CHAPTER II

LITERATURE REVIEW

This chapter comprises of three sections of literature review. This first section provides a comprehensive review of normal gait cycle and age-related changes on gait characteristics. The second section discusses the effects of up-and downslope on gait characteristics. The third section provides a preliminary knowledge of 2-D Motion Analysis System that used to capture participant's motions in this thesis.

2.1 Normal gait cycle

Normal gait appearance involves a network of neural connections and centers regulated by peripheral and internal feedback mechanisms. For the purpose of analysis, human walking can be expressed a repetitive cycle divided into smaller components (Figure 1). A single gait cycle is termed a stride, and consists of the events which occur when one foot contacts to the ground, following by contacting of the same foot (i.e. two steps, Figure2) (38).

One gait cycle for each extremity can be divided into two major phases: stance phase, in which the foot of the reference extremity is in contact with the ground, and swing phase, in which the reference extremity is above the ground or lifted from the floor. Stance phase can be divided into single limb support and double limb support, named according to the number of limbs in contact with the ground at that particular time (39-40).

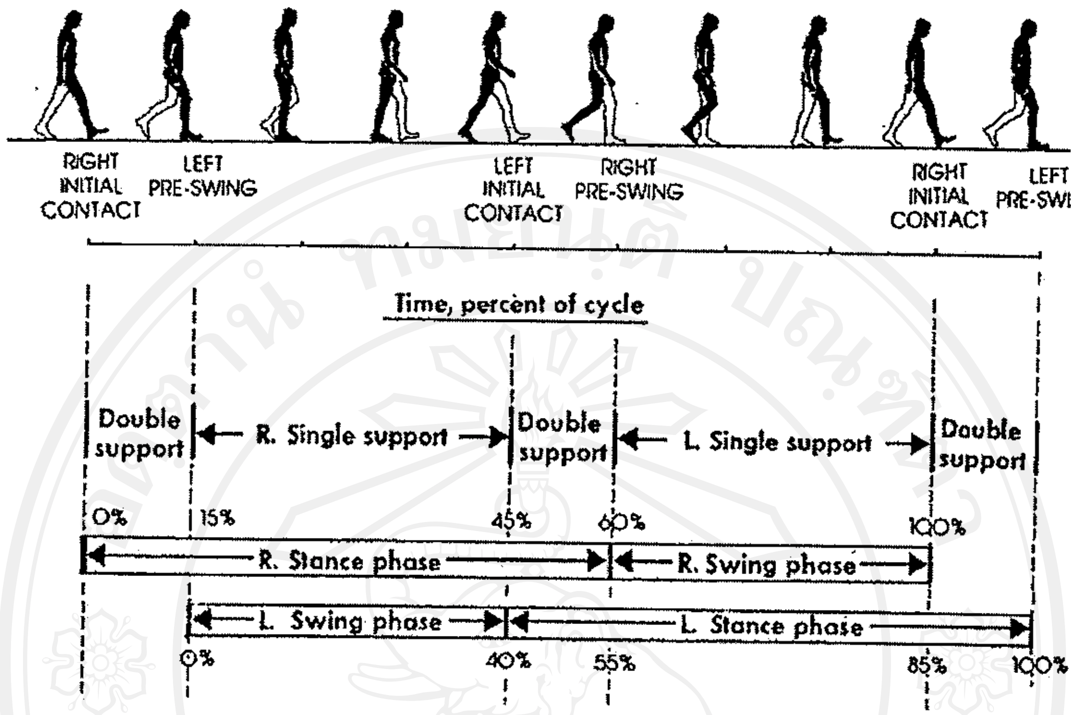

Figure 1 Subdivision of normal gait cycle (38)

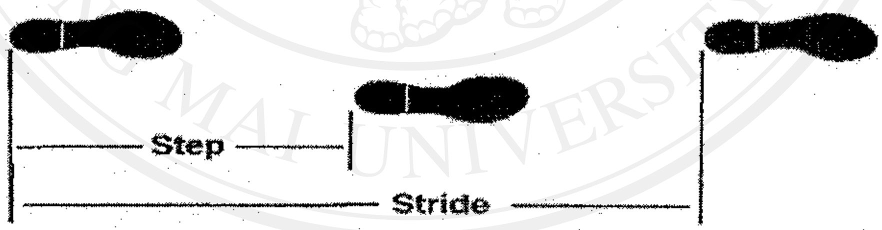

Figure 2 A single gait cycle illustrates step and stride length (41)

Observational gait characteristic is actually the initial stage in constructing someone gait pattern (42). Because it needs both very little and non-sophisticated equipment, temporo-spatial parameters were the first gait related data to be assessed during locomotion. The most basic spatial descriptors of gait include the length of a step and stride. Stride length is the distance of a full gait cycle, from the point heel contact of one extremity to the point of heel contact of the same extremity (1). Step length, in contrast, is the distance between successive heel contacts of the two different feet. Comparing right with left step length can help to evaluate the symmetry of gait between the lower extremities (38)

The most basic temporal descriptor of gait is cadence, the number of steps per minute, which is also called step rate. Other temporal descriptors of gait 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) (41)

Walking speed combines both spatial and temporal measurements by providing information on the distance covered in a given amount of time. The units of measurements are typically meters per second (m/s) or miles per hour (mph). Speed can be calculated by measuring the times it takes to cover a given distance, or the distance covered in a given amount of time, or by multiplying the step rate by the step length (42). Walking speed varies considerably between persons based on factors such as age and physical characteristics, such as height and weight.

2.1.1 Age-related changes on gait characteristics

Previous studies have been described age-related changes on musculoskeletal and neural components. They found that age-related changes in acuity and depth perception, decreases in visual field and diminishes the number of hair cells in the vestibular system (43). Additionally, the proprioceptive system is also negatively impacted in elderly persons by increasing threshold of the joint, muscle and cutaneous receptors (44). In the aspect of musculoskeletal system, the majority of investigators found that the number of motor unit and muscle fibers decline with age as a result of decreased muscle strength (45). As indicated above, all the sensory system deterioration, coupled with a decreased in muscle strength and bone density, affected dynamic walking balance and increased risk of fall.

Due to the high prevalence of chronic condition and falling problem in the elderly population, the scientific and medical communities need to know more about what is the normal gait pattern in the elderly to establish a valid data base for making a comparison with the elderly patients that need special care. Therefore, researchers have explored a complementary way of quantifying gait and its change with ageing and diseases. They suggested that the basic temporo-spatial parameters of gait can be used as global measures of the success of the walking task, and therefore provide some indications of walking stability (46-48). This approach is based on the assumption that older people are inherently less stable than younger people; therefore, the measurement of temporo-spatial parameters of gait would provide a useful indicator of walking stability.

Many researchers have investigated temporo-spatial parameters of gait compared between elderly persons and younger adults. Findings from comprehensive reviews showed that temporo-spatial parameters of gait in elderly persons are different from those in younger adults (1-10). The most consistent finding of these studies is that older people walk more slowly than young people. This has been found to be a function of both a shorter stride length while increase time spent in double limb support. In addition, previous work found that when older people were aware that they might be tripped as part of the experimental protocol, they respond to a perceived balance threat by reducing their toe clearance (49-50). The authors suggested that this reduced toe clearance was also related to reduce walking speed.

Although, this is likely to have some benefits with respect to maintenance of balance, it can be also increasing the probability of being tripped due to reduce toe clearance.

Furthermore, several studies have investigated changes on temporo-spatial parameters of gait in elderly persons which apparent dynamic walking instability, especially, elderly persons who had history of fall. Many researchers found specific gait parameters that distinguish between these 2 groups. Chiba and co-workers (18) examined gait kinematics parameters based on biomechanical features causing of fall (tripping). They suggested that tripping caused by insufficient dorsiflexion of the foot both during swing phase and just prior to heel contact. The results showed that fallers exhibit a decrease in toe clearance and maximal sole inclination during the swing phase. Therefore, minimum toe clearance and maximal sole inclination can be used to provide gait characteristics among elderly persons which apparent dynamic walking instability. In addition, Kemoun and colleagues (16) investigated kinematics characteristics of walking in non-faller elderly persons in order to develop predictive parameters for falls (prospective study). They found that elderly persons who had fallen in 1 year follow-up time walked more slowly and tended to spend longer period in double support.

Woolley and co-workers (17) examined gait kinematics among elderly persons with and without history of fall. They found that elderly fallers showed much shorter step length and a longer duration of the support time period. Similarly, Guimaraes and colleagues (15) investigated gait characteristics among healthy elders, elderly fallers and normal young subjects. They found that gait parameters of faller group differed from all other groups. Specifically the faller group walked with slower speed and shorter step length compared to other groups.

There is a fundamental paradox in the way in which these age-related differences have been interpreted. It could be argued that changes in temporo-spatial gait parameters in older subjects are thought to indicate diminished stability, on the other hand, these changes are thought to be a compensatory strategies adopts by older adults with destabilizing gait (1, 11-14, 22). However, previous studies suggested that the distinct changes of gait parameters (e.g. step length, double-support time, toe clearance, sole inclination) among young and elders (with and without history of fall) can reflect the unsteady-state of gait.

Like most physiologic signals, measures of gait are not constant but rather fluctuate with time and change from one stride to the next, even when environmental and external conditions are fixed (51). For elderly people even in an absence of pathology, it is common to find an increased inconsistency and arrhythmicity from one stride to the next (gait variability) which cause gait instability (23). However, it is not entirely clear why gait instability occurs in older individuals without apparent of neurological pathology. One explanation is that gait variability reflects motor control efficiency. Thus, increased gait variability in elders may be an indicator of motor control inefficiency. It is known that integrity of the nervous system is declined as age increases. Regardless of the causes, gait instability can be quantified.

Many researchers have investigated temporo-spatial variability compared between elders and younger adults. Findings from comprehensive reviews showed that temporo-spatial parameters of gait in elderly persons are different from those in younger adults (5-6, 15-21). They found that older subjects exhibit significantly greater variability in both stride length and cadence and this variability are associated with an increased risk of falling (5, 24). In addition, previous studies have investigated stride-to-stride variability compared between healthy elders and elderly faller. They found that stride time variability of gait were significantly increased in elderly fallers (5, 15, 23, 27-29). Therefore, the increased wide range of gait parameters may indicate an increased risk of falling during walking as a result of errors in control of foot placement.

Maki and co-workers (22) suggested that while the average gait parameters may reflect gait instability and associated with fear of falling, markers of stride-to-stride variability are the best representative of gait instability. Results from many studies have supported this notion (22, 23, 27, 52). They suggested that the degree of variability is more closely related to fall risk than average gait speed, average stride length, and average stride time. These results suggested that measures of gait variability may be more sensitive than other measures of gait. Therefore, gait variability is one feature of gait parameters that provide clinical index of gait instability and identify people at risk of falling. If one views gait variability as a reflection of the inconsistency in the central neuromuscular control system's ability to regulate gait and maintain a steady walking pattern, then it makes sense that measures of gait variability would be associated with instability and fall risk.

2.2 Effects of up-and downslope on gait characteristics

Human walking consists of four main concepts: (1) the initiation and termination of locomotor movements, (2) the generation of continuous movement to progress toward a destination, (3) maintenance of stability during progression, and (4) adaptability to meet any changes in the demands of the environment (12) The maintenance of stability is a particular challenging task for the human postural control system, especially, in the task that required specific locomotor control (e.g. walking on slope surface).

Walking on slope surface is a challenge task in our daily living environment since it places unique demands on the neuromuscular system. Many studies have investigated the neural control of locomotion in quadruped by using slope surface paradigm. These results showed the difference of neuromuscular response from those observed during level walking (53-54). These findings conflict with the traditional idea of a single Central Pattern Generator (CPG) controlling all forms of locomotion, and instead suggest that sloped surfaces require specialized responses from the nervous system, which have been modeled as task-specific CPG (54). The results from the quadruped studies can be extended to humans: one would expect that the changes in mechanical demands during slope walking would require a change in the neural control strategy, which would result in modifications of the pattern of lower limb motions.

Changes in the pattern of biomechanical parameters (i.e. joint kinematics, kinetics, electromyography) between tasks, such as walking on slope surface, may provide some insight into different control strategies used by the nervous system (55). However, to date, only few studies used slope walking paradigms to investigate neural control strategies in human. Particularly, a limited number of studies on temporo-spatial parameters of gait while walking on slope surfaces have been reported.

Leroux and colleagues (37) investigated postural strategies to adapt to uphill and treadmill inclination (0-5.6°). They found that uphill walking induced a progressive forward tilt of pelvic and trunk as well as increasing flex of hip, knee and ankle joint. The increase in trunk tilt was performed to assist lower limbs generating more momentum to counteract the resistance due to gravity. The need for generating this greater momentum was also reflected by a progressive increase in stride length. In contrast, Wall and colleagues (35) showed that walking on upslope surface (11.25°) had no effect on stride length of healthy young subjects. Similarly, Lay and co-workers (31) found no significant differences in the stride duration or stride length between level walking (0°) and upslope walking (8.5° and 21°). However, they found significant changes of lower limb kinematics, similar to that reported by Leroux and colleagues (37).

Leroux and colleagues (37) found that when walking on downslope surface, the main features were observed at the hip and knee joint. The hip joint showed a progressive decrease in flexion from mid-swing to early stance as well as increase in knee flexion during weight acceptance and late stance. These changes were accompanied by a gradual decrease in stride length. Similarly, Redfern and co-workers (34) investigated the biomechanical of human gait while descending ramps (0°, 5°, 10°, 15° and 20°) in healthy young subjects. They suggested that during downhill walking, the body had greater forward momentum. To counteract the forward momentum force, decreasing knee joint angle from mid-stance to toe-off was warranted. Change in knee joint during weight acceptance was pronounced by a gradual decrease in stride length.

In summary, previous studies have shown that gait adaptation during walking on slope surface is achieved by changing the pattern of lower limb motions, indicating that unique neural control strategies may be required during up-and downslope walking.

2.3 Motion Analysis Systems

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 (56). This method is subdivided into two board categories: two-dimensional (2-D) Motion Analysis Systems and three-dimensional (3-D) Motion Analysis Systems.

2-D Motion Analysis recording of images may take place using a variety of possible methods. For example, digital video cameras (camcorders) with digital video tape (DVT), digital video disk (DVD), or hard disk drives (HDD) are cheap and convenient devices for capturing visual images of relatively large objects, such as the human body, in movement. Almost all analysis is now done with the use of computers and software to analyze the recorded images separately or in sequence or to compare them with other single or sequences images in order to detect patterns of movement (42).

Digitization of visual images is the process to convert a part of an image to numerical position data by either manual or automatic method. In manual digitization, the operator displays a single image on a video screen, moves a cursor in turn to the marker point (i.e. ankle, knee, hip joints), and clicks a key or mouse to define a data point. For automatic analysis, the body is fitted with small reflective markers before image capture at strategic points (i.e. on the outer joint surfaces on the hip, knee, and ankle), usually using an adhesive sticker of some sort. In this 2-D system, digitizing frame was obtained x, y coordination. Here "x" is used to stand for distance measured along an axis pointing the horizontal direction, and "y" stands for distance measured along an axis pointing vertically up (57). The video image is transferred to the pixel information to provide a suitable calibration (56). A typical video screen is shown in Figure 3 together with the location of the origin of horizontal and vertical coordinates and a marker point.

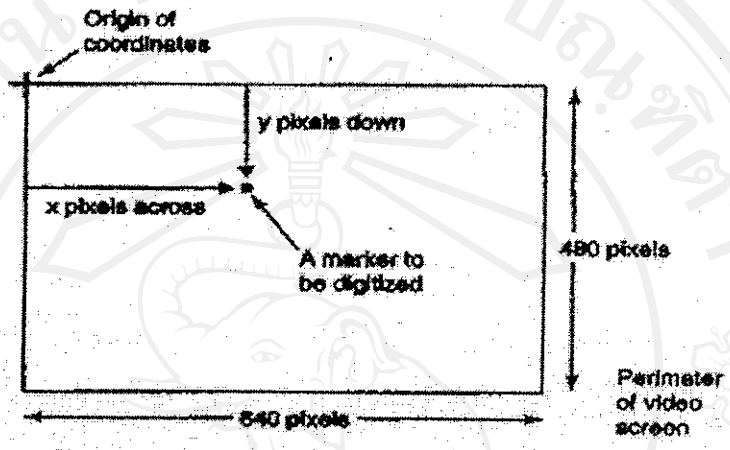

Figure 3 A typical video screens with an indication of the pixel coordinates used for analysis (56)

Calibration of a 2-D motion analysis system is usually achieved by using a reference object of known size placed in the field of view to correct for any lens aberrations that might affect the kinematics measurement (58). Figure 4 shows two typical calibration objects for video-based analysis systems.

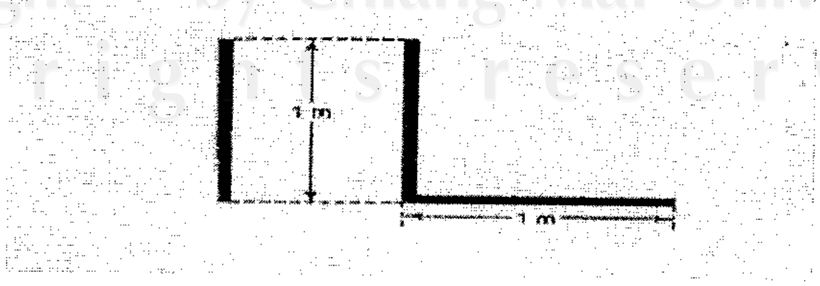

Figure 4 Two possible reference objects for two-dimensional video calibration (56)

The referenced object may be a one-dimensional object (left panel of Figure 4) placed at a given orientation within the field of view, or it may be a two-dimensional object (right panel of Figure 4) so that it can be oriented along two manually perpendicular directions. Note that the referenced object can be accurately known in size. The length of the reference object is usually measured within the analysis software in term of pixels. The calibration of the systems is inferred from this result. For example, a 1-m reference might correspond to 150 pixels on the video screen. This implies that each screen pixel corresponds to a real separation of 1/150 = 0.00666 m.