# CHAPTER II

# LITERATURE REVIEW

This chapter consists of five sections of literature review. The first section provides a comprehensive of aging, age-related changes on balance of the body, age-related changes on gait characteristics. The second section discusses the effects of walking over obstacle on gait characteristics. The third section provides a preliminary knowledge of the body accelerometry in gait analysis. The fourth and fifth sections provide comprehensive of the Berg Balance Scale (BBS) and the Timed up and go test (TUG), the clinical test of balance. The last section provides the information about a two-dimensional (2D) motion analysis system, a science of motion analysis, that used to capture the motion of the elderly women with and with out balance impairment during walking over obstacle in this thesis.

## 2.1 Ageing

Ageing is defined by biologists as progressive changes in the tissues or organs of the body, leading to a decline in function until death (2). The definitions of ageing can be defined as chronological age, biological age and sociological age (2). Chronological age is the most common method to define age that is according to the passage of time from birth onwards. World Health Organization (WHO) generally uses aged 60 years and over to refer to the elderly adult (16). Ageing in human refers to a multidimensional process of physical, psychological and social change. In the present study, the focus would be on physical changes associated with aging that adversely affect the performance of the activities of daily living.

### 2.1.1 Age-related changes on balance of the body

In biomechanics, balance of the body is an ability to maintain the center of gravity (COG) of a body within the base of support (BOS) (17). Winter (18) described that the balance is a generic term describing the dynamics of body posture to prevent fall. The balance construct includes the ability to remain still (static), to appropriately respond to a postural challenge and to move the body over the base of support (BBS) and from one point to another (dynamic) (19). Keeping balance requires integration of inputs from sensory and musculoskeletal systems such as visual system, vestibular system, proprioception, muscle strength and reaction time (3).

With advancing age, there is a progressive loss of sensorimotor functioning that affected to balance deficits during moving. For the sensory factors affecting balance, there is a general progressive loss of visual function, vestibular sense and proprioception due to normal ageing. In general, vision becomes progressively worse with increased age such as visual acuity, contrast sensitivity, glare sensitivity, dark adaptation, accommodation and dept perception (3). The input from the eyes (vision) is used by the central nervous system (CNS) to create a spatial map of the environment, in which we can quickly assess the speed and direction of moving objects and locate hazards in our path (3). Movement of the visual field can also provide information on movement of the body with respect to the world, which helps control upright posture (3). In the aspect of the vestibular sense, it detects position and motion of the head and this information contributes to balance through corrective movements elicited by the vestibulo-ocular and vestibulospinal pathways (3). The vestibulo-ocular reflex helps maintain visual fixation during head movement and vestibulospinal reflexes stabilize the head and help maintain upright stance, by triggering muscle activity in the neck, trunk and extremities (3). In the elderly, there is a reduction in hair cells that generally found in both the left and right labyrinths, whereas a vestibular pathology results in asymmetry between left and right labyrinths. People with vestibular malfunction can experience a range of symptoms such as dizziness, vertigo, orientation problems. However, people with these disorders who are aware of their poor balance may adopt appropriate corrective strategies and minimize risk-taking behaviors. For the proprioception, sensory information from receptors in the muscles, tendons and joints provide feedback regarding joint position sense, movement and touch (20).

For the part of motor system factors affecting balance, muscle strength is the most important to perform any activity in daily life. The declining of muscle mass and strength are common occur in individual elderly, especially, the weakness of lower limb muscle is revealed in poor performance on test of balance, abnormal gait patterns and reduced general mobility (3). With advancing age, there is a degenerative change of muscle mass, muscle strength and bony density. Sarcopenia is the degenerative changes of muscle mass and function that mostly affects on skeletal muscle especially type II fibers (21). Sarcopenia include the decreasing of number and cross-sectional area of muscle mass, muscle strength, metabolic rate and maximal consumption (21). In elderly adults, muscle mass decrease while body fat increases such that this shift in body composition with age is often masked by relative stability in overall body weight and occurs even in physically active elderly adults who exercise. Furthermore, in elderly people, the mass of the upper body increase at the expense of the upper body, thereby the body's center of mass (COM) is elevated (2). Additionally, a change in body posture is also a result of skeletal changes that resulted from osteoporosis.

Osteoporosis is common occur in elderly adults. It is decrease bone strength that includes the changes of bone structure (size, shape and microarchitecture) and material property (matrix, mineralization and damage) (22). Furthermore, osteoporosis is also one cause of vertebral fracture in elderly adults that lead to the kyphosis or stooped posture and instability. Furthermore, age-related changes on reducing range of motion of the trunk muscle and spine is one cause of the kyphosis. Kyphosis is causing an anterior shift in the body's COM and an increased demand on the posterior muscles, further stressing the balance control system. Moreover, muscle strength and age have been shown to be independent predictors of loss of balance. For the aspect of reaction time (RT), it is an ability to react quickly and appropriately, which is also important for maintaining balance and avoiding a fall when exposed to a postural challenge (19). The reaction time is also declining with age. Tucker et al (23) examined age-related changes in RT and the pattern of temporal coordination between center of pressure (COP), trunk and head motion during voluntary postural sway movements. They reported that the elderly adults exhibited slower RT during static and dynamic reaction, and smaller differences in RT and phasing between COP, trunk and head motion than the young did. Their finding suggested that the elderly adopted more rigid coordination strategies compared to the young when executing a rapid change in direction of the whole body motion.

As indicated above with increasing age, crucial sensory organs providing feedback to motor control system are progressively deteriorated, in coupled with a declined in musculoskeletal properties the dynamic balances that associate the ability and safety for performing the functional movement in daily life are in jeopardy.

### 2.1.2 Age-related changes on gait characteristics

Normally, the locomotor system integrates input from the motor cortex, cerebellum and basal ganglia as well as feedbacks from visual, vestibular and proprioceptive sense to produce carefully controlled motor commands that result in coordinated muscle firings and limb movements (24). Walking or gait is a complex activity and cyclic process. It consists of four main sub-tasks as (i) the initiation and termination of locomotor movements, (ii) the generation of continuous movement to progress toward a destination, (iii) the maintenance of equilibrium during progression and (iv) adaptability to meet any changes in the environment (19).

A gait cycle comprises of the events which occur when one foot contacts to the ground, following by contacting of the same foot (25). One gait cycle for each extremity can be divided into two phases, stance and swing phases. Stance phase is 60 % of a gait cycle and can be subdivided into four phases: initial contact, loading response, mid stance and terminal stance. Swing phase is described when the limb is not weight bearing and represents 40 % of a gait cycle that can be subdivided into three phases including initial swing (acceleration), midswing and terminal swing (deceleration). The quantitative gait analysis is useful as an objective documentation of walking ability as well as identifying the underlying causes for walking abnormalities. Temporospatial parameters are the general gait data that are assessed during locomotion (25). Spatial descriptors of gait include the length of step and stride. Stride length is the distance of full gait cycle, from the point heel contact of one extremity to the point of heel contact of the same extremity. In contrast, step length is the distance between successive heel contacts of the two different feet. For the temporal descriptors of gait, cadence, it is the number of steps per minute.

Walking speed combines both spatial and temporal measurements by providing information on the distance-covered a given amount of time. The other temporal descriptors are stride time (the time for a full gait cycle) and step time (the time for the completion of a right or a left step).

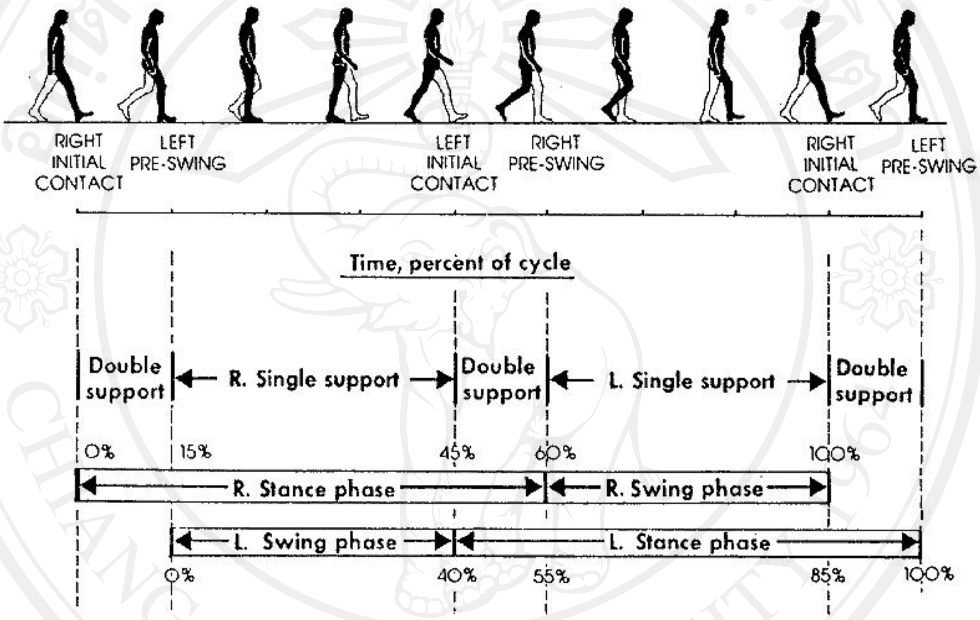


**Figure 1** Time dimensions of the gait cycle (26)

With increasing age, several studies revealed that temporospatial parameters of gait in elderly adults are different from the younger adults. Elderly adults displayed slow walking speed, and wild base gait than the young. This has been found to be a function of both a shorter stride length while longer time spent in double limb support (27). Furthermore, elderly adults were aware during walking over obstacle that they might be tripped, they respond to a perceived balance threat by reducing their toe clearance and decreasing walking speed (5).

## 2.2 Walking over obstacle

Stepping over obstacle during walking is one of the activities of daily living and require a complex motor task, requiring precise swing foot control while maintaining body balance through highly coordinated joint movements of the stance and swing limbs (5). Tripping over obstacles and imbalance during gait were also reported as two of the most common causes of falls in the elderly (5). In recent year, there has been increasing interest in the biomechanical characteristics of adaptations to obstacles and the contribution of these measures to understanding processes of gait over obstacle. Several gait studies were performed to study the effect of the obstacle height during walking over the obstacle of either the leading (limb crossing the obstacle first) and trailing (limb crossing the obstacle last) limbs. Many studies have examined specific gait parameters, for example, lead and trail toe clearances (the vertical distance between the toes and the obstacle when crossing), pre and post-obstacle distances (the horizontal distance between the feet and the obstacle).

### 2.2.1 Effect of stepping over obstacle during walking on gait characteristics

In healthy young adults, Patla et al (28) have focused on the effects of obstacle properties on the locomotor control. They examined the gait characteristics in six young healthy adults during level walking and crossing the obstacle of different heights (6.7 cm, 13.4 cm, and 26.8 cm). The results indicated that the gait patterns during obstructed gait were different from level walking. The differences in limb trajectory between obstructed gait and level walking took place during at the swing phase beginning at toe-off. The average clearance of the toe over the obstacle was about 10 cm. While there was an increase in vertical trajectories of all markers as the obstacle height increased, the limb trajectories were minimally changed for the different obstacle widths. As the limb trajectory was adjusted at the initiation of the swing phase, the authors noted that control of the gait patterns was actively modulated at the end of stance phase and at the swing phase. Similar to Austin et al's study (29), they examined the kinematics of the swing phase limb in 15 female young participants with mean age of 26.3 years during level walking and stepping over obstacle of different heights of 3.1 cm, 7.6 cm, and 12.6 cm. Two-dimensional (2D) video analysis was used to collect the angular displacements of the lower extremity, toe clearance, and the heel distance from the obstacle during toe-off and heel contact. The authors reported that a significant increase in both toe and heel clearances in vertical direction as obstacle height increased. However, plateaus of toe and heel clearance were observed at the greater obstacle heights. The angular displacements of hip, knee, and ankle joints also significantly increased as the obstacle height increased. The authors proposed that there exists a transition phase characterized by invariance in clearance distances with maintain a margin of safety and efficiency of movement during stepping over an obstacle. Furthermore, Chou and Draganish (30) also performed gait analysis in 14 young adults with mean age of 23 years. Toe-obstacle clearance and 3D motions and moments of the trail limb were obtained while the participants stepped over obstacles of heights of 5.1, 10.2, 15.3 and 20.4 cm. The authors reported that toe clearance of the trail foot at any obstacle heights was significantly greater than that of the unobstructed gait. However, no significant differences in toe clearance were found among different obstacle heights. The authors also reported that, for the sagittal plane, the hip and knee flexion angles of the trailing limb increased as the obstacle height increased. There were no significantly changes in the range of motion of the hip, knee, or ankle in the transverse or coronal plane. There was a 28% decrease in hip extension but a 27% increase in the hip adduction moment when stepping over the highest obstacle compared to the level walking. The adduction and external rotation moments at the knee and ankle at any obstacle height condition were significantly greater than those during the unobstructed gait were, but not significantly different as the obstacle height increased.

For the effect of gender, Sparrow et al (31) investigated gait characteristics of healthy young adults during stepping over obstacles. Six males with mean age of 40.8 years and six females with mean age of 36.3 years participated in the study. Kinematics characteristics of the leading and trailing feet during stepping over the obstacle which height adjusted to 10%, 25% and 40% of each participant's leg length were calculated from there-dimensional video analysis. The authors reported that the lead foot clearance was relatively uninfluenced by obstacle height whereas the trail foot clearance increased systematically and always cleared the obstacle by a greater margin. The male participants cleared the obstacle by a greater margin than the female participants did (by approximately 5 and 10 cm for the lead and trail foot, respectively). Obstacle crossing stride did not change as the step height increased. The obstacle crossing time decreased as the step height increased. A decrease in crossing time was a result of the shorter crossing time of the lead foot.

In the aspect of control of the center of mass (COM) during stepping over obstacle, Chou et al (32) investigated the effect of obstacle height on the motion of the whole body's COM and its interaction with the center of pressure (COP) of the stance foot while negotiating obstacles. Six healthy young adults (3 males and 3 females) with mean age of 30 years participated in the study. Each participant performed unobstructed level walking and stepped over obstacles of heights corresponding to 2.5%, 5%, 10%, and 15% of his or her height. The authors reported that stepping over the higher obstacles resulted in significantly greater displacements of the COM in the AP and V directions, a greater velocity of the COM in the V direction, and a greater AP distance between the COM and COP. In contrast, the motion of the COM in the ML direction was not affected when negotiating obstacles of different heights. Additionally, Wang and Watanabe (33) investigated the effect of obstacle height on the COP velocity when negotiating obstacles. Seven healthy female subjects were instructed to perform level walking and to step over obstacles corresponding to 5%, 10%, and 15% of their height. The results revealed that no significant differences in COP velocities for different obstacle height in the loading response phase. For mid-stance, the COP velocity decreased as obstacle height increased. For pre-swing, the COP velocity of the leading foot increased as obstacle height increased. For the trailing foot, there was a quadratic decrease in the COP velocity from 15.7 cm/s during unobstructed level walking to 12.1 cm/s when stepping over the obstacle of 15% body height. The author suggested that the COP velocity during stance phase prior to obstacle crossing appears to be regulated for the presence of different obstacle heights.



**2.2.2 Age-related changes on gait characteristics during walking over obstacle**

Chen et al (5) compared the kinematics of obstacle avoidance between healthy young and older adults. The trajectories of the lead foot while stepping over obstacles were examined in 24 young adults with mean age of 21.6 years and 24 older adults with mean age of 71.3 years. Equal numbers of male and female participants were presented in each group. Testing conditions included level walking and stepping over the obstacle at 2.5, 5.1 and 15.2 cm height. It was reported that crossing speed of the older participants was slower than the young adults as a result of shorter step length, for example at the 2.5 cm-obstacle height, the averaged older adults' crossing speed was 1.16 m/s compared to 1.30 m/s for the young adults. After crossing an obstacle, foot placement of the older adults was significantly closer to the obstacle than the younger adults did. Although the authors reported that age had no effect on minimum foot clearance over an obstacle, the older adults exhibited less of an increase in step length over the obstacle and tended to produce lower foot clearances and placing the trail foot farther form the obstacle. Similar to Chou et al's study (6), they examined the gait characteristics during obstacle crossing. Six healthy young adults with mean age of 30 year and six elderly adults with mean age of 70 years was participated in their study. Gait analysis was performed at the unobstructed level walking and at the 2.5%, 5%, 10%, and 15% obstacles of heights of each participant's body height. It was reported that the healthy elderly adults crossed the obstacles with slower speed and took a shorter step compared the young adults. The authors found that for the young adults, the displacements of the COM were greater in the anteroposterior (AP) and mediolateral (ML) directions for level walking and all obstacle heights, except the 15% height. At the highest obstacle, the elderly adults had a significantly greater COM displacement in the mediolateral direction. In addition to the study of Hahn and Chou's study (34), they estimated the effect of aging in sagittal plane of COM motion during obstacle crossing. Obstacle heights were normalized to individual body height (2.5%, 5%, 10%, and 15%). Temporal-distance (T-D) variables of gait were also compared. Neither the T-D parameters were not significantly different between groups; nor were frontal plane COM and COP parameters. Significant age differences did exist for AP motion of the COM and its relationship with the COP. Anterior COM velocities were also significantly lower in the elderly group as compared to the young group. The results confirm the ability of healthy elderly adults to maintain dynamic balance control in the frontal plane during locomotion. Reduced AP distances between the COM and COP indicate a conservative reduction of the mechanical load on joints of the supporting limb. The authors suggested that the conservative strategy might be related to a reduction in muscle strength as it occurs in the natural aging process. From the literature, the majority of the previous studies points out that the healthy older adults exhibited a more conservative strategy when crossing obstacles. Shorter crossing step lengths, slower crossing velocities, shorter post-obstacle heel strike distances, longer pre-obstacle toe approach distances and lower foot-obstacle clearance were demonstrated by the older adults compared to the young adults during obstacle negotiation tasks. These findings suggest that older adults are at a greater risk for tripping during obstacle negotiation tasks than young adults because the probability for obstacle contact is enhanced by the low clearance height.



To our knowledge, no reports that had been used the accelerometer to investigate during stepping over obstacle, therefore, this study are interest on it. In this study, the selected obstacle heights were 10% and 30% of individual's leg length (7). These obstacle heights were tested to ensure that individuals of different stature made the same qualitative adoption in going over obstacles (7). The lowest height of obstacle at 10% of leg length is approximately 7 centimeters that represents a typical door threshold or small step while the greatest height of obstacle at 30% of leg length is approximately 21 centimeters is similar to a high curb or stair (7).

**2.3 Accelerometry in gait analysis**

Accelerometry is a technique to quantify the acceleration using an accelerometer, a device for measuring the acceleration in term of gravity (g) (1g=9.80665m/s$^2$) (35). The acceleration is a vector quantity (magnitude and direction). In human movement study, the accelerometer is most common used to quantify the body accelerations during moving because the acceleration can be used to explain the control of movement, associated with the velocity and direction of movement. Accelerometer is used depending on a number of techniques of the accelerometer class such as strain gauge, piezoresistive, capacitive and piezoelectric that can serve the same of output (35). In gait analysis, accelerometers is common used because it has the low cost compared to more commonly used gait laboratory equipment and the testing is not restricted to a laboratory environment. Furthermore, accelerometer is small which enables subjects to walk relatively unrestricted and a variety of accelerometer designs offer diversity of dynamic range and sensitivity (35).

The mechanism of accelerometer for detecting an acceleration based on the tilting axis during moving that a sensitivity axis of the accelerometer under static conditions aligned with the global horizontal or parallel to the surface of the earth will detect an acceleration of 0 g or no acceleration and an axis of the accelerometer aligned with the global vertical or points directly to the center of the earth will measure an acceleration of 1 g (35). Under dynamic conditions, a sensing axis oriented and traveling in the global horizontal would have a purely accelerative output

(35). If the sensing axis deviated from the global horizontal, the output would contain an accelerative element due to gravity. The output of a body mounted accelerometer is composed of an inertial component of interest (linear acceleration), a static component (gravity), and noise which may be either biological (crosstalk from physiological systems) or environmental (electronic, motion artifact, etc.) (35). Accelerometer will indiscriminately detect rotational and translational accelerations to the extent that tangential or linear acceleration vectors of a moving body segment align with the device's sensing axis (35). Selective placement of accelerometers on the body may reduce the effect of rotational motion from contaminating the linear accelerometer output.

For the acceleration signal processing, raw data of acceleration are shown on computer that the accelerations are described in the time domain as the time (second) and the acceleration (g). The acceleration cannot be determined from the direction of movement and it represent in positive and negative acceleration that will be equal, and the average acceleration will be zero (or -1 g for the vertical direction) (35). Many studies have acceleration root mean square (RMS) transformed the acceleration data to show the magnitude of acceleration. The acceleration RMS provides a measure of dispersion of the data relative to zero (36, 37). Furthermore, direct examination of maximum and minimum in the acceleration signal was also used to represent the magnitude of acceleration (35).



### 2.3.1 The body acceleration during walking

In recent years, accelerometers have been used to measure the body accelerations in horizontal and vertical directions. Most studies involving the body accelerations have been limited on analysis of walking. The acceleration based gait studies is used to quantify the stability of the body segments using time and frequency domain and coupling of segmental accelerations (35). In normal walking, frequencies and magnitudes of the acceleration tend to increase from the head to the ankle and are generally greater in V direction than in the transverse plane (AP, ML) (9-11, 13). At natural walking speed of both young and elderly adults, the range of the body accelerations are approximately -1 to 1 g (35), such as at head and trunk (the third lumbar vertebral (L3)) of the young adults, the accelerations are ± 0.25-0.5 g and ± 0.5-0.75 g respectively (10, 11). Especially in the trunk acceleration, the previous study used the accelerometer placed on the third lumbar vertebral spinous process or L3 to measure the trunk acceleration that the L3 was closed to the COG and COM of the body (11, 13, 35). Trunk acceleration produced an acceleration profile associated with the ground reaction forces typically seen during gait (35). This region was shown low transverse plane rotation relative to axial rotation of the trunk and pelvis (35).

Previous studies have been studied the age-related changes on upper body acceleration (head and trunk or L3). Kavanagh et al (9, 10) used the tri-axial accelerometers, a device for measuring acceleration in V, AP and ML directions, to assess differences in the upper body accelerations between the young and elderly subjects during preferred walking speed. Their results reported that the elderly adults exhibited different patterns of upper body motion in the direction of travel or AP compared to young adults. Elderly subjects had the trunk acceleration in AP direction differed from the young adults. The elderly subjects had significantly lower peak positive AP trunk acceleration associated with push-off and significantly higher peak negative AP head and trunk acceleration following heel contact compared to young subjects. These results indicated that elderly subjects accelerated less during late stance and braked more during early stance than younger adults indicating a more cautious gait strategy. Elderly adults decreased the trunk acceleration patterns while the head acceleration patterns did not changed. The author suggested that these differences were probably motivated by the need to maximize dynamic stability during critical parts of the gait cycle. Elderly adults walked with a more rigid upper body and attempted to reduce the peak accelerations of the upper body around initial foot contact. The rigid movement strategy of the elderly was presumably generated in an effort to compensate for increased challenge to the maintenance of stability. For the effect of surface during walking, Menze et al (11, 13) used the tri-axial accelerometers to evaluate the acceleration patterns of the upper body (head and trunk or L3) in young and older subjects when walking on a level and an irregular walking surface, in order to develop an understanding of how ageing affects postural responses to challenging walking conditions. They reported that elderly subjects exhibited a more conservative gait pattern by having a reduced velocity, a shorter step length and an increase in step timing variability. These differences were particularly pronounced when walking on the irregular surface. The magnitude of accelerations at the head and trunk of elderly subjects were also generally smaller than young. In summary, the elderly adults displayed a cautious gait more than the young did. The elderly adults might reduce the trunk acceleration to stabilize balance of the body during moving for safety.

### 2.4 Berg Balance Scale (BBS)

Berg Balance Scale (BBS) is an observational test which was invented by Kathy Berg (38), a Canadian physical therapist, to apply in the clinical setting. The BBS is a commonly used for examining functional balance skills and for predicting risk of fall in both healthy and unhealthy elderly adults in a clinical setting and research purposes (39, 40). The BBS consists of 14 subtests performed in a standard order including (1) sitting to standing, (2) standing to unsupported, (3) sitting with back unsupported but feet supported on floor, (4) standing to sitting, (5) transfers, (6) standing unsupported with eyes closed, (7) standing unsupported with feet together, (8) reaching forward with outstretched arm while standing, (9) pick up object from the floor from a standing position, (10) turning to look behind over left and right shoulders while standing, (11) turning 360 degrees (12) place alternate foot on step or stool while standing unsupported, (13) standing unsupported one foot in front of the other foot and (14) standing on one leg. The equipment used for the BBS is a step stool, a mat table, a chair with arms, a tape measure, a stopwatch, a pen, and a table. Each task of the BBS is scored on a five-point scale (0-4) according to the quality of the performance or the time taken to complete the task, as ranked by the test developers. The maximum score for this assessment is 56. Furthermore, the BBS has been shown to have high intrarater and interater reliability, 0.98 and 0.97-0.99 (41, 42). Validity of the BBS has been supported by moderate to high correlations with other clinical performance measures (Tinetti, Barthel Mobility sub-scale, Timed up and go test and gait speed) (38).

Based on clinical experience, Berg et a1 (38) contend that scores below 45 indicate that someone is impaired balance, with an increased risk of falls. Hence, this study used the BBS score to a criterion to classify the elderly women into balance-impaired and non-balance-impaired groups for participating in the study.

**2.5 The Timed up and go test (TUG)**

The Timed up and go test (TUG), a common test for measuring the balance control in term of functional test for frail elderly adult, was developed from the original get up and go test. The get up and go test used an ordinal scoring based on the observer's assessment of the patient' risk of falling (43). It was developed to be a satisfactory clinical measure of balance in elderly adults. It requires subjects to stand up from an armchair, walk a distance of 3 meters, turn 180 degrees, walk back to the chair and sit down again. Balance function is scored on an ordinal scale of a five-point scale: 1 = normal, 2 = very slightly abnormal, 3 = mildly abnormal, 4 = moderately abnormal and 5 = severely abnormal. Elderly adult with score of 3 or more is at risk of falling.

Podsiadlo and Richardson (44) modified the get up and go test by timing the performance. The TUG measures the time that it take a subject to rise from sitting in a standard armchair, walk a distance of 3 meters, turn 180 degrees, walk back to a chair, and sit down. Equipment of the TUG includes a standard armchair, tape measure, tape and stopwatch. Begin the test, the subject sit on a standard armchair and the subject's backrest on the backrest. Markers are placed on the floor 3 meters away from a chair so that the subject easily sees it. When the instructions on the word "GO", the subjects will stand up, walk fast and safe to the line on the floor, turn around and walk back to a same armchair and their backrest on the backrest (39). In the TUG, the subjects can wear their regular footwear and may use the any gait aid but not be assisted by another person. The TUG has no time limit so that the subject may want to stop or rest during performing the task but not sit down. The subject should be given a practice trial before testing. The TUG has been shown to have good test-retest and inter-rater reliabilities in many different population such as people with chronic stroke and people with impaired mobility (45). Furthermore, the TUG score also were Highly correlated with BBS score (r=0.81) (46).

The time cut-off point of the TUG for detecting impairment in functional movement level is inconclusive. Podsiadlo and Richardson (44) suggested that healthy elderly adults usually complete the task in 10 seconds or less. Those who complete the task in 20 seconds or less can go out alone without a gait aid. While those who complete the task in 30 seconds or less have the problems that cannot go outside alone and may use a gait aid. In another study, Bischoff and co-workers (47) defined the practical time cut-off value to indicate normal versus below normal. Results revealed that 92% of community-dwelling elderly women (age range 65-85 years) performed the TUG in less than 12 seconds and in contrast only 9% of institutionalized elderly women performed the TUG in less than 12 seconds. Their results recommended the TUG as a screening tool to determine an in-depth mobility assessment and community-dwelling elderly women between 65 and 85 years of age should be able to perform the TUG in 12 second or less. Furthermore, Shumway-Cook et al (39) used the TUG to predict the probability for falls in 15 community-dwelling elderly adults with no history of falls, age range 65-85 years and in 15 community-dwelling elderly adults with a history of 2 or more falls in previous 6 months, age range 76-95 years. They found that the elderly adults who take the time to complete the TUG longer than 14 seconds have a high risk to fall.

**2.6 Two-dimensional (2D) Motion analysis system**

Motion analysis is the science of comparing sequential still images captured from photographic a body in motion in order to determine or evaluate the pattern of locomotion (48). It concludes two board categories as two-dimensional (2D) motion analysis systems and three-dimensional (3D) motion analysis systems. For the 2D motion analysis, recording of images may use a verity of possible methods such as digital video camera with digital video tape (DVT), digital videodisk (DVD) or hard disk drives (HDD) (48). The video image is transferred to the pixel information to provide a suitable calibration. Calibration of the 2D motion analysis system usually achieved by using a reference object of known size placed in the field of view to record for any lens aberrations that might affect the kinematics measurement (48). The referenced object may be a one-dimensional object placed at a given orientation within the field of view. The length of the referent object is usually measured within the analysis software in term of pixels. Computer and software are used to analyze images by manual digitizing from reflective marker that placed on the body. The operator displays a single image on video screen, moves a cursor in turn to the marker point and clicks a key or mouse to define data point. A 2D reference system has two imaginary axes perpendicular to each other. The two axes (x, y) are positioned so that one is vertical (y) and the other is horizontal (x), although they match by oriented in any manner. These two axes (x and y) from a plane are referred to as the x-y plane. An ordered pair of numbers is used to designate any point with reference to the axes, with the intersection or origin of the axes designated as (0, 0). This pair of numbers is always designated in the order of the horizontal or x-value followed by the vertical or y-value. A 2D reference system is used when the motion being described is planar.

For example, if the object or body can be seen to move up or down (vertically) and to the right or to the left (horizontally) as viewed from one direction, the movement is planar.

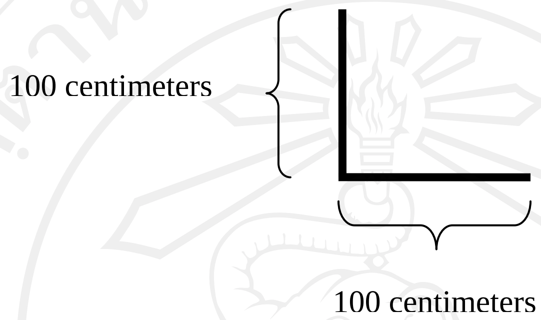


**Figure 2** Two possible reference objects for two 2 dimensional video calibration