CHAPTER 2

LITERATURE REVIEW

1. Falls in elderly

Definition of fall

Fall is generally defined as an unintentional, unplanned, unexpected fall to the floor or supporting surface, not preceded by loss of consciousness, syncope, seizure, stroke and not a result from an external force (such as being pushed or hit). Supporting surface in this definition is not confined to only the floor, but could be a chair (as when a person falls back unexpectedly into the chair) or a wall (as when a person staggers into a wall) (13, 20, 21). The operational definition of fall or loss of balance in research is the situation where the center of mass is outside the limits of base of support (21).

Definition of Elderly Person

The definition of "elderly" or "old age" varies between countries, depending on the current social, political, and economic situation (22). Most developed countries define "elderly" using a chronological age of 65 years and older (23). The cutoff age is somewhat lower in the developing countries than that in the developed countries. In many countries including Thailand, the definition of elderly is linked to the retirement age. At the moment, the United Nations (UN) accepts the cutoff at 60+

years to refer to “elderly” (22). In Thailand, a chronological age of 60 years and older is officially used to define “elderly” (24). Thus, in the present study, the operational definition of elderly will be those who are 60 years and older.

Incidence of fall in elderly people

Approximately 17- 45% of elderly people had at least one fall in the past one year (1, 25). Of those elderly fallers, 17-27% reported having fallen more than once a year (25, 26). Twenty-three percents of elderly aged 65 to 74 years had fallen in the previous year compared to 31% of elderly aged over 75 (4). Those who aged 70 years and above often reported recurrent falls (1, 12). The incidence of falls rise steadily from middle age and peaked in persons older than 80 years (27). The rate and risk of falling increased progressively with age (4, 5, 28). Falls were more common in elderly women than elderly men with the ratio of approximately 2:1 (8, 12).

Falls occurred outdoors (56.5-61%) more often than indoor (1, 13, 29). Locations of outdoor falls occurred most often at the yard, sidewalks, curbs, and streets (2, 29). Most indoor falls occurred in the living room, followed by the kitchen/dining room, and bedroom. Falls tended to occur during the day (76.1%) rather than at night (1). Times of falls were most frequently reported in the morning from 6:01 AM to noon time, followed by the evening from 6:00 PM to midnight and least frequently reported after midnight to 6:00 AM (2).

Eighty-eight percent of fallers reported that falls were associated with movements (2). The most common activity at the time of falls was walking (55%) (8). Mechanisms of falls were often associated with trips (39%) followed by slips (15%) (2).

In Thailand, 9.8% of elderly fallers were hospitalized (30, 31). Up to 27.9% of elderly reported one or more falls in past 6 months (7, 30). The National statistical office of Thailand survey reported that in 2007, 10.3% of elders had history of falls. Of these elderly fallers, 55.7% had one fall, 23.7% had two falls, and 7.7% had more than five falls. Falls increased progressively with advanced age. Approximately 13% of elderly fallers were over 80 years of age, 11.7% were 70-79 years, and 9.2% were 60-69 years (31). Approximately 28.2% of fallers have recurrent falls. Elderly with history of falls had significantly worse mobility than those without history of falls (30). Elderly women (12.6-21.5%) fell more often than elderly men (7.4-14.4%). Most falls occurred during the day time (62.6%) and outside home (62.5%). Falls outside home most commonly occurred at the wet areas after raining especially a tile surface or trip sidewalk whereas fall inside home most commonly occurred in the bathroom (7, 30, 31). Trip was the most common cause of fall (33.8%) followed by slip (31.8%) and dizzy (14.9%) (31).

Consequences of falls

The rate of hospitalization for fall related trauma was 13.5 per 1000 persons aged 65 and older, that was five times of the non-fall related trauma (28). Twenty to thirty percents of fallers suffered moderate to severe injuries (28). Fifty seven percents of fall-related injuries occurred outdoors and 43% occurred indoors (2). These fall-related injuries included soft tissue injuries, skin tear, abrasions, hematomas, contusions, lacerations (requiring suturing or caused musculoskeletal pain that lasted for at least a week after the fall), head injury and fractures (2, 8). The most common fractures associated with falls were hip and upper extremity fractures (2). Hip fracture was one of the most serious consequences of falls (9, 32, 33). Twenty to thirty percents of fall-related hip fracture had mortality within 1 year. Majority of non-fatal fallers with hip fracture (25-75%) reported loss of independence for activity of daily living. One fourth of falls caused elderly to limit their normal activities, usually because of injury (25).

In addition, falls may induce fear of falling, which can lead to restriction in activity or avoidance of activity or loss of independence, a subsequent decline in physical function, and can cause isolation and depression (10, 11, 34). Fear of falling was a factor that decreases the quality of movement, and the physical capability which consequently results in weakening muscles. Therefore, fear of falling can led to increase the frequency of falls, resulting from balance impairment (35).

2. Factors related to fall

A cross-sectional study reported that significant factors associated with increased falling in the elderly were 1) aged over 75 years old, 2) female elderly, 3) poor vision, 4) having history of hypertension, 5) having less than 20 score of Barthel index and 6) taking two or more medications daily (1). The elderly are especially prone to falls because of age-related physiological changes as well as pathological diseases of various body systems. The probability of falling increases with the use of medications, advanced age, having a history of falls and unsafe environment (36)

Risk factors of fall can be classified as intrinsic and extrinsic factors. Extrinsic causes accounted for 56% and intrinsic causes accounted for 44% of falls. Extrinsic causes for falls were more common for elderly aged 60-69 years than those aged over 70 years due to greater activity and mobility (12).

Intrinsic factors

Physical and cognitive changes were one intrinsic factor that results from age-related changes (8). Intrinsic factors were often focused on normal age changes include physiological changes such as medical and physical problems, lower extremity weakness, poor grip strength, visual deficits, muscular strength, balance, cognitive impairment, dizziness/vertigo, syncope, stroke and degree of physical activity (8, 12, 37). Intrinsic factors included those causes from musculoskeletal problems such as arthritis, foot deformities; from diseases and medical conditions such as Stroke, Parkinson's disease, epilepsy, dementia, peripheral neuropathy, autonomic dysfunction, postural hypotension, cardiovascular syncope (12). Recent study reported that fallers were more likely to be women, have a lower body weight, Body Mass Index (BMI), disabling foot pain, severe hallux valgus, impaired lower limb proprioception and reduced ankle and quadriceps strength compared to non-fallers (38). Degree of physical activity may be related to risk of falls. Sedentary elderly people have an increased risk of falls, whereas individuals who are physically active have a decreased risk of falls. The sedentary group fell more frequently than exercising group (physically active) due to lack of stability (12). Furthermore, other problems such as dehydration, anemia, compromised cerebral blood flow, or autonomic changes because of diabetes can all result in orthostatic hypotension and cause a fall (8).

Of the medical conditions predisposing to falls, musculoskeletal problems and visual defects were common. Among the medical disorders causing falls, musculoskeletal problems were most common. These included osteoarthritis of knee joints (56%), rheumatoid arthritis with joint deformity (4%), myopathy secondary to hypothyroid state (2%), cervical and lumbar spondylosis (10%). Visual causes (54%) were mainly related to cataract. Causes of neurological illness (28%) were peripheral neuropathy of sensory type (16%), post stroke residual weakness (4%), Parkinson's disease (3%), cervical myelopathy (3%), cerebellar disease (1%), and postvaccinial demyelination (1%). Other causes responsible for falls were vestibular (18%), syncope (18%), systolic hypertension (14%), postural hypotension (10%) (12).

Extrinsic factors

Extrinsic factors are related to medications and environmental hazards (8, 39). Drug use, particularly drugs that act on the central nervous system has been reported to associate with an increased risk of falls, especially psychoactive medications (39). Drug induced falls were commonly associated with sedatives. Forty two percent patients had history of drug intake of which sedatives were the most common drugs that caused falls. The usage of sedatives was 20%, antihypertensive 12%, diuretics 4%, antiparkinson drugs 4% and tricyclic antidepressants 2% (12). Elderly were more likely to take psychoactive medications (38), be on polypharmacy (i.e. multiple medications or four or more prescription medications) and experience drug interactions. Prospective study reported that 18% of the falls were associated with use of alcohol, barbiturates, or sedative hypnotics within 4 hours of the fall. Moderate alcohol intake was associated with having multiple falls. Alcohol use is likely to put the elderly adults at risk of falling due to the effect of alcohol on balance and interaction with other medications (8).

Nonsyncopal falls were most common associated with environmental factors that may have contributed to falls, such as stairs or tripping and slipping hazards. Environmental factors were associated with 61% of falls that occurred away from home and with 33% of those that occurred at home (25). Environmental factors particularly home environments such as common household hazards such as loose rugs/carpets, poor lighting, unsafe stairways, and irregular floor surfaces/uneven floor, lack of bathroom safety equipment, tripping over objects, slippery floors (i.e. slippery toilets), low toilet seats, improper walking aids, carrying heavy or bulky objects and improper footwear (8, 12, 37). Among the extrinsic precipitating causes, the most frequent were slipping, uneven floor surfaces including steps, tripping or stumbling, external forces (such as being pushed) and insufficient illumination (40). Elderly adults reported that one or more environmental factors, such as poor lighting or low seats, interfered with activities of daily living in the home had increased risk of multiple falls in the home (25). Footwear has been reported as a significant contributing factor of falls (4, 8, 13). Previous studies reported that 45-51% of falls and 75% of fall-related hip fracture were associated with inappropriate footwear (9, 15-17)

3. Age-related changes on postural control

Definition of postural control

Postural control is defined as the control of the position of the body in space for the purpose of balance and orientation (21). Postural orientation is defined as the ability to maintain an appropriate relationship between the body segments and between the body and the environment for a task (41). Postural stability or balance is defined as the ability to maintain the Center of Mass (COM) within the Base of Support (BOS), referred to as the stability limits (21). Postural control is a complex process involving the coordinated actions of biomechanical, sensory, motor, and central nervous system components (42).

Requirements for postural control

Postural control requires complex interactions between multiple sensorimotor processes. The central nervous system (CNS) must coordinate motions across many joints and muscles using sensory information provided by visual, somatosensory and vestibular systems to maintain upright stance. The role of different sensory systems changes as a function of task for appropriate stable balance control under different task conditions (43). Figure 1 summarizes 6 important resources important for postural control (44). Deficits in any one or a combination of these systems result in postural instability.

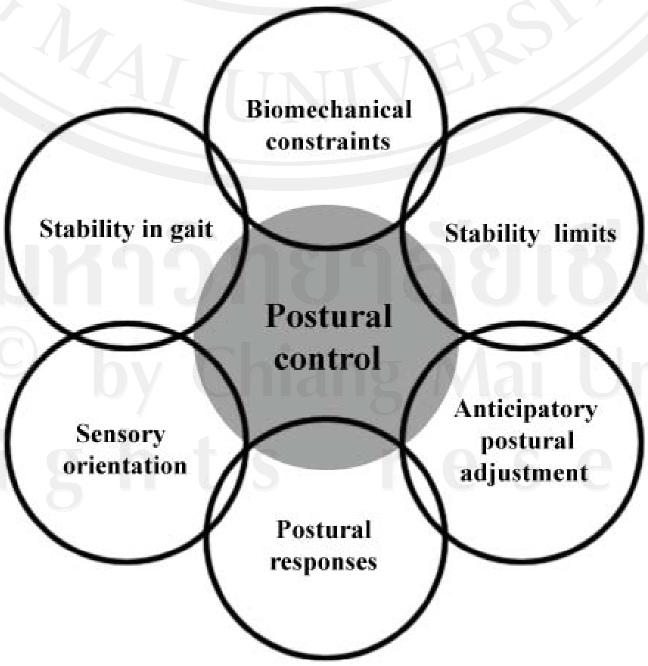

Figure 1 Diagram of summarized systems contributing to postural control (44)

Sensory mechanisms related to postural control consist of visual, somatosensory, and vestibular inputs. Visual inputs report information about the head's position and motion with respect to surrounding objects. Somatosensory inputs report information about the body's position and motion with reference to supporting surfaces. In addition, somatosensory inputs also report information about the relationship between each body segment. The vestibular input is a powerful source for postural control. Vestibular inputs report Information about the head's position and movement with respect to gravity and inertial forces (21).

The role of the biomechanical constraints in postural control is concerning the musculoskeletal components. Limitations in postural alignment, muscle flexibility, muscle strength, muscle tone, range of motion, and pain in the trunk and lower extremity can affect postural control. The ideal postural alignment helps maintain body in equilibrium with the least expenditure of internal energy (21).

An ability to control or adjust the body's center of mass (COM) within the base of support (BOS) is important for postural stability. Limit of stability (LOS) or stability limit is defined as an area a person is able to move safety within BOS without loosing balance. The area of LOS has a cone-liked shape and depends on the area of BOS (both anteroposterior and mediolateral dimensions) (21). This cone shape, LOS is small in elderly with impaired postural control.

Postural control strategies can be classified as ''reactive'' (adaptative) or ''predictive'' (anticipatory) (21). Postural adjustments depend on the integration of sensory feedback from the visual, vestibular and somatosensory systems (45). Balance reaction or adaptive postural control involves modifying sensory and motor systems in response to changing task and environmental demands. Three types of adaptive motor strategies are used in response to perturbation. First, the ankle strategy adjusts the COM to a position of stability through body movement primarily at the ankle joints. This strategy is the first pattern for controlling upright sway. Second, the hip strategy controls motion of the COM by producing large and rapid motion at the hip joints without moving of the ankles joints. Finally, the stepping strategy is used when ankle and hip strategy were insufficient to recover balance. Anticipatory aspects of postural control prepare sensory and motor systems for postural demands based on previous experience and learning (21). Laessoe and Voigt (46) are among many other researchers who investigated age-related changes in anticipatory postural control adjustment. They found that postural control is less automatic in elderly and becomes insufficient during challenged perturbation such as dual tasks.

4. Footwear styles and features and their influences on postural control in elderly

4.1 Footwear Styles

The 7 basic shoe styles are boot, clog, sandal, Oxford, slipper, mule, and moccasin (47). However, a number of footwear styles other than these basic 7 styles have been designed and widely used. In a study by Menz and Sherrington, the additional 8 shoe styles were added into shoe type category. These additional shoe styles were high heel, court shoe, athletic shoe, walking shoe, backless slipper, thong, and surgical/bespoke shoe (Figure 2) (47).

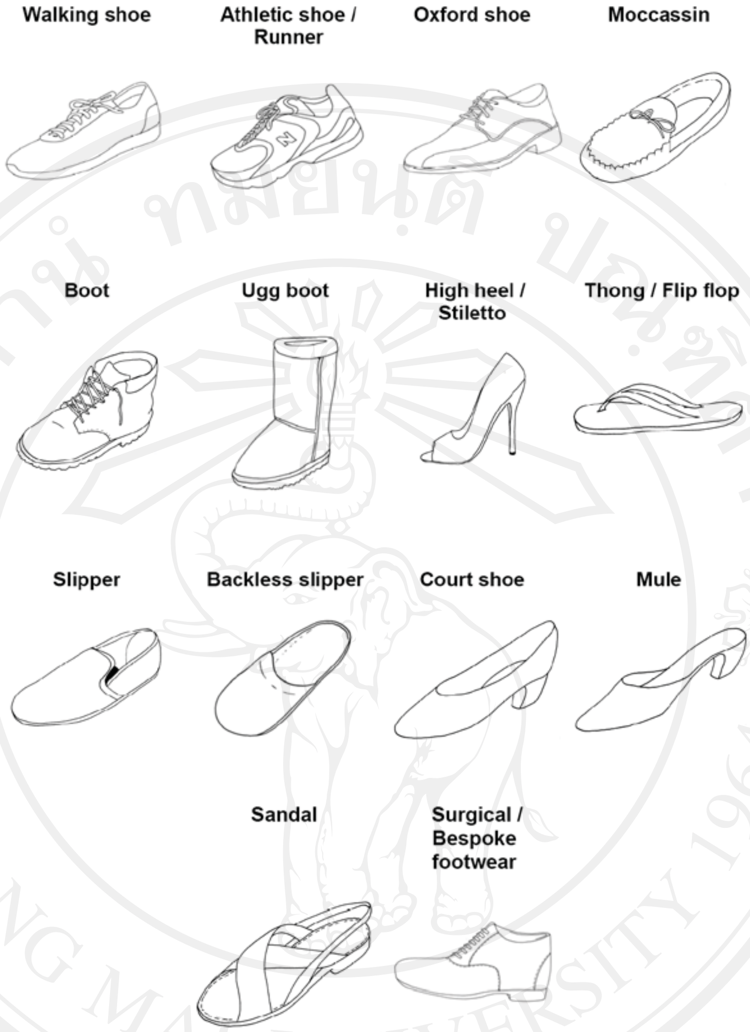

Figure 2 Various shoes styles (47)

Previous study reported that only one-quarter of elderly people in the United State wore proper shoes, which help reduce the risk of falls (4). Falls indoors for elderly people was associated with going barefoot or wearing socks (38). Many recent studies emphasized on the importance of footwear styles for optimal stability. Koepsell and colleague (13) revealed that athletic and canvas shoes (sneakers) were the most commonly worn styles of footwear and associated with lowest risk of falls. Thus, it was recommended to elderly people. Footwear can influence on scores of the standardized measurement of balance and gait. Wearing dress shoes resulted in the worst scores on functional Reach Test (FRT), Timed Up & Go Test (TUG), and 10-Meter Walk Test (TMW) compared to barefooted and walking shoes (48). Many studies investigated the effects of shoe features on balance and gait in elderly people. Each feature of shoes design (Figure 3) can influence postural stability such as heel height, the cushioning properties of the midsole, and the slip resistance of the outer sole (14).

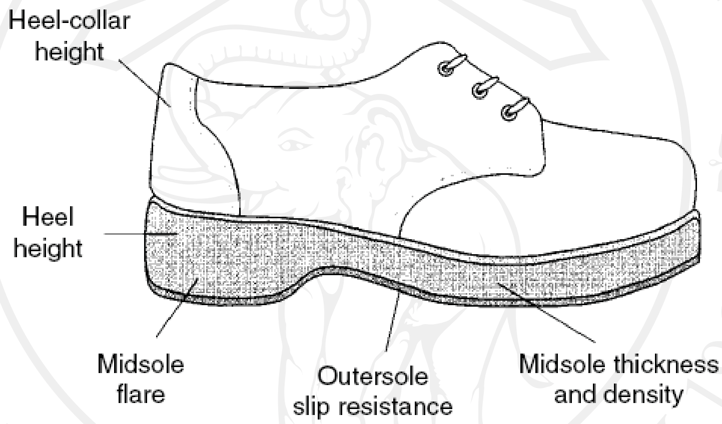

Figure 3 Features of footwear reported to affect postural stability (14).

4.2 Footwear Features

- **Shoes Heel**

Tencer and colleague (49) reported that high heel shoes with 2.5 cm or greater was associated with increased risk of falls, whereas greater sole and surface contact area were associated with decrease risk of falls in elderly people. Similarly, Menant and colleague (50) showed that elevated heel shoes led to 16% increase in postural sway compared to the standard shoes in elderly people. Recently studies (19) investigated the effects of walking surface and shoes features on temporo-spatial gait variables in elderly adults. Findings revealed that wearing the elevated heel shoes resulted in increasing double-support time, heel horizontal velocity at heel strike and toe clearance, and reduced walking velocity as compared to standard shoes. This same group (18) also investigated the effects of various footwear features on dynamic balance control and perceptions of comfort and stability in young compared to older people while walking over even and uneven surfaces. They found that when compared with standard shoes, wearing the elevated heel shoes resulted in increased double support time, step width, and decreased posterior center of mass (COM) - base of support (BOS) margins and braking loading rate. Participants rated for the elevated heel shoes as significantly less comfortable and less stable than the standard shoes. Furthermore, Lord and Bashford (51) investigated the effects of shoes characteristics on balance in women aged 60 to 89 years. Postural sway, maximal balance range, and coordinated stability measures were evaluated while participants were barefoot, wore standard low-heeled shoes (walking shoes), standard high-heeled shoes, and wore their own shoes. Findings revealed that elderly women performed best in barefoot or low-heeled shoes and worst in high-heeled shoes. Therefore, high-heeled shoes have detrimental effects on balance in elderly women.

- **Heel-collar**

High heel-collar led to reduced choice-stepping reaction times (50). Menant and colleagues (52) found that elders who worn high-collar shoes showed approximately 10% reduction in total stopping time at gait termination, especially when walk on wet surface. Thus, this footwear feature provides stability at gait termination for elderly. For temporo-spatial gait variables, wearing raised collar height led to an increased double support time and step width, reduced toe clearance (19), increased lateral

COM-BOS margin, and reduced posterior COM-BOS margin compared to wearing the standard shoes (18).

- **Shoes Sole**

Midsole Cushioning

The midsole cushion for each shoe varies in hardness levels from soft, standard, and hard. Many studies showed that soft sole shoes had detrimental effect on postural control. The soft sole shoes have detrimental effect to balance control during gait termination as they caused longer total stopping time than the standard shoes. These findings suggested that elderly have more difficulty terminate gait rapidly when worn soft sole shoes (52). A previous study (19) found that wearing the soft sole shoes led to greater step width, shorter step length and flatter foot landing in elderly as compared to the standard shoes. This phenomenon was heightened when walking on wet surface. Perry and colleagues (53) studied the effects of various midsole hardness on dynamic balance control between soft, standard, hard, and barefoot. The soft and standard midsole hardness led to decreased in maximum anterior–posterior center of mass (COM) - center of pressure (COP) difference. Increased midsole hardness was related to increase the range of the medial–lateral (center of mass) COM movement. These results suggested that nature of softer midsole material impairs the dynamic balance control system. In contrast, Menant and colleague (18) reported that wearing the soft sole shoes led to greater lateral center of mass (COM) - base of support (BOS) margins, and faster gait speed when compared to standard shoes. More recent studies (18, 19) reported that wearing the hard sole shoes resulted in prolonged double support time compared to the standard shoes, indicating adaptations for improved walking stability.

Midsole Flaring

The midsole flare is defined as the difference between the width of the midsole at the level of the upper and its width at the level of the outer sole (14). Findings on the effects of midsole flaring on gait and postural stability were inconclusive. For example, Menz and Lord (14) found that a flared sole improved medial-lateral stability by increasing base of support (BOS). Menant and colleagues (19) found that a flared sole shoes led to greater step width while walking as compared to the standard shoes. A recent study (50) reported no differences on balance tests (postural sway, maximal balance range, and coordinated stability) and stepping between standard shoes and flared sole shoes in elderly.

Slip Resistance of Shoe Outersoles

Inadequate slip resistance of shoe outersole led to increase risk of slip-related falls (54). Thus, elderly people may benefit from slip-resistant shoes. Tread sole or sole pattern with an indented tread all over the outer sole can potentially affect balance. Elderly walked faster in tread sole shoes than in standard shoes (18). There was also a significant greater step length and step width when walking with the tread sole shoes on the even surface than with the standard shoes (18, 19). One feature of shoes associated with slip resistance of shoes outersole is bevelled heel (Figure 4) (14). Similar to wearing a tread sole, wearing shoes with a bevelled heel led to greater step width compared to the standard shoes, suggesting that it improves walking stability (19). Lloyd and Stevenson found that shoe with a bevel of approximately 10° improved slip resistance by increase surface contact area at heel strike compared to shoe with a square-edged heel (55).

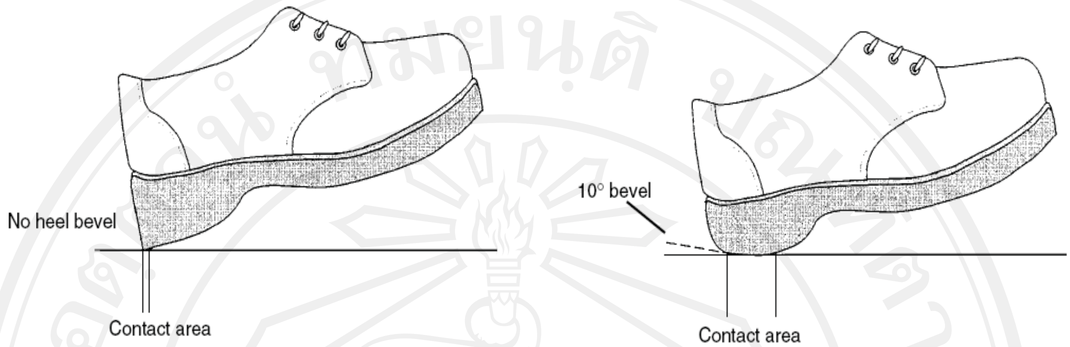

Figure 4 Bevelled heel shoes (14)

5. Measurement of postural control

Currently, several standardized assessment tools for postural control are available for clinical and laboratory testing. The aims of these tools are to identify balance problems or predict fall risk. Given that postural control is very complex and requires interaction of many systems, a single assessment tool is often unable to give comprehensive information on a person's postural control ability. Recently, Horak and colleague developed a new clinical balance tool to assess 6 different balance control systems. This test is called "The Balance Evaluation System Test (BESTest)" (44). The BESTest is, however, very new, consisted of many items (36 items), and has not been widely documented in the literature. This section, we review only the postural control assessments that will be used in the study.

***One-Leg Stance test (OLS)**:* The OLS assesses a person's anticipatory postural adjustment ability. It requires adequate anticipatory postural weight shifting from two-leg to one-leg stance (transition of body's center of mass) (44). The ability to change position from two-leg to one-leg is required in many every day activities such as walking, climbing stairs, and dressing. The OLS assesses postural steadiness in a static position by measuring the time a person can maintain the OLS position. Each standard balance test established different OLS times for its maximal score. For example, a person will get the highest score on OLS if she/he can stand on one leg for at least 10 sec in Berg Balance Scale, 30 sec in Bohannon's balance scale, 5 sec in Tinetti's Balance Test, and 20 sec in BESTest (44, 56-58).

Reach Test*:* The functional and lateral reach tests assess a person's limit of stability in the anterior and lateral directions, respectively. Reduced postural stability is known to be a risk factor for fall in elders. Functional (or anterior) reach test, developed by Duncan, measured the maximum distance an individual can reach forward while standing in a fixed position (59). Limitations of this test are that it is influenced by subject's height and it measures limits of stability only in the anterior direction. Later, Brauer and colleague (60) developed the lateral reach test to assess limits of stability in the lateral direction. The lateral reach test measured the maximum distance an individual can reach laterally while standing in a fixed position. The normative mean values of functional and lateral reach test for elderly aged 60-69 yrs was 36.85±0.53, and 17.11±0.48 cm (mean ± SE), respectively (61).

Modified Clinical Test of Sensory Interaction and balance (mCTSIB): The CTSIB is a timed test that was developed to systematically testing the influence of visual, vestibular, and somatosensory input on standing balance. The CTSIB, as originally designed by Shumway-Cook and Horak included 6 conditions: (1) standing with eyes open on a firm surface, (2) standing with eyes closed on a firm surface, (3) standing with a visual conflict dome on a firm surface, (4) standing with eyes open on a compliant surface, (5) standing with eyes closed on a compliant surface, and (6) standing with a visual conflict dome on a compliant surface (62). However, the mCTSIB does not include the visual conflict dome condition. Therefore, the mCTSIB consists of 4 conditions: (1) standing with eyes open on a firm surface, (2) standing with eyes closed on a firm surface, (3) standing with eyes open on a foam surface, and (4) standing eyes closed on a foam surface (63). The mCTSIB assesses any increase in body sway during stance associated with altering visual or somatosensory information for control of standing balance (44). The time that participants are able to maintain standing in each condition, is recorded for a maximum of 30 seconds (highest score) (64).

Gait speed (10-Meter Walk test; TMW): Stability in gait include an assessment of a person's ability to control balance during gait (44). Gait speed is measured over a relatively short distance, and thus does not include endurance as a factor (65). The TMW measures the time (in seconds) needed to walk for 10 meters. The test is performed on a flat, smooth, and non slippery surface. The participants are instructed to walk at their preferred speed (66). Oberg and colleagues (67) reported that mean normal gait speed for elder women 60-69 years was 115.7±16.7 cm/sec.

Timed Up & Go test (TUG): The Timed Up & Go Test (TUG) is a test of balance that is widely used to examine functional mobility in frail community-dwelling elderly (68). The test was designed primarily to identify persons with balance deficits and elderly with risk of fall (69). The test requires participants to stand up, walk 3.0 meters, turn, walk back and sit down (70). Participants are instructed to walk at their maximum speed and safe pace (71). Time taken to complete the test is strongly correlated to level of functional mobility (68). Elderly persons who take longer than 14 seconds to complete the TUG are at high risk for falls (71). The TUG has been reported to be reliable, sensitive and specific in identifying community-dwelling older adults who are at risk of falls (71).