CHAPTER 2

LITERATURE REVIEW

2.1 Falls in older adults

A fall is commonly defined as an unplanned, unexpected coming to rest on the ground or nearby supporting surfaces such as a chair, a counter, or a wall (6, 16). Approximately 30 % of persons 65 years and older have suffered one or more falls each year (3, 20, 28). Among those aged 75 and older, the falling rate increases to 40 % (4, 5). It has been reported that falling rates are higher in women than in men until the age of 75 years, after which the frequency is similar in both sexes (1). Among fallers aged 65-69 years, 62% report falling outdoors and 38% report falling indoors. In those over 85 years and older, the proportions are 30% and 70 %, respectively (1).

Falls among the elderly are a major health care problem because of their frequency and their physical, psychological, and social consequences (2, 13, 29, 30). It has been reported that falls account for 40% of all accidental deaths (31). According to the Centers for Diseases Control and Prevention (10), an older adult dies every 35 minutes due to a fall. In addition, every 18 seconds, an older adult is treated in the emergency room for fall-related injuries. Non-fatal falls often lead to serious injuries such as a hip fracture, traumatic brain injuries, and upper limb injuries (3). Even when no serious injury occurs, psychological consequences such as fear of falling, loss of self-confidence, and depression are prevalent (29, 32, 33). Fear of falling is often accompanied by social avoidance, self-imposed restrictions in mobility and function, greater use of home services, and nursing home admission, all of which place a substantial burden on older adults, caregivers, and health care resources (13, 29). It has been reported that the medical costs for falls among older adults in the United States was 20 billion dollars in the year 2000 and will reach 54 billion dollars in the year 2020 (10, 11).

Since falls in older adults are associated with serious adverse outcomes, interventions to prevent falls in this population are desperately needed. It has been suggested that a training program which aims toward specific modifiable risk factors will be the most efficient at reducing the incidence of falls (12, 13). Fall risk factors are often categorized into intrinsic (personal) and extrinsic (environmental) factors. Examples of intrinsic factors include balance impairment, neurological disorders, postural hypotension, cognitive impairment, and medication use (1, 13). Examples of extrinsic factors include ill-fitting footwear, poor lighting, slippery surface, and inappropriate furniture (34, 35). Although falls are a multifactorial problem with many intrinsic and extrinsic factors, balance impairment during gait remains the leading cause for falls in the aging population (13, 14).

2.2 Postural control

Postural control is often defined as the control of the body's position in space for the purposes of orientation and stability (36). While postural orientation is the ability to maintain the relative position of the body segments with respect to each other and with respect to the environment, postural stability (also known as balance) is the ability to maintain the body's center of mass in relationship to the base of support (36). The body's center of mass, often located at L4-L5 in quiet stance, is a theoretical point at which all of the body's mass is concentrated. The base of support is the area of the body that is in contact with the support surface (36). Postural control is a fundamental part of all tasks such as sitting, standing, walking, and moving from sitting to standing.

2.2.1 Postural control under dual-task conditions

Traditionally, postural control has been considered an automatic task requiring minimal higher cognitive processing. However, more recent investigations provide evidence that the regulation of posture involves higher cognitive resources (37, 38). Dual-task paradigms, which require participants to perform a postural task and a secondary task simultaneously, have been used to investigate the effect of secondary tasks on postural control. These studies suggest that there are significant attentional requirements for postural control in both stance and gait tasks. In addition, these requirements vary depending on the age of the individual, their balance abilities, and type and level of difficulty of the secondary tasks. Since people tend to lose their balance and fall while walking, a wealth of research has focused on the effect of a secondary task on balance control during gait. Thus, a literature review on dual-task related gait changes as a function of age, balance abilities, and task characteristics is provided in the following sections.

2.2.1.1 Dual-task related gait changes: the role of age

Hollman et al. (7) examined the spatiotemporal gait parameters during single-task walking and dual-task walking in 20 younger adults, 20 middle-aged adults, and 20 older adults. All participants were asked to walk across the walkway at their self-selected speed under two conditions: 1) walking without any secondary tasks; and 2) walking while verbally spelling a five-letter word backward (e.g. spell "earth" backward). The results showed that gait velocity was slower and stride-to-stride variability of gait velocity was greater in the dual-task walking condition compared to the single-task walking condition (Figure 1). In addition, gait velocity was slower and stride-to-stride variability of gait velocity was greater in older adults compared to middle-aged adults and younger adults. More importantly, it was shown that the greatest differences in gait velocity between groups were found in the dual-task walking condition. Thus, it was suggested that a secondary task has a destabilizing effect on gait and that dual-task walking may place older adults at a greater risk of falling.

Beauchet et al. (39) compared stride-to-stride variability in stride length and stride velocity between 12 healthy young adults and 12 healthy older adults when performing single-task walking and dual-task walking (i.e. walking while counting backward by 1 out loud from 50). The results showed no dual-task related gait changes in gait variability among healthy young adults, though an increase in stride length and stride velocity variability was observed in healthy older adults while dual-task walking (Table 1). The authors, then, concluded that the observed increase in variability while dual-task walking among older subjects might be a marker for age-related decline in gait control and might be a sensitive predictor of falls.

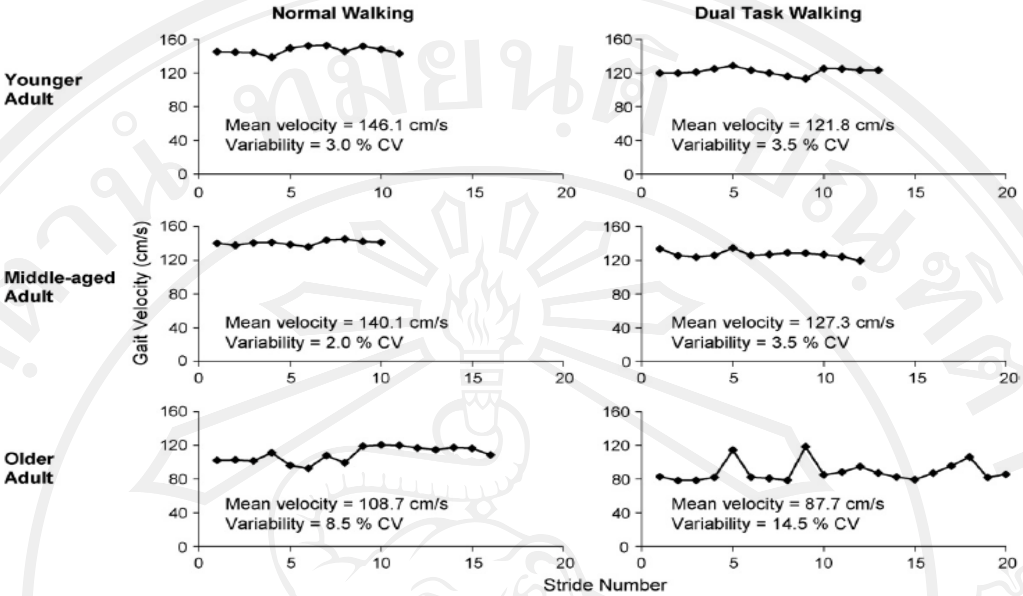

Figure 1 Representative examples of gait velocity and stride-to-stride variability in gait velocity during single-task (normal) walking and dual-task walking (7)

Table 1 Coefficients of variation for stride length and stride velocity (Mean ± SD) among young and older subjects under both walking conditions (39)

Characteristic	Walking Alone	Walking While Backward Counting	P-Value*
Young Subjects (n = 12)			
Stride length CV (%)	2.3 ± 0.8	2.7 ± 1.2	.308
Stride velocity CV (%)	3.2 ± 1.3	3.5 ± 1.8	.638
Old subjects (n = 12)			
Stride length CV (%)	3.9 ± 1.6	10.2 ± 9.3	.023
Stride velocity CV (%)	5.6 ± 2.2	12.5 ± 9.2	.015

2.2.1.2 Dual-task related gait changes: the role of balance ability/fall history

To our knowledge, there are a number of studies examining the effect of balance ability on dual-task performance during stance, but there has been no research investigating the effect of balance ability on dual-task related gait changes. However, several studies have examined the role of a fall history on these changes. For example, Springer et al. (21) investigated the effects of age and fall history on gait variability in 19 young adults, 24 elderly non-fallers (no history of falls), and 17 elderly fallers (≥ 2 falls in the previous year). Four different walking conditions were tested in the study: 1) walking without any secondary tasks; 2) walking while performing the Simple Phoneme Monitoring task (i.e. walking while listening to a text via headphone, and then answering 10 multiple-choice questions); 3) walking while performing the Complex Phoneme Monitoring task (i.e. walking while listening to a text via headphone, and counting the number of times that a prespecified word appeared); and 4) walking while performing the Serial 7 Subtraction (i.e. walking while counting backward by 7s from 500). The results showed an increase in swing time variability under dual-task conditions compared to single-task condition only in the elderly fallers (Figure 2). Thus, it was suggested that a secondary task has a destabilizing effect on gait only in elderly fallers, not in young adults and in elderly non-fallers.

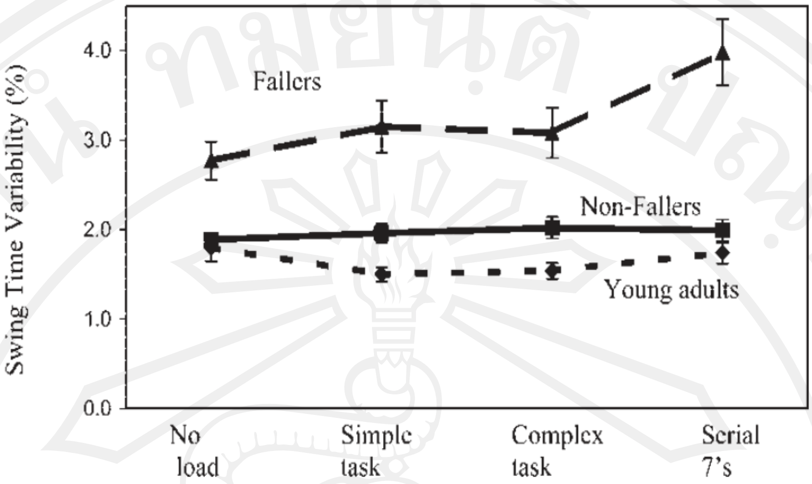

Figure 2 The effects of a secondary task on swing time variability among young adults, elderly non-fallers, and elderly fallers (21)

Toulotte et al. (40) studied gait parameters measured under single- and dual- task conditions in 19 elderly non-fallers and 21 elderly fallers (≥ 1 falls in the 2 preceding years). All participants were asked to walk across the 10 meter walkway under single-task and dual-task conditions in random order. For the single-task condition, participants were asked to walk at their preferred gait speed without any secondary tasks. For the dual-task condition, they were asked to walk at their preferred gait speed with a glass of water in their dominant hand. The results showed that elderly fallers had poorer gait performance (i.e. slower cadence, slower walking speed, longer stride time, longer step time, and longer single-support time) than non-fallers under the dual-task condition (Table 2). No significant differences in these gait parameters were found under the single-task condition.

Table 2 Parameters of walking performance under dual-task conditions for elderly non-fallers and elderly fallers, * $P < 0.05$ significant differences between groups (40)

Dual-task gait performance	Non-fallers	Fallers
Cadence (steps/min)	116 ± 9	107 ± 15*
Walking speed (m/s)	1.08 ± 0.17	0.96 ± 0.19*
Stride time (s)	1.04 ± 0.09	1.14 ± 0.16*
Step time (s)	0.52 ± 0.05	0.56 ± 0.07*
Single support (s)	0.46 ± 0.06	0.55 ± 0.09*
Stride length (m)	1.08 ± 0.18	1.07 ± 0.16
Step length (m)	0.61 ± 0.16	0.53 ± 0.10

2.2.1.3 Dual-task related gait changes: the role of secondary task type

Ebersbach et al. (41) examined the effect of the type of secondary tasks on the control of gait in 10 healthy adults (aged 25 to 42 years). All participants were instructed to walk with their preferred gait speed across a 10 meter walkway under both a single-task condition and four dual-task conditions. The following dual-task conditions were assigned in random order: 1) walking while performing a memory-retention task (i.e. random digits were read to the participants, which participants had to vocalize upon termination of each gait trial); 2) walking while performing a fine motor task (opening and closing a coat button continuously); 3) walking while performing a combination task (i.e. digit-recall and buttoning task simultaneously); and 4) walking while performing a fast finger-tapping task (i.e. opposing first and second fingers of the non-dominant hand quickly and repetitively and operating the button with the index finger of the dominant hand). The results showed an increase in double-support time during walking while simultaneously performing a combination task. In addition, there was a decrease in stride time and an increase in stride frequency during walking while performing a fast finger-tapping task.

Paul et al. (42) also examined the effects of a secondary motor and cognitive task on gait performance in diabetic patients without peripheral neuropathy (DM) (mean age 70±2.9 years) and diabetic patients with peripheral neuropathy (DPN) (mean age 69±3.0 years). All participants were asked to walk under 3 conditions: 1) single-task walking; 2) walking while carrying a tray with cups of water (motor task); and 3) walking while counting backwards by 7s (cognitive task). Gait parameters (i.e. gait speed, step length, step time, double-support time, and cadence) were measured using the GAITRite system. The results showed that there was a significant difference in all gait parameters between the DM and DPN groups. Specifically, patients with DPN demonstrated slower walking, smaller steps, longer step time and double-support time, and slower cadence compared with those with DM. Moreover, the addition of both motor and cognitive tasks had similar adverse effects on gait speed (slower gait speed), step time (longer step time), and cadence (slower cadence). However, step length (smaller steps) and double-support time (longer double-support time) were more affected by the motor task than the cognitive task.

2.2.1.4 Dual-task related gait changes: the role of secondary task difficulty

Armieri et al. (43) examined the effects of complexity and articulation of secondary tasks on spatiotemporal gait parameters in 14 healthy young adults. Each participant was asked to walk 20 feet on the instrumental walkway under 6 dual-task walking conditions: 1) walking while performing a “low complexity” digit span task with “no articulation”; 2) walking while performing a “low complexity” digit span task with “articulation”; 3) walking while performing a “medium complexity” digit span task with “no articulation”; 4) walking while performing a “medium complexity” digit span task with “articulation”; 5) walking while performing a “high complexity” digit span task with “no articulation”; and 6) walking while performing a “high complexity” digit span task with “articulation”. For the digit span task, participants were presented with a digit sequence, asked to memorize it, and then asked to repeat the digits. The complexity of the digit span task was manipulated using three blocks of random, non-repeating sequences of three (low complexity), five (medium complexity), and seven (high complexity) digits in length. Articulation was manipulated by having participants continually rehearse the digits either out loud (with articulation), or silently (no articulation) during walking. The results showed that the effects of task complexity were most pronounced under the “with articulation” condition compared to the “no articulation” condition. In addition, there was an increase in gait speed and a decrease in step length in the “high” complexity condition compared to the “low” and the “medium” complexity conditions.

Allali et al. (44) investigated the effects of level of difficulty of two mental arithmetic tasks involving similar articulo-motor components on the mean values and coefficient of variation (CV) of stride time among 16 older adults with frontal lobe dysfunction. All participants were asked to walk along a 10 meter walkway under 3 walking conditions in random order: 1) single-task walking; 2) walking while counting forward; and 3) walking while counting backward. The results showed that the mean values and CV of stride time increased significantly under both dual-task conditions compared to the single-task condition. In addition, stride time during backward counting was significantly higher than during forward counting (Table 3). Therefore, it was suggested that backward counting is more difficult than forward counting. Consequently walking with backward counting provoked higher increase in stride parameters than walking with forward counting.

2.2.2 Association between dual-task gait performance and recurrent falls

It has been shown that dual-task balance performance is associated with the number of retrospective falls in older adults. For example, Faulkner et al. (16) investigated the association between dual-task gait performance and the history of recurrent falls in 377 community-dwelling older adults. The participants were asked to perform a "straight walk" and a "turn walk" task with and without a visual spatial decision task. For a "straight walk" test, the participants were asked to walk down a straight 20 meter corridor. For a "turn walk" test, they were asked to walk for 20 meters with a turn at the 10 meter mark point. Walking times were recorded for both walking conditions. In addition, the participants were interviewed regarding the number of falls in the previous 12 months. The results showed that slower walking speed under dual-task condition (compared to single-task condition) was associated with 34% and 42% higher odds of recurrent falls history on the straight and turn walks, respectively. Thus, it was suggested that older adults who walked more slowly under dual-task conditions were at a greater chance of having multiple falls.

The association between dual-task gait performance and the number of prospective falls has also been investigated. Beauchet et al. (22) determined whether dual-task related gait changes were associated with recurrent falls in 213 frail older adults. Participants were asked to walk 10 meters at their self-selected speed under 2 task conditions: 1) single-task walking; and 2) dual-task walking (i.e. walking while counting backward by 1 aloud starting from 50). Walking speed was measured using a stopwatch. In addition, information about incident falls during the 1 year follow-up was collected by telephone each month. Participants were divided into three groups based on the occurrence of falls: no fall (0 fall), single fall (1 fall), and recurrent falls (≥2 falls). The results showed that a decrease in walking speed corresponded with an increase in the risk of recurrent falls, by a factor of 4.2% for single-task walking and 66.7% for dual-task walking. However, after adjusting for walking speed, age, and number of drugs used, it was shown that only walking speed under dual-task condition was associated with incident falls.

Table 3 Mean values and coefficients of variation of stride time parameters under walking with counting forward and backward conditions among demented older adults (n=16) (44)

	Dual-task conditions	
	Walking while counting	
Stride time	Forward	Backward
Mean value (ms)	1336.0 ± 304.1	1497.0 ± 323.5*
CV (%)	7.6 ± 10.0	15.4 ± 16.2*

2.3 Ability to allocate attention

There is growing evidence suggesting that falls in older adults occurring under dual-task situations may be caused by the reduced ability to allocate attention between tasks, specifically to give postural stability a top priority when needed (24-27). Yogev-Seligmann et al (27) examined the ability to allocate attention between a postural task (i.e. walking) and a cognitive task (i.e. verbal fluency, VF) in 40 healthy young adults and 17 healthy older adults. All participants were asked to walk at their preferred pace along a 30 meter corridor under 4 conditions: 1) walking without any secondary tasks; 2) walking while performing a VF task with no explicit instruction for prioritization (no priority); 3) walking while performing a VF task with gait priority (gait priority); and 4) walking while performing a VF task with cognitive priority (cognitive priority). For the gait priority condition, participants were told to "concentrate mainly on the gait task" and to "walk as if they were not simultaneously performing a cognitive task". For the cognitive priority condition, they were asked to "match their performance on the VF task (recall as many words as possible beginning with a predefined letter) to the sitting, single-task condition". The results showed that only young adults significantly increased their gait speed in the "gait priority" condition compared with gait speed in the "no priority" condition. In addition, there was a tendency in young adults toward a decrease in gait speed in the "cognitive priority" condition compared with gait speed in the "no priority" condition. Moreover, when prioritization was not given, gait speed was similar to those seen in the "cognitive priority" condition in both age groups (Figure 3). It was then suggested that there was an age-associated decline in the ability to flexibly allocate attention between tasks and that both healthy young and older adults may not give postural stability a top priority.

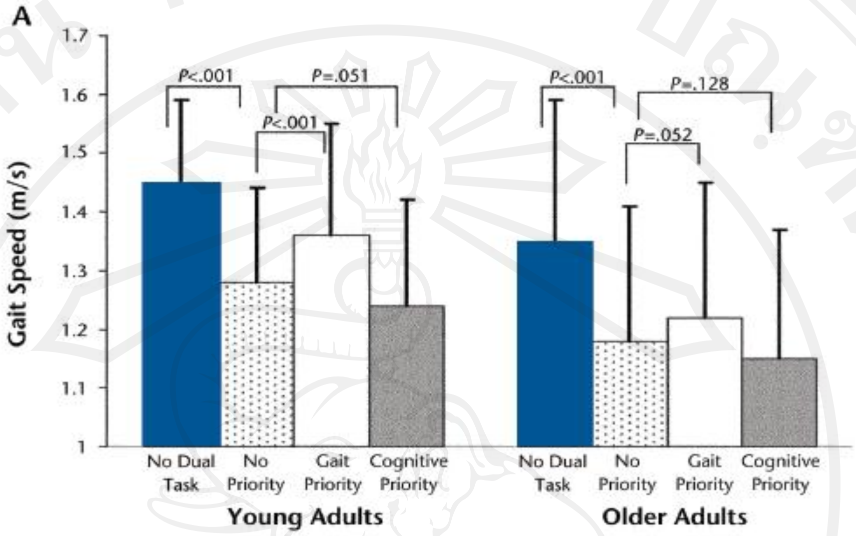

Figure 3 The effect of dual task and three prioritization conditions on gait speed in healthy young adults and healthy older adults (27)

Siu et al. (24, 25) investigated the ability to flexibly allocate attention between a postural task and a cognitive task under 3 different instructional sets (i.e. no priority focus, focus on postural task, and focus on cognitive task) in 12 healthy young adults (HYA), 12 healthy older adults (HOA), and 12 older adults with balance impairment (BIOA). All participants were instructed to perform an obstacle avoidance task with and without an auditory Stroop task. For the obstacle avoidance task, individuals were instructed to walk and step over an obstacle (10% body height), which was placed at the 6 meter mark. For the auditory Stroop task, the words “high” and “low” (spoken at a high or a low pitch) were presented and the participants were asked to report the pitch of the voice as quickly and accurately as possible while ignoring the meaning of the words. For the “no priority focus” condition (NF), participants were asked to focus on both tasks equally. For the "focus on obstacle crossing task" condition (FO), they were asked to prioritize their focus on the obstacle crossing task and try not to hit the obstacle while maintaining stability. Finally, for the "focus on Stroop task" condition (FS), they were asked to prioritize their focus on the Stroop task and to respond to the task as fast and as accurate as possible. An attentional allocation index (AAI) was computed for each variables. The AAI was derived from the following equation: (O-S)/N, where O refers to the outcome measures in the "FO" condition, S refers to the outcome measures in the "FS" condition, and N refers to the outcome measures in the "NF" condition. The primary outcome variables for the postural and cognitive task were gait velocity (GV) and verbal response time (VRT), respectively.

The results showed that both HYA and HOA increased their VRT when the priority was shifted to the obstacle avoidance task and decreased their VRT when priority was given to the auditory Stroop task (Figure 4a). In addition, both age groups decreased their gait speed when the priority was shifted to the obstacle avoidance task and increased their gait speed when priority was given to the auditory Stroop task (Figure 4b). Thus, it was suggested that both healthy young and older adults were able to shift their attention between the obstacle avoidance task and the auditory Stroop task according to instructions. However, BIOA did not significantly decrease or increase their GV and VRT according to instructions (Figure 5a and 5b). Moreover, the overall distribution of AAI values was somewhat smaller and more centered for BIOA than HOA (Figure 6). Thus, it was suggested that only older adults with balance impairment showed deficits in flexibly allocating their attention between two tasks according to instruction.

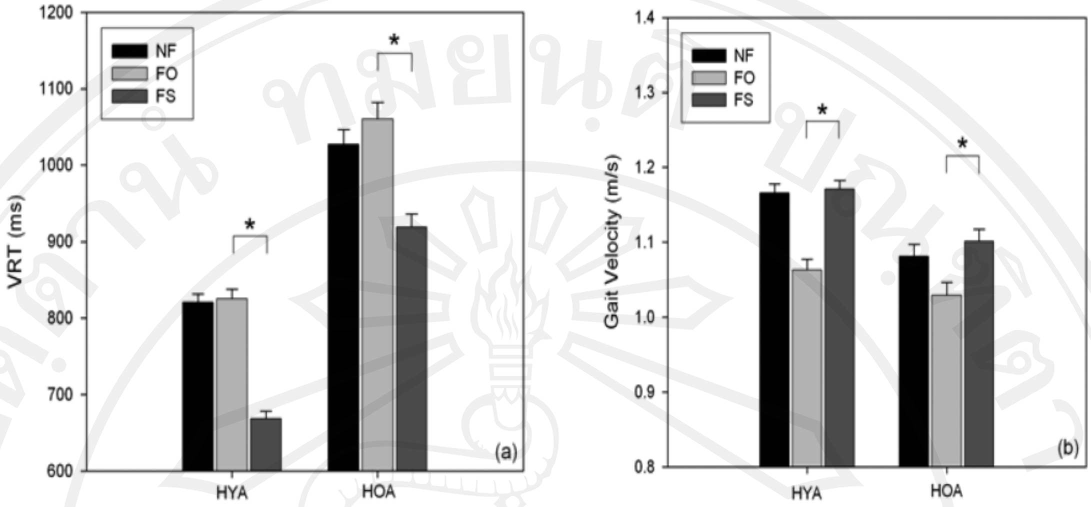

Figure 4 Performance in verbal response time (a) and gait velocity (b) in healthy young adults (HYA) and healthy older adults (HOA) under three instructional conditions (24)

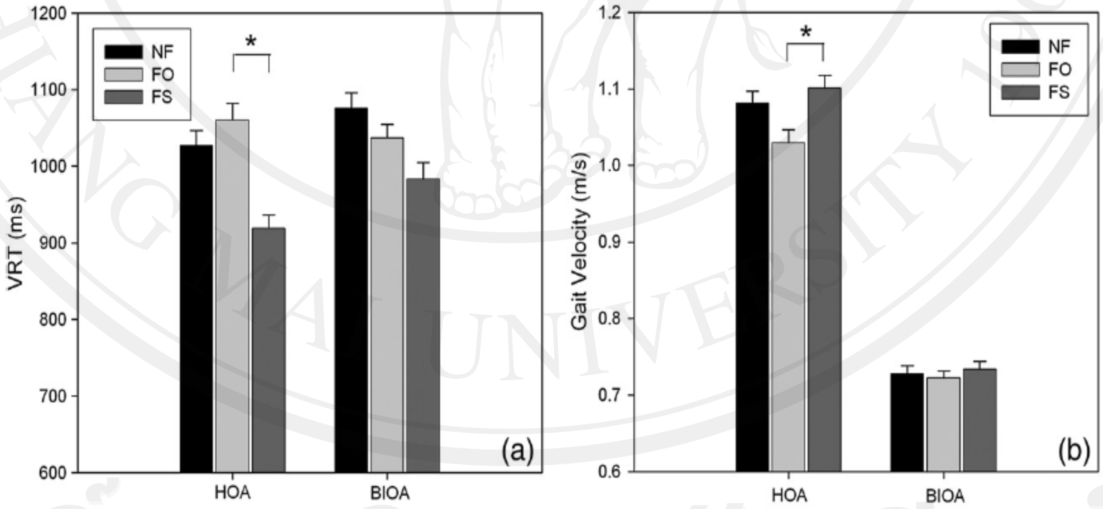

Figure 5 Performance in verbal response time (a) and gait velocity (b) in healthy older adults (HOA) and older adults with balance impairments (BIOA) under three instructional conditions (25)

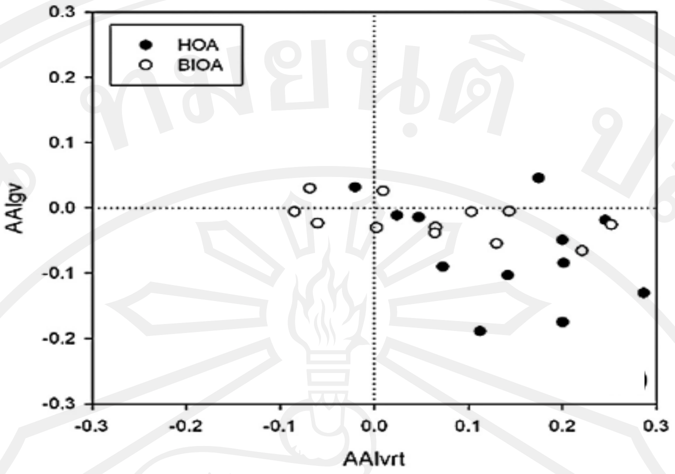

Figure 6 Attentional allocation index (AAI) for healthy older adults (HOA) and older adults with balance impairments (BIOA): AAIvrt = AAI value of VRT; AAIgv = AAI value of GV (25)

To date, little is known about the potential factors contributing to the ability to allocate attention during gait in older adults. Yogev-Seligmann et al. (27) suggested that there was an age-related decline in the ability to flexibly allocate attention between level walking and verbal fluency tasks. Siu et al. (24, 25) found that only older adults with balance impairment were unable to shift their attention between obstacle avoidance and auditory Stroop tasks. Neither study was directly designed to explore the potential factors that could possibly contribute to the ability to allocate attention during level walking. Thus, the purpose of this study was to investigate the ability to allocate attention during gait as a function of age, balance ability, and secondary task characteristics.