกติ สามารถแก้ไขได้ด้วย ☐ แว่นสายตา

☐ แก้ไขไม่ได้

5. ที่อยู่ตามทะเบียนบ้าน

ที่อยู่ บ้านเลขที่ .................... หมู่ที่ ........ ซอย ...................... ถนน...........................

ตำบล/แขวง ......................... อำเภอ/เขต .....................จังหวัด ...............................

รหัสไปรษณีย์ ................ โทรศัพท์บ้าน.....................................................

ปัจจุบันอาศัยอยู่กับ: ☐ บิดาและมารดา ☐ บิดา ☐ มารดา

(เลือกได้ 1 ข้อ) ☐ ผู้ปกครอง โปรดระบุ........................................................

6. ข้อมูลผู้ปกครองที่สามารถติดต่อได้

ชื่อ นาย/นาง/นางสาว ......................................................................... อายุ ............ปี

เบอร์โทรศัพท์ ................................. E-mail.............................................................

เกี่ยวข้องเป็น ☐ บิดา ☐ มารดา ☐ อื่นๆ ........................................

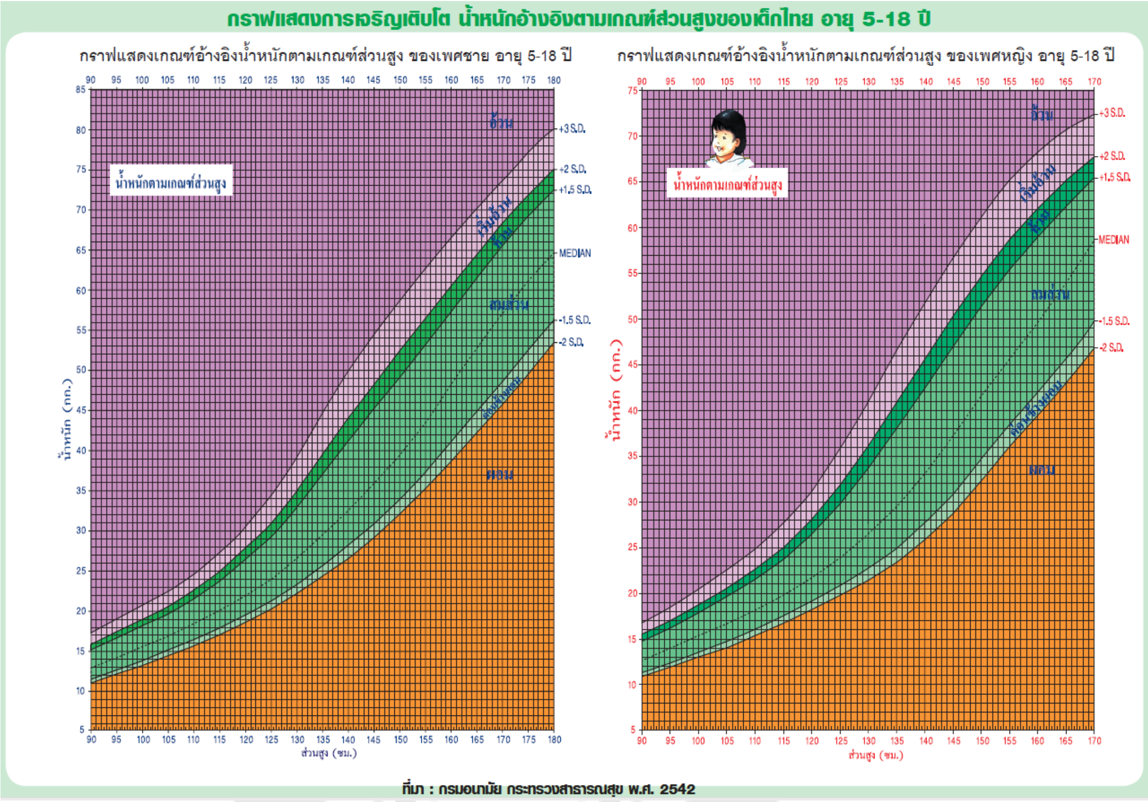
ที่อยู่ ☐ ตามทะเบียนบ้านข้างต้น

☐ ต่างจากทะเบียนบ้าน โปรดระบุด้านล่าง

ที่อยู่ บ้านเลขที่ .................... หมู่ที่ ........ ซอย ...................... ถนน...........................

ตำบล/แขวง .......................... อำเภอ/เขต .....................จังหวัด ...............................

รหัสไปรษณีย์ ................ โทรศัพท์บ้าน....................................................



Date.............................. No................. 

Appendix B: Physical examination

Assessor: ……………………..................

Subject name: (girl/boy)........................................................................... Age: …………

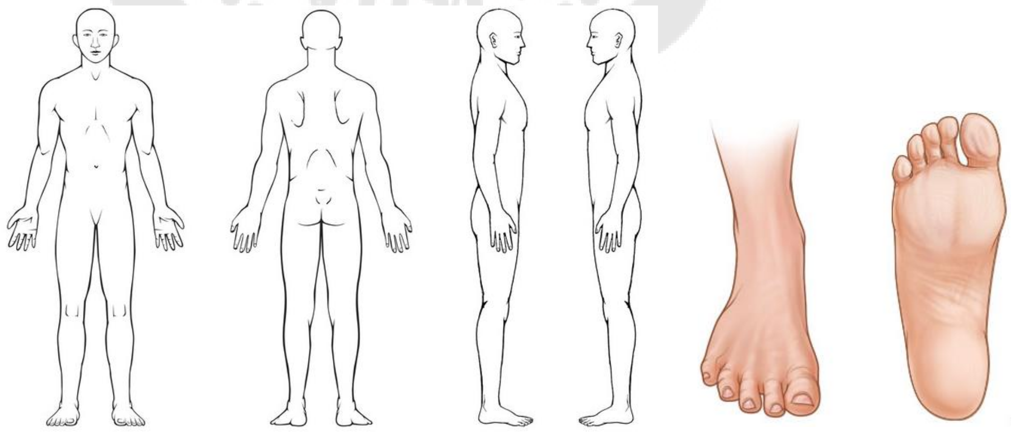
---

1. Vision problem

☐ No have ☐ Have and can't correct ☐ Have but can correction by lens

2. Vestibular disorder problem ☐ No have ☐ Have


3. Area of injury: ☐ No have ☐ Have and where



4. Leg length

Right.......................... centimeters Left.......................... centimeters

☐ Normal ☐ More than 2 centimeters

5. Type of arch of foot assessment by navicular drop test. ..........................millimeters

☐ Less than 4 millimeters : High arch

☐ 5-9 millimeters : Normal (Control group) : Group 1

☐ More than 10 millimeters : Flatfoot group : Group 2

6. Dominant leg test (2 in 3)

| | | | |
|---|---|---|---|
| 6.1 Kick a ball | ☐ Right | ☐ Left | |
| 6.2 Step on bug | ☐ Right | ☐ Left | } ☐ Right ☐ Left |
| 6.3 Step forward | ☐ Right | ☐ Left | |

7. Muscle strength test by hand held dynamometer in dominant side

7.1 Hip flexor: ............................................................ kilogram

7.2 Hip extensor: ....................................................... kilogram

7.3 Hip abductor: ....................................................... kilogram

7.4 Hip adductor: ....................................................... kilogram

7.5 Knee flexor: ......................................................... kilogram

7.6 Knee extensor: ..................................................... kilogram

7.7 Ankle dorsiflexion: ................................................ kilogram

7.8 Ankle plantar flexor: ............................................ kilogram

Date..............................                                        No................



Appendix C: Pre-exercise, single leg standing and Y balance test

Assessor: …………………..................

Subject number: ……………… Date of assessment: …………………………………………..

---

Single leg standing (SLS) Testing in 4 protocol:

SLS in eye open with firm surface: Total times: …………………. seconds.

SLS in eye open with foam surface: Total times: …………………. seconds.

SLS in eye closed with firm surface: Total times: …………………. seconds.

SLS in eye closed with foam surface: Total times: …………………. seconds.

---

Y balance test (YBT) in 3 directions

Leg length: Right / Left side: ....................................centimeters

| Reach Percentage = Reaching distance / Leg Length) x 100 |
|---|

Anterior direction:

Peak distance....................... centimeters, Reach Percentage = ...................%

Postero-lateral direction

Peak distance....................... centimeters, Reach Percentage = ...................%

Postero-medial direction

Peak distance....................... centimeters, Reach Percentage = ...................%

Date.............................. No................. 

Appendix D: Post-exercise, navicular drop, single leg standing and Y balance test

Assessor: …………………...................

Subject number: ……………… Date of assessment: …………………………………………..

---

Navicular drop test: ..................................millimeters

---

Single leg standing (SLS) Testing in 4 protocol:

SLS in eye open with firm surface: Total times: …………………. seconds.

SLS in eye open with foam surface: Total times: …………………. seconds.

SLS in eye closed with firm surface: Total times: …………………. seconds.

SLS in eye closed with foam surface: Total times: …………………. seconds.

---

Y balance test (YBT) in 3 directions

Leg length: Right / Left side: .....................................centimeters

| Reach Percentage = Reaching distance / Leg Length) x 100 |
|---|

Anterior direction:

Peak distance....................... centimeters, Reach Percentage = .....................%

Postero-lateral direction

Peak distance....................... centimeters, Reach Percentage = ....................%

Postero-medial direction

Peak distance....................... centimeters, Reach Percentage = ....................%