EFFECT OF SOUND AND VISION ON BALANCE PERFORMANCE

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EFFECT OF SOUND AND VISION ON BALANCE PERFORMANCE

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ABSTRACT

Postural control is important to human movement and acting in daily living. Sensory systems including the visual, vestibular and proprioceptive systems are significant components of the postural control mechanism. The auditory system also appears to influence postural control.

The aim of this study was to investigate the effect of sound and vision on balance performance. Fifty Thai women aged between 20 and 35 years participated in the study. Balance performance was examined by using the SMART Balance Master System. A total of 12 conditions were examined: eyes open, eyes open with sound on left ear, eyes open with sound on right ear, left eye closed, left eye closed with sound on left ear, left eye closed with sound on right ear, right eye closed, right eye closed with sound on left ear, right eye closed with sound on right ear, eyes closed, eyes closed with sound on left ear and eyes closed with sound on right ear. The parameters of the present study were the center of gravity (COG), sway excursion in the anteroposterior (AP) and the mediolateral (ML) directions, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy.

The results demonstrated the visual-auditory interaction inducing an increase in COG sway excursion in the AP direction and a decrease in the percentage of maximum stability. The visual feedback was more dominant than the auditory input at the left ear. Additionally, the auditory input at the right ear appeared to disturb the COG sway excursion in the AP direction when there was full visual feedback. When loss of visual feedback from both eyes or an eye occurred, postural destabilization was observed in all parameters. Moreover, the auditory input influenced postural control in the COG sway in the ML direction.

In conclusion, the interaction and individual effects of the visual and the auditory inputs affect postural balance performance. It is suggested that the visual input is more dominant than the auditory input in controlling posture.

KEY WORDS: POSTURAL CONTROL/ POSTURAL INSTABILITY/
VISION/ AUDITORY

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ผลของเสียงและการมองเห็นต่อความสามารถในการทรงตัว (EFFECT OF SOUND AND VISION ON BALANCE PERFORMANCE)

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บทคัดย่อ

การควบคุมการทรงตัวเป็นส่วนสำคัญในการเคลื่อนไหวและทำกิจวัตรประจำวันต่างๆ ระบบรับความรู้สึกเป็นส่วนหนึ่งซึ่งมีความสำคัญในกลไกการควบคุมการทรงตัว ซึ่งประกอบไปด้วย ระบบการมองเห็น, ระบบการควบคุมการทรงตัวผ่านทางหูชั้นใน และระบบการรับสัมผัสผ่านทางข้อต่อ นอกจากนั้นระบบการได้ยินเป็นอีกระบบที่มีอิทธิพลต่อการทรงตัว

การศึกษาครั้งนี้มีวัตถุประสงค์ที่จะศึกษาผลของเสียงและการมองเห็นต่อความสามารถในการทรงตัว ผู้เข้าร่วมการศึกษาครั้งนี้เป็นหญิงไทย จำนวน 50 คน มีช่วงอายุระหว่าง 20 ถึง 35 ปี ทดสอบการทรงตัวโดยใช้เครื่อง Smart Balance Master การทดสอบมีทั้งหมด 12 รูปแบบ คือ เปิดตาทั้งสองข้าง, เปิดตาทั้งสองข้างร่วมกับเสียงที่หูซ้าย, เปิดตาทั้งสองข้างร่วมกับเสียงที่หูขวา, ปิดตาซ้าย, ปิดตาซ้ายร่วมกับเสียงที่หูซ้าย, ปิดตาซ้ายร่วมกับเสียงที่หูขวา, ปิดตาขวา, ปิดตาขวาร่วมกับเสียงที่หูซ้าย, ปิดตาขวาร่วมกับเสียงที่หูขวา, ปิดตาทั้งสองข้าง, ปิดตาทั้งสองข้างร่วมกับเสียงที่หูซ้าย และปิดตาทั้งสองข้างร่วมกับเสียงที่หูขวา ตัวแปรที่ใช้ในการศึกษา คือ การเคลื่อนที่ของจุดศูนย์ถ่วงร่างกายในทิศทางหน้า-หลัง และซ้าย-ขวา, ความเร็วเฉลี่ยของการเอนเอียง, ร้อยละความมั่นคงสูงสุด และร้อยละกลไกการใช้ข้อเท้า

ผลการศึกษาพบว่า ปฏิสัมพันธ์ระหว่างเสียงและการมองเห็นมีผลเพิ่มการเคลื่อนที่ของจุดศูนย์ถ่วงร่างกายในทิศทางหน้า-หลัง และลดร้อยละความมั่นคงสูงสุด ข้อมูลจากระบบการมองเห็นเด่นกว่าข้อมูลจากระบบการได้ยินที่หูซ้าย นอกจากนี้ข้อมูลจากระบบการได้ยินที่หูขวาดูเหมือนจะรบกวนการเคลื่อนที่ของจุดศูนย์ถ่วงร่างกายในทิศทางหน้า-หลังเมื่อมีข้อมูลจากระบบการมองเห็นเต็มที่ เมื่อสูญเสียข้อมูลจากระบบการมองเห็นจากตาทั้งสองข้างหรือข้างเดียว พบความไม่มั่นคงในการทรงตัวในทุกตัวแปรที่ใช้ในการศึกษา นอกจากนั้นยังพบว่า ข้อมูลจากระบบการได้ยินมีผลต่อการทรงตัวในการเคลื่อนที่ของจุดศูนย์ถ่วงร่างกายในทิศทางซ้าย-ขวา

โดยสรุป ผลของเสียงและการมองเห็น และปฏิสัมพันธ์ระหว่างเสียงและการมองเห็นส่งผลต่อความสามารถในการทรงตัว การศึกษานี้เสนอว่า ข้อมูลจากระบบการมองเห็นเด่นกว่าข้อมูลจากระบบการได้ยินในการควบคุมการทรงตัว

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LIST OF ABBREVIATIONS

COG	= Center of Gravity
ML	= medio-lateral
AP	= antero-posterior
Hz	= Hertz
dB	= Decibels
EO	= Eyes open
EC	= Eyes closed
LEC	= Left eye closed
REC	= Right eye closed
EOLS	= Eyes open with sound on left ear
EORS	= Eyes open with sound on right ear
ECLS	= Eyes closed with sound on left ear
ECRS	= Eyes closed with sound on right ear
LECLS	= Left eye closed with sound on left ear
LECRS	= Left eye closed with sound on right ear
RECLS	= Right eye closed with sound on left ear
RECRS	= Right eye closed with sound on right ear
NS	= No sound
LS	= Sound on left ear
RS	= Sound on right ear

CHAPTER I
INTRODUCTION

The ability to control the body's position in space while performing various activities such as quiet standing, walking, or complex tasks is due to postural control system. Postural control is defined as the ability to maintain the body's center of mass over the base of support (1-3) and required integration of the sensory inputs, motor control and the higher level processes that is essential for postural adaptation and anticipation (4). The ability to stand erect is regulated predominantly by visual, proprioceptive and vestibular afferent information, which is itself organized in a dominant hierarchical manner (5).

The visual cue plays an important role in the stabilization of posture by providing the nervous system with continually update information about the position and movement of the body segments in relation to each other and the environments (5-9). Postural instability can occur during the conflict of self-motion and external motion (6). For example, a study of the influence of moving visual surround on postural control showed the large amplitude of body sway when visual surround motion was in conflict with body motion (10). Bronstein's study in 1986 (11) has shown that vision is initially dominant in sway control during the presence of conflict between different sensory cues. Moreover, in the patients with a reduction in proprioceptive sense e.g. peripheral neuropathy or patients with vestibular input reduction, the postural control is greater relied on visual information (6, 12, 13).

Normally, postural balance was deteriorated when loss of visual feedback such as in the eyes open condition compare with eyes closed condition (14, 15) or in the blind people compare with normal adults (16, 17). The disturbance of equilibrium was found in the patients with visual defect. For example, the reduction of visual acuity leads to increase in postural sway in anteroposterior (AP) direction greater than mediolateral (ML) direction (5, 7). In addition, the impaired postural control in patients affected by congenital nystagmus is mainly due to ocular oscillation, with reduced visual acuity creating a second effect (18-20). However, Jahn in 2002 (21) found that the suppression of nystagmus can reduced postural sway. Hemianopia patients who have defect of visual field, showed the error in identifying objects on the ipsilateral side than the contralateral side of the lesion in the brain (22). Furthermore, Rondot's study in 1992 (23) demonstrated that lateral sway increased in hemianopia patients during standing posture. Moreover, the projection of the body's center of gravity shifted toward the effected side. However, in healthy adults there is no report in loss of visual feedback from an eye on postural control.

Although it is widely accepted that a constant interplay between visual, vestibular and proprioceptive information provides the basic for the maintenance and control posture. However, postural control remains plastic and can be modified with practice (24). Recently, Horak in 2001 (25) supported the hypothesis that postural compensation including; sensory substitution, predictive mechanism and increase sensitivity of remaining sensory information. These can be used when postural destabilization occurred in various conditions. There is evidence to suggest that the auditory environments and auditory feedback can also influence sway behavior (26).

The auditory system enables us to identify sound signal and to locate sound source (27). Hearing is the afferent sensory information provides a basic for orientation in space. Human with normal hearing can use the various of sound in daily life as warning signal or to facilitate orientation in space such as that found in the blind people (28). In addition, auditory cues can be used to indicate perturbations onset and then can trigger functional postural response (29). Kilburn et al in 1992 (30) reported that the workers exposed to noise at work have greater speed of sway more than the normal subjects. In addition, Juntunen in 1987 (31) revealed that the subjects with more severe hearing loss showed more sway than subjects with less hearing loss and healthy adult. The study of influence of auditory input on postural control in normal adult (28, 32) in the blind (17) and in the stroke patients (29) showed that the auditory input and the auditory feedback can reduce the postural sway. However, Raper and

Soames reported that either stationary and moving auditory field have a destabilizing influence on postural sway behavior (26, 33).

Neurophysiological recording in the primate superior colliculus have suggested that spatiotopic maps of visual and auditory space superimposed in multimodal midbrain area (34, 35). Several studies found that eye movements can be induced by acoustic signal (36, 37). Therefore, the interaction between visual and auditory pathway should present in cerebral cortex. However, it is reported that there is no interaction between auditory and vision in postural stabilization (33, 37). Owing to Horak's hypothesis about the sensory compensation in impaired postural control (25), the auditory input may compensate for postural adaptation in some visual defect conditions.

Therefore, the present study examined the individual effect of auditory and visual input on balance performance. In addition, the interactive effect of stationary auditory input and visual input on postural maintenance was determined.

Purpose of the Study

General Objective

To determine the interactive and individual effects of stationary auditory and visual inputs on balance performances.

Specific Objectives

1. To determine the interaction between auditory and visual inputs on balance performance.
2. To determine and compare balance performances when there was visual input in both eyes, an eye and no visual input
3. To determine and compare balance performance when there was auditory input in either left or right ear.

Parameters of the Study

1. COG sway excursion in anteroposterior direction (mm.): a total distance of COG sway in anteraposterior direction, which could be measured on printout.

2. COG sway excursion in mediolateral direction (mm.): a total distance of COG sway in mediolateral direction, which could be measured on printout.

3. Average velocity (degree/sec): the mean sway velocity of the center of gravity (COG), which including both anteroposterior and mediolateral direction.

4. Percentage of maximum stability (%): The amount of stability, which 100% represent no sway and 0% indicates loss of balance.

5. Percentage of ankle strategy (%): the percentages of total use of ankle strategy to stabilize posture during testing.

Scope of the Study

This study determined the interactive effects of the stationary auditory and visual inputs on balance performance in healthy women. It was also investigated individual effect of auditory and visual inputs on balance performance. The balance performance was measured by Smart Balance Master system.

Hypotheses of the Study

1. There was significant interaction effect of auditory and visual inputs on COG sway excursion in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy.

2. There were significant individual effect of visual input on COG sway excursion in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy.

3. There were significant individual effect of auditory input on COG sway excursion in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy.

Advantages of the Study

The results of this study provided the understanding of the effect of visual feedback and auditory input on postural control in normal subjects. Moreover, it can be applied as one of the rehabilitation programs in subjects with loss of balance.

CHAPTER II
LITERATURE REVIEW

2.1 Postural Control and Balance

2.1.1 Definitions

2.1.1.1 Balance and postural control definitions

The term balance is used in mechanic, defined as the state of an object when the resultant force acting upon it is zero (38). The ability of an object to balance is related to the position of the center of mass and the area of the base of support of that object. If the line of gravity of an object fall within the base of support of that object then the object is balance. In the same way, a body is in a state of balance or equilibrium when the projection line of its center of gravity fall within the base of support and when the resultant of all force that acting it is zero (39, 40). In addition, the human balance is referred to the ability of person not to fall (41, 42). In another way, balance is defined as a complex function requiring the central processing of multiple sensory inputs that leads to specific response selection and expression involving pattern of muscle activity to keep the body weight over the base of support (3). Balance is often described as a complex motor skill and is also often referred to as postural control (39).

Horak defined postural control as the ability to maintain equilibrium in a gravitational field by keeping the center of mass over the base of support (43). In the same way, many authors defined postural control as the ability to maintain or control the body’s center of gravity over the base of support during quiet standing and movement (2). Moreover, Pollock et al gave the definition as the act of maintaining, achieving or restoring to a state of balance during posture or activity (44).

2.1.1.2 Postural sway

In normal stance, the body movement is like an inverted pendulum that oscillating around the ankle joint. The continuous body sway is occurred by the disturbation from the process of respiratory, circulation and external force such as gravity (45). Postural sway, as defined by Swift, is continuous corrective movement around the center of gravity of a body, designed to maintain postural control in the upright position while stand still (46). Moreover, the spontaneous postural sway is also produced by the muscle tone, which keeps the body from the displacement of the COG in response to the pull of gravity (4). In the normal standing, the COG moves continuously in the anteroposterior direction more than in the mediolateral direction (45).

2.2 The Mechanism of Postural Control

Postural control is a complicated function requiring central processing of multiple sensory inputs from somatosensory, vestibular and visual system. The processing causes the specific response operating the pattern of muscle activity all over the body, maintaining the body's position, adjusting posture to move voluntary and protects against outside perturbation (3). Therefore, the mechanism of postural control requires an integration of sensory system, motor system and central nervous system.

2.2.1 Sensory system

The senses that perceive the orientation in relation to gravity, support surface and surrounding objects require the individual and combination of information from the vestibular system, somatosensory system and visual system.

Vestibular system consists of semicircular canal, saccule and utricle, which located in the inner ear. Semicircular canal is sensitized by movement of head. Saccule and utricle provide signals about the orientation of head to the gravity. Therefore, vestibular system provides the information about head position corresponding to gravity and head acceleration or deceleration. Furthermore, this system has two roles in motor control, that are gaze stabilization and postural adjustment (4). In situation of head and external environment is in the motion, sometimes visual and proprioceptive information are not sufficient for central nervous system to distinguish. Therefore, postural balance required visual, somatosensory and vestibular clues to work together. Vestibular systems have frequency range that affects to postural sway in difference situation. The semicircular canals have a sensory threshold during stance in range 0.5 to 1.0 Hz. While the otolith organs are used below 0.5 Hz. (6). The perception of vestibular system was slower than the somatosensory and vision system (47).

Dichgans studied the contribution of vestibulo-spinal mechanism to the maintenance of upright posture. The loss of vestibular function not only effect to destabilization, but also interfere with the selection of preprogrammed motor synergies (48). In the patient with central nervous disorder showed a significant increase in sway velocity of both anteroposterior and mediolateral direction when compare with normal subjects.

Shupert and Horak in 1996 (49) studied the effect of vestibular loss on head stabilization in response to head and body perturbation in 13 normal subjects and 4 patients with bilateral vestibular loss. The result showed that patients with vestibular loss in adulthood showed increasing head acceleration in response to both head and body perturbation, but patients with vestibular loss in infancy showed more normal head acceleration when compare with normal subjects. Body perturbation, poor head control during the execution of postural response and increase trunk angle in patients for forward body perturbation when compare with normal subject. These result indicate that the vestibular system play an important role in head and trunk stabilization.

Somatosensory system provides information concerning movement of body segment with reference to each other through plantar mechanoreceptors, joint receptors and muscle receptors (27). Somatosensation perceive a wide variety of movement from slow to fast. During stance, somatosensation from ankle joint and feet has been shown to contribute to standing postural stability at frequencies greater 0.1

Hz. (6). The effectiveness of somatosensory system could be altered in several situations. Standing on compliant surfaces or foam could change the input to both joint receptor and cutaneous mechanoreceptor in the foot, while the muscle receptors in the stretched muscle are keeping on (50).

Kavounoudias et al in 1999 (51) studied the role of muscle proprioceptive information on balance regulation. Proprioceptive stimulation was delivered by mechanical vibrator at neck and ankle muscle. The result showed that the body sway was always in the contralateral direction with respect to the vibrated muscle site at the neck level. On the other hand, ankle muscle vibration gave rise to the postural response ipsilaterally with respect to the vibrated muscle site. In addition, the result of neck and ankle muscle were simultaneously vibrated, demonstrated the sum of the responses obtained when the vibration was applied separately to each of the muscle group. The study concludes that the multiple proprioceptive inputs originating from either one or both body levels may be co-processed in term of vector-addition laws. Moreover, the proprioceptive informations from ankle and neck muscle were used for balance control and body orientation.

McChesney and Woollacott examined the effect of a decrease in threshold joint position sense (TJPS) at the knee and ankle, and of total knee replacement (TKR) on postural control in older adult. They found that a decrease in TJPS in knee and ankle was correlated to increased COP displacement amplitude and velocity in a anteroposterior (AP) and mediolateral (ML) direction during quiet stance. However, no significant difference of the COP amplitude in AP or ML direction and velocity in TKR subjects when compare with normal subjects. It is suggested that joint proprioceptive input provided significantly to static balance control (52).

In aging, the sensory status in the lower limbs plays an important role for postural control (53). Moreover, the loss of cutaneous sensation which appear to correlate with impair postural control and increase risk of fall (54). In the same way, the diabetic patients with cutaneous sensory deficit in the foot has significant postural instability when compare with normal subjects (55, 56). Impaired proprioceptive sensory input from the lower legs in polyneuropathy patients altered balance correction response in ankle muscle, while the response in moving proximal body segment such as the trunk was normal. These indicated that lower legs propriception was not required to trigger all balance corrections (57).

Vision of human come about the image of the object being viewed on the retina of the eye, which received information about form and color from photoreceptor. The impulses from the retina pass through the optic nerves. All fibers from opposite nasal of retina cross and join with fibers from the temporal retina of the same side to form optic tract. The point of crossing the optic nerve calls optic chiasma. The fiber from optic tract will synapse in lateral geniculate body of hypothalamus and pass to visual cortex of occipital lobe (area 17). Visual fibers also pass to the brain, hypothalamus, superior colliculus and pretectal area (58).

The role of visual system is the sight. In addition, it play an important role in the stabilization of posture by providing the nervous system with continually updated information about the position and movements of body segment in relation to each other and the environment (5-9). Sometimes, there is conflict between self motion and external motion. As a result postural instability can occur. For instance, the studied of the influence of moving visual surround on postural control showed the large amplitude of body sway when visual surround motion was in conflict with body motion (10). Moreover, in the conflict between different sensory clues, vision is initially dominant in sway control (11). Talbott stated that the sensory control of body sway is hierarchically organized, vision normally dominates over proprioceptive information from the lower limbs. However, this arrangement can be quickly reversed depending upon the changing conditions in the environment (59). The contribution of visual input to control of postural sway is particular importance when proprioceptive feedback is reduced (8). For example, in the above knee amputee patient it was found that mean of sway in the amputee patient was greater than normal subjects with the eyes closed (12). In the condition of lower limbs muscular fatigue, the availability of visual cues becomes a great importance for an appropriate control of stance (13).

The role of visual effect to stabilize posture was studied by Palus et al in 1987 (7). Influence of visual input consists of visual acuity, eye-target distance and visual input rate. The result showed slightly increase in AP and ML sway at 33, 50 and 100 cm. eye-background distance. However, at 2 m. distance, AP body sway increase. For the visual acuity, balance performance significantly deteriorated with visual acuity below 0.3. Furthermore, body sway increased in AP direction more than the ML during decreasing flicker frequencies of illumination of the background. This study confirmed the importance of eye-object distance and visual acuity for stabilize posture. Similarly to the previous studied (7) visual acuity cause a linear increasing postural instability twice prominent for the AP than ML sway. Furthermore, the central area of visual field exhibits a powerful contribution of postural control more than peripheral visual field (5).

Day et al in 1993 studied the effect of vision and stance width on human body motion. It was found that the speed of body sway was increased by closing the eyes or narrowing the stance width. In addition, there was an interaction between these two factors such that vision reduced lateral body speed of sway more effectively when the feet were closed together. Moreover, the effect of stance width increase fluctuation of body position in lateral more than the AP direction, but no interaction between vision and stance width in the fluctuation of body position (60).

Normally, postural control was deteriorated when loss of visual feedback such as in the eyes open condition compare with eyes closed condition (14, 15). Lee and Lishman have investigated the influence of visual feedback in less familiar stance (e.g. standing on a beam), where mechanical proprioception was poor. The result showed that no subject could balance for 30 seconds with eyes closed, where as every subjects could do this with eyes open (61). Portvin and associates studied the aspect of the reliability and validity of balance under eyes open and eyes closed conditions in men from 20 to 80 years. The inference of this research is that balance with eyes closed is a more sensitive test of postural control than balance with eyes open (62). Nevertheless, the study of Stones proposed that the eyes open test were more reliable than the eyes closed test of postural control. Moreover, this research compared balance performance in the blind people and the minimally sighted subjects. The result revealed that minimally sighted subjects control balance for longer than fully blind subjects, but no significant difference in balance between the blind from birth versus acquired blindness subjects (16).

Isotalo et al in 2004 (63) studied the postural control in monocular versus binocular vision. The result of the study showed that no significant difference between monocular and binocular vision. Whereas, the finding of Fox revealed that postural stability was better under binocular vision than under monocular vision (64).

Nakata and Yabe in 2001 (65) examined the effect of the absence of vision from birth on automatic postural responses to platform displacements during stance. Postural response to forward and backward translation, and toe up and down rotation were measured in these parameters; electromyography (EMG), reaction time and postural sways before, during and after perturbation in the AP and ML directions. The result demonstrated that blindness from birth had no effect on the automatic postural response in response to platform perturbations. There was no significant difference between blind and sighted subjects in the pattern of EMG activities, EMG onset latencies and postural sway during perturbation. On the other hand, blind subjects showed faster reaction times to stimuli generated by platform displacement when compare with sighted subjects.

Jahn et al in 2002 (21) investigated the effect of suppression of eye movement on postural balance in the patients with vestibular neuritis. All patients exhibited horizontal nystagmus with their eyes open in darkness. Sway velocity and root mean square (RMS) were calculated for the AP and ML direction during upright stance on firm and foam surfaces. In order to suppressed the eye movements, the subjects wore a mask that allowed fixation of a head-fixed target. The study revealed that the suppression of nystagmus could reduced postural sway during standing on foam surface. Furthermore, Savino supported the role of ocular oscillations in the visually dependent postural control in the congenital nystagmus patient (18). In the case of homonymous hemianopic patients, Rondot found that hemianopia patients increase lateral oscillations in the standing posture. Moreover, the projection of the body's center of gravity shifted toward the effected side. In addition, in the normal subjects were masked half the visual field showed the body's center of gravity shift to that side, like as the hemianopia patients (23).

2.2.2 Central nervous system

Postural stability can be controlled by central nervous system which use sensory information from visual, somatosensory and vestibular systems to organized motor response that restored body alignment automatically (66). Shumway-Cook in 1995 described that postural control required the integration of sensory information to assess the position and movement of body in space in order to generate force for controlling position. Therefore, a complex interaction of musculoskeletal and the neural system is necessary for postural control. The neural system include motor response (neuromuscular response synergies), sensory process, sensory strategies that organize multiple inputs, internal representations for the mapping of sensation to action and higher process essential for postural adaptation and anticipatory (4).

Postural adjustments are necessary for motor task and need to integrate with voluntary movements by two mechanisms that are feed forward and feedback mechanisms. Feed forward control result in anticipatory postural adjustments which are trigger prior to the self-induced disturbance (2). For example, in the case of arm raising in the adult, the changing in the activities of several trunk and leg muscles involved in postural control that occurred before the onset of the arm muscles activity. Where as, feedback mechanism are used for coping with unpredictable externally that generated postural disturbance (67). These automatic postural adjustments are rapid response and like reflex as they have a relative stereotyped spatiotemporal organization. However, the responses are unlike reflex due to the responses depending on practices and learning (24).

Ouchi et al in 1999 (68) examined neural substrates for maintaining standing posture by using positron emission tomography (PET). Several posture of the study consisted of standing with feet together with eyes open and eyes closed, standing on one foot with eyes open and standing in tandem posture with eyes open. These postures were compared with supine position. Maximal lateral deviations of the head in lateral direction and number of side steps within 60 seconds were recorded for determination of magnitude of sway before PET measurement. The result showed the difference in sway magnitude during several task. There are significant of regional cerebral blood flow (rCBF) increase in the right primary and secondary visual cortex, the left cerebellar anterior and the anterior vermis during bipedal stance when compared with supine posture. In addition, tandem standing activated temporal cortex (BA 37), left midbrain corresponded to the red nucleus and the left thalamus. The researchers discussed that the differences in sway magnitude indicating different stimuli caused by altering upright posture could cause focal brain activation in the areas contributing to each postural regulation. Moreover, the finding confirmed that the cerebellar vermis efferent system is involved in the active maintenance of body balance.

2.2.3 Motor component

Body movement is the motor component for maintaining postural control. It comprises of reflex, autonomic and voluntary movement. Maintaining postural equilibrium requires the central nervous system to process and integrate afferent information from sensory system into the selection and execution of appropriate and coordinate musculoskeletal response throughout the joint of lower extremity, therefore efficiency of musculoskeletal including strength, flexibility, endurance of muscle that effect on postural stability (69). In addition, limitation by pain, restriction of joint rage of motion can affect the available movement strategies for achieving equilibrium. For example, muscle weakness or range of motion limitations at the ankle joint may result in large compensatory hip and trunk motions to correct disequilibrium in standing (70).

2.2.4 Movement strategy

The postural strategies were referred as the appropriate movement organization for controlling body posture (4). The ankle strategy was related to a distal to proximal muscle activation pattern (ankle, knee, hip and back), whereas the hip strategy was related to proximal to distal pattern (back, hip, knee, and ankle) (4). In small disturbance on firm surface and enough base of support, most normal persons control COM by primarily inverted pendulum sway at the ankle. In order to responses to larger, faster COG displacement, the primary action was present at the hip or upper body as the hip strategy (71). Gatev et al in 1999 (72) emphasized that the decrease in ankle strategy was due to the insufficient ankle proprioception. Day 1993 (60) studied the effect of vision and stance width on postural control. The increase in body sway was presented in narrowing stance and visual elimination.

2.3 Factors Influencing Balance

2.3.1 Age and gender

Peterka and Black (73) studied relation between age and postural control in 214 subjects ranging in age from 7 to 81 years by using sensory organization test measured body sway in six conditions. The result of the study showed age related increasing sway in condition involving altered visual and somatosensory clues. Subjects younger than 15 years has greater swayed than subjects in middle ages in some conditions (eye open and support surface sway, eye closed and support surface sway, and visual reference sway and surface sway) that showed younger subjects rely more heavily on somatosensory clues. However, subjects older than 50 years increased number of fall and increase sway greater than non fallers in visual reference sway and support surface sway condition.

Hageman et al in 1995 (74) found the postural sway related to age. The older adult (60-75 years) showed larger areas of sway, longer movement times, path length sway, and shorter distance of Functional Reach Test when compare with younger adult (20-35 years) Moreover, this study determined effect of gender on postural sway and found that the men who taller showed larger values of functional reach test. However, when functional reach scores were normalized to height, the result has shown no significant difference between them. Similarly, Colledge et al in 1994 (75) found that postural sway increased linearly with age but no relationship between gender and postural sway.

Wolfson et al (66) examined the effects of gender difference in balance by Sensory Organization Test (SOT) and Motor Coordination Test (MCT) in 234 healthy elderly age 60 years or older. In condition of swayed surface support, the women swayed and loss of balance more than men suggesting differentiation between men and women in biomechanics of postural response such as joint function or strength. On the other hand, Kollegger et al found that in older age group males had greater postural sway than female but in younger groups no significant between male and female was observed (76).

2.3.2 Height

Berger et al (77) studied effect of subjects' height on postural stability in 45 subjects (5-45 years, height 113-193 cm.). The electromyography (EMG) activity was recorded from gastrocnemius and tibialis anterior muscle of one leg. The result showed close correlation between displacement amplitude at ankle joint and height of subjects, with the largest displacement in small subjects. The consequence of this relationship showed that there was larger response of gastrocnemius muscle and stronger coactivation of tibialis anterior muscle in compensatory reaction. Moreover, increasing of momentum resulted in larger increment of both ankle joint displacement and EMG response of gastrocnemius muscle in small when compare with larger subjects.

Carpenter et al in 1999 (78) studied effect of surface height on postural control in 28 adult subjects during standing in normal stance on low (0.19 m.) and high (0.81 m.) platform under various condition of reduced visual and vestibular input. Postural control was examined by recording amplitude frequency (RMS) and mean power frequency (MPF) of center of pressure. The result showed that vestibular input influenced postural control at both low and high levels with significant increase in RMS when vestibular input was reduce and when vision was available and significant decrease in RMS and increase MPF during quiet standing on high surface compared to low surface. Similarly, Adkin et al in 2000 (79) have investigated that the control of posture during standing at different surface heights above ground level. The 62 healthy adult volunteers (mean age 20.3 ± 1.3 years) stood quietly on force plate at

40 cm., 100 cm., and 160 cm. above ground level. The amplitude of center of pressure (COP) displacement was shown to increase from the low to the high.

2.3.3 Attention

Shumway-Cock and Woolacott in 2000 (80) examined the effect of a secondary auditory task performing on postural stability and the attentional demands of standing under change of sensory contexts. The 18 healthy adults, 18 healthy older adults and 18 older adults who have balance impairments and a history of recent falls was measured a choice reaction time auditory task and postural stability. The result showed that the auditory task did not effect to postural stability in young adults. In the healthy older adults, a second task only affected postural stability when reduced visual and somatosensory inputs. In the older adult who has a history of imbalance and recent fall, a secondary task affected to postural stability in all sensory conditions.

Rankin et al in 2000 (81) studied the neuromuscular response of young and older adult while controlling standing balance on platform perturbation and simultaneously performing math task. The result demonstrated a decrease in muscle response amplitude in both agonist (gastrocnemius) and antagonist (tibialis anterior) muscle when the cognitive math task was performed. In addition, the dual task activity has a greater impact on balance control in the older adults than the young adults. It is concluded that the decline of muscle activity when the secondary task was performed, due to less attention processing capacity being available for balance control during dual task.

2.3.4 Disease

Voorheesin in 1990 (82) studied perception of long loop latencies by posturography (SOT and MCT test) in 151 patients. The 31 subjects were diagnosed as CNS disorder such as cerebrovascular accident, trauma. The SOT result showed abnormal in 28 of 31 control disorders (90.3 %) and 35 % of these were abnormal in sway-reference surface condition and more than 70 % of these were associated with abnormal MC scores. The result of specific diagnosis indicated pathology in cerebral hemispheres, brainstem, spinal cord and peripheral nerves. All of these structures may be anatomically important in long-loop reflex pathways. The nonfocal character of these lesions may account for failure of conventional vestibular and clinical test to consistently detect abnormalities.

2.3.5 Alcohol

Tianwu et al in 1995 (83) studied acute effect of a moderate quantity of alcohol on balance, related to vestibular function in ten healthy males (19-27 yrs.) The subject's blood alcohol level was measured before test and then after 30, 90 and 150 minutes. Balance test (vestibulo-ocular reflex test, caloric test and dynamic posturography) were immediately perform after each of blood sampling. At the highest of alcohol level, then was significant reduction in VOR gain, maximum slow-phase velocity of caloric test and equilibrium score of SOT in condition of eyes closed with swayed surface support. When compare with those before drinking. The study of Wöber et al in 1999 (84) determined the relationship between alcohol consumption and postural control in alcohol-dependent patients. The result showed the lifetime alcohol consumption relating with posturographic finding and the prevalence of peripheral neuropathy. The posturography demonstrated the significant increase in the sway path, the area of sway and the antero-posterior sway of both eyes open and eyes closed. However, lateral sway was not related to the lifetime alcohol consumption. In addition, daily alcohol consumption and the consumption during six month before admission for alcohol withdrawal therapy had no effect on postural control.

2.3.6 Smoking

Uchida et al in 1980 (85) studied the effect of cigarette smoking on body sway. The displacement of the center of gravity in AP direction was measured by polygraphic recorder during standing upright. The smoker showed higher in frequency and larger in amplitude of oscillatory body sway in AP direction than that in the non-smoker. It is suggested that the absorption of nicotine into blood may affects the structure in brain stem that related to the regulation of standing posture. Similarly, the study of Iki et al in 1994 showed that the smoking habit affected postural stability. The moderate smoker showed the significant increase in average sway velocity, while the heavy smoker showed significant increased in both average sway velocity and the

COG sway in ML direction when compared with light smoker and non-smoker. In addition, the researcher suggested that habitual smoking had a long effect on balance control system due to the effect of nicotine on the central and peripheral nervous system (86).

2.3.7 Medication

Parkinson's disease is a neurodegenerative disorders of the older person. The disease is characterized by the cardinal signs of tremor, bradykinesia, rigidity and postural instability, which lead to functional disability. Pharmacology intervention is one choice of the treatment. Drugs have been effective in treating some of the effect of the disease including bradykinesia, rigidity and tremor, but it can affect postural instability and impaired motor planning (87). In addition, Parkinson's disease drugs (L-dopa, dopamine agonist and anticholinergic) have side effect to central nervous system such as confusion, delirium, hallucination and behavioral change (88).

Lord et al in 1995 (89) evaluated the association of psychological medication use and fall in the older women. The medication use were divided into three groups; hypnosedatives, antipsychotic and antidepressants. The subjects were assessed sensori-motor function (peripheral sensation, strength and reaction time), balance control (postural sway, static and dynamic balance), and postural hypotension. Women taking psychoactive medications showed impaired performance in a number of sensori-motor measure including tactile sensitivity, lower limbs muscle strength, reaction time and postural stability when compared with women not taking these medications. In addition, there were significant association between benzodiazepine use and postural instability, antidepressant use and lower limb muscle weakness. This study suggested that psychoactive medication use may predispose older people to falling by impairing important sensori-motor systems that contribute to postural stability.

2.4 Auditory System

The auditory system enables us to detect the frequency composition of sound and locate sound sources. The external ear and the middle ear form a mechanical transmission system that converts sound or air pressure wave into fluid wave in the inner ear. In the inner ear, sensory transduction occurs in the organ of Corti, where the hair cell interact with supporting elements to convert fluid wave into the bending of the hair bundles and resultant ion influxes. Therefore, signal occurs initially at the synapse between the hair cells and the fibers of the auditory nerve. The provide a profile of sound input, including the spectrum of frequencies, the phase or timing relations of different frequency components and their relative amplitude. Then the auditory portion of the eight nerve relays information about sound to the brainstem. The cochlear nucleus, which lies on the lateral aspect of the inferior cerebellar peduncle, receives the auditory input and sends the axon to synapse in the inferior colliculus. Neurons in the inferior colliculus transfer their axons to the medial geniculate nucleus of the thalamus, which projects upon the primary auditory cortex of the temporal lobe (27).

Alain et al in 2001 examined the extent to which processing sounds identify and sound location in the auditory pathway. Functional magnetic resonance imagines (fMRI) and the event-related brain potential (ERPs) were measured for determined brain activation. The result showed that the pitch processing was associated with greater activity in auditory cortices and inferior prefrontal gyrus. Conversely, spatial judgment was associated with greater bilateral activation in posterior temporal areas, inferior and superior parietal cortices. This finding revealed that the processing of pitch information was primarily distributed in the ventral of the brain, where as the sound localization process was distributed in the dorsal region of the brain (90).

Hearing is the afferent sensory information providing a basic for orientation in space. Normally, human can perceived sound in frequency range from 20 to 20,000 Hertzs (Hz). The loudness of sound at 70 decibels (dB) was a normal conversation source, while the loudness of sound more than 120 dB given pain and harm to the ear (27). Human with normal hearing can locate sound sources with good precise, which is the basic for the use of diverse sound in daily life as warning signal or to facilitate orientation in space such as that found in blind people (28).

Juntunen et al in 1987 (31) studied the postural sway in subjects who had various degrees of noise-induced hearing loss and healthy adult. The result showed that the subjects with more severe hearing loss showed greater sway than subjects with less severe hearing loss and healthy adults. Similarly, Kilburn et al (30) studied balance performance in ironworkers compare with histology technicians. The ironworkers showed greater hearing loss and had faster sway speed than histology technicians both with eye open and eyes-closed. In addition, Siegel in 1991 (91) found that the deaf children had poor balance when compared with normal children.

Petersen et al in 1995 (28) studied the effect of auditory input on postural control in healthy volunteers. Two types of sound input were used as feedback sound from two loudspeakers providing frame of reference. Vibratory stimulation was applied to right (Rt.) and left (Lt.) gastrocnemius muscle to induced body sway. Body sway was recorded by force platform. All experimental consist of three test sequences that are eye opened, eye closed and eye closed with feedback or reference auditory input. The result showed a significant increase in saggital body sway when visual clues were eliminated. Additionally, the auditory input as a feedback significantly reduces body sway in subjects standing with eye closed during perturbation at low intensity vibration. The result of Peterson study was similar to Eatson and Greene in 1998 (17). The stationary auditory information could effect of body and head sway in 10 sighted and 8 congenitally blind people. The experimental trials included five conditions eye open (sighted only), eye closed, eye closed with one speaker in the front, two speaker placed in the right and left, and sonar tandem Romberg position. The result showed that two speaker significantly stabilized center of pressure sway in tandem Romberg stance while neither a single speaker nor head sonar feedback reduced center of pressure sway. The sound from two speakers can reduce center of pressure sway in same level for sighted and blind subjects, however, blind subject's head sway was significantly larger than sighted subjects. Furthermore, Peterson et al in 1996 (29) studied the effect of auditory input on an impaired postural control perturbation induced by vibration at RT. & Lt. gastrocnemius muscle. This experimental was similar to his previous study (28). There was significantly reduced body sway in recent stroke patients (<12 months) when receiving auditory feedback, but no observation in a decrease body sway in less recent stroke group (>12 months). This findings suggest that the effect of auditory feedback on stability may contribute to minimizing response to sudden perturbation and this effect becomes gradually apparent. Therefore, it may represent a learning effect and auditory feedback may be useful in rehabilitation training programmer aiming to augment postural skills.

Raper and Soames in 1991 (33) studied the influence of stationary auditory fields on postural sway in 30 younger subjects. Static auditory field (pure tone (252Hz), and background conversation at intensity of 65 dB. were applied to subject standing with eye open and closed. Postural sway was significantly increase in eye-closed condition and the presence of auditory field tended to have a destability. It is demonstrated that postural stability can be modified by auditory information. The influence of moving auditory field on postural sway during standing with eyes open and eyes closed was examined (26). Two dynamic auditory field conditions were created by moving the sound between speakers, either from side-to-side and from front-to-back. The result showed that sound moving from side to side resulted in a significantly greater ML sway than did a sound moving from front to back. Similarly, a front to back auditory field produced a significantly greater AP sway than did a side to side field. It is suggested that moving auditory field tend to have a destabilizing effect on posture and increase postural sway behavior (26).

Recently, the studied of the influence of moving auditory stimuli on standing balance showed that in the conditions of reduction of tactile sensation or deprivation of visual information, the lateral body sway was influenced by the lateral moving auditory stimulation. Moreover, it is suggested that auditory stimulation and a sound field produced in a daily life can influence standing posture and balance (32).

2.5 Interaction of Visual and Auditory System

Visual system plays an important role in the stabilization of posture. The system provides information about the body movement in relation to the environments. In addition, it regulates of eye and head movements in attention and perception associated with vision. The regulation of eye and head movements is distributed in superior colliculus. The superior colliculus received somatosensory, auditory input from the inferior colliculus and input from wide spread corticles areas (58). Neurophysiological recording in the primate superior colliculus have suggested that spatiotopic maps of visual and auditory space are approximately superimposed in this multimodal midbrain area. In addition, the spatial agreement of these sensory representation is maintained even when the position of the eyes in the orbit deviates from straight ahead (35, 92). Furthermore, Cohen and Knudsen in 1999 proposed that an auditory space map is synthesized in the midbrain pathway in order to transform auditory spatial information into spatiotopic format that is consistent with, and can be merged with, topographic code for controlling gaze direction (35). Several studied found that eye movements can be induced by acoustic signal (36, 37). Lewawad's study revealed that sound was perceived opposite to the direction of gaze. It is indicated a relative shift of the perceived sound azimuth toward the side of eccentric gaze (92).

Sakellari and Soames in 1996 (37) studied the interaction of auditory and vision in postural stabilization. Center of pressure in AP and ML directions, length of sway path, the velocity of movement and the area of movement were measured for determining postural balance. The test was consisted of standing with eyes open and eyes closed simultaneously presenting of sound at 70 dB and 80 dB with twenty three frequency bands. The result demonstrated that the frequency of sound appeared to influence the regulation of AP sway, where as, loudness tended to regulate ML sway. The visual feedback has a significant stabilizing effect on all AP parameters of sway. In addition, the interaction of sound and vision lead to increased sway behavior. It is suggested that the auditory system was more dominant than visual in maintaining balance in ML direction (37).

2.6 Postural Control and Balance Assessment

The measures of the success of postural control require to consider the context and task-specific goals of posture. It is included with control of the center of body mass (COM) over the base of support, maintenance of a vertical trunk, stability of the head and limbs, as well as the effective and efficient movement of the body through space and limb over a stable body. Horak in 1997 divided clinical balance assessment into three main approaches; a functional assessment, a system assessment and quantitative posturography (43).

2.6.1 Functional and system assessment.

Functional assessment tools were developed to identify the functional limitation or capacity to do a task or activity with respect to postural control. There are several tests for balance assessment during perform functional task such as Functional reach test, Get up and Go test, and Functional balance and mobility scale.

The Functional Reach test is a dynamic measurement of stability during a self-initiated movement. The test is the difference between a person's arm length and maximum forward reach with the shoulder flexed to 90° while maintaining a fix base of support in standing (93, 94).

Timed Up and Go test is used to examine functional mobility. The test demands a subject to stand up, walk 3 meters, turn, walk back and sit down. This test is a sensitivity and specific measure for identifying community dwelling adults who are at risk of fall (95).

The popular functional balance assessment tools in physical therapy are Berg Functional Balance Scale and Performance-Oriented Assessment of Mobility by Tinnetti. Berg Functional Balance Scale consists of 14 items. The items involve common postural balance to many functional tasks such as reaching, picking up an object from the floor, turning the head, alternative stepping onto a stool and standing on one leg. The items are graded on a five point ordinal scale (0-4) (43). The Performance-Oriented Assessment of Mobility by Tinnetti is a performance test of balance and gait during normal daily activities. It consists of 9 items such as sitting to standing and turning 360 degrees, response to perturbation during feet close together position, and 16 items for gait tests including the time for initiation, symmetry, continuity and step length and height. Each task is rated performance on three points scale (96). The advantages of functional tests such as the Berg Functional Balance

Scale, Timed Up and Go test and the Performance-Oriented Assessment of mobility by Tinnetti are the assessments that examine in many different aspects of balance, quick to perform, require no expensive equipment and easy to administer. However, these assessments do not test for performance under altered sensory context conditions. Shumway Cook and Horak in 1986 designed the clinical test for sensory interaction on balance. The method required to examine standing balance under six different intersensory conditions, which either eliminate input or produce inaccurate visual and surface orientation input by dome and foam (97). The clinical test for sensory interaction on balance (CTSIB) is shown to have high inter-rater and test-retest reliability. In addition, it is correlated well with posturography for identifying patients with abnormal postural control (98).

2.6.2 Quantitative Posturography

Quantitative posturography used technology to assess balance control including to measure forces at the surface, kinematic patterns and biomechanical analysis associated with a variety type of postural tasks. Five main types of posturography tests included; stance, reaction to surface displacements, sensory organization, voluntary movement and gait (43). Posturography testing was supported for sensitivity in detecting abnormal postural control and exact for defining the specific pattern of dysfunction (99). Force platform are common tool utilized to provide a sensitive means to measure postural steadiness and stability (100). Some investigators have analyzed the amount of body movement, which includes the total sway distance during the test period (101), the extent of forward-backward and lateral postural sway, sway area (100), and total force on force platform. The test of sway by force platform were indicated to be a useful clinical tool for determine balance problems in normal individual and patients with neuromuscular or skeletal disability such as patients with the Parkinson's disease and the cerebella ataxia, hemiplegia (102) and traumatic brain injury (103).

Smart Balance Master System is one of commercial systems, which is provided by NeuroCom International, Inc. The Balance Master was designed to provide quantitative assessment of static and dynamic balance performance and visual feedback of the excursion and position of the COG. The system utilizes force platform to determine the location of the COG with in the limit of stability (104). The static assessment is sensory organization test (SOT). The SOT quantifies impairments related to effective use sensory inputs to balance by comparing the postural sway during exposure to six increasingly difficult sensory conditions. Sensory conditions are modified by a technique of sway-referencing. During sway-referencing, the support surface, the visual surround, or both are actively and continuously driven in response to the subject’s spontaneous sway motion. This test provides quantitative measures of COG sway (average sway velocity in degree/seconds), the stability score (%maximum stability), COG alignment and strategy analysis (% ankle strategy) (105). The SOT has proven effective in isolating impairments related to use of visual, somatosensory and vestibular inputs (106). Wallman in 2001 investigated Functional reach test, limit of stability and SOT test in elderly with nonfallers and fallers. The study demonstrated that SOT test could differentiate elderly nonfallers from fallers for balance impairments (105, 107). In addition, SOT provided stable, useful measures of sensory system effectiveness and maturational change of postural control in young children (108). The dynamic balance assessments consist of center target, rhythmic weight shift, and limit of stability tests. These quantify time and accuracy variables: on axis velocity (degree/second), directional control (%), reaction time (seconds), movement velocity (%), end point and maximum excursion (%) variables (105). The dynamic measures of balance from Balance Master system were reliable and correlated with both Berg Balance Scale and Gait velocity outcomes in stroke patients (102). Furthermore, the outcome measures which derived from the limit of stability test were consistent across multiples times (104, 109).

CHAPTER III
MATERIALS AND METHODS

3.1 Subjects

Healthy Thai women who ranged in ages 20 to 35 years volunteered to participate in this study. The exclusion criteria of the subjects were as follows;

1. Visual impairment that could not be corrected by lens.
2. Hearing impairment
3. Musculoskeletal disorders
4. Neurological disorders
5. Vestibular deficits
6. Persistent symptom of vertigo or dizziness
7. Alcohol intake within 24 hours
8. Medication taking that affected postural balance within 24 hours

3.2 Instrumentation

1. Smart Balance Master system with software version 5.0 (Figure 3.1) consisted of:
   - Dual forceplates consisted of two 9”× 18” footplates connected by a pin joint
   - Five force transducers supporting the forceplate that the four detect vertical force and one detects shear force.
   - Visual surround
   - IBM-compatible PC/AT computer with SMART BALANCE MASTER system software version 5.0 consisting of a keyboard, HP-deskjet 520-printer and two monitors providing visual feedback.
   - Overhead bar and safety harness to prevent falling during the test.

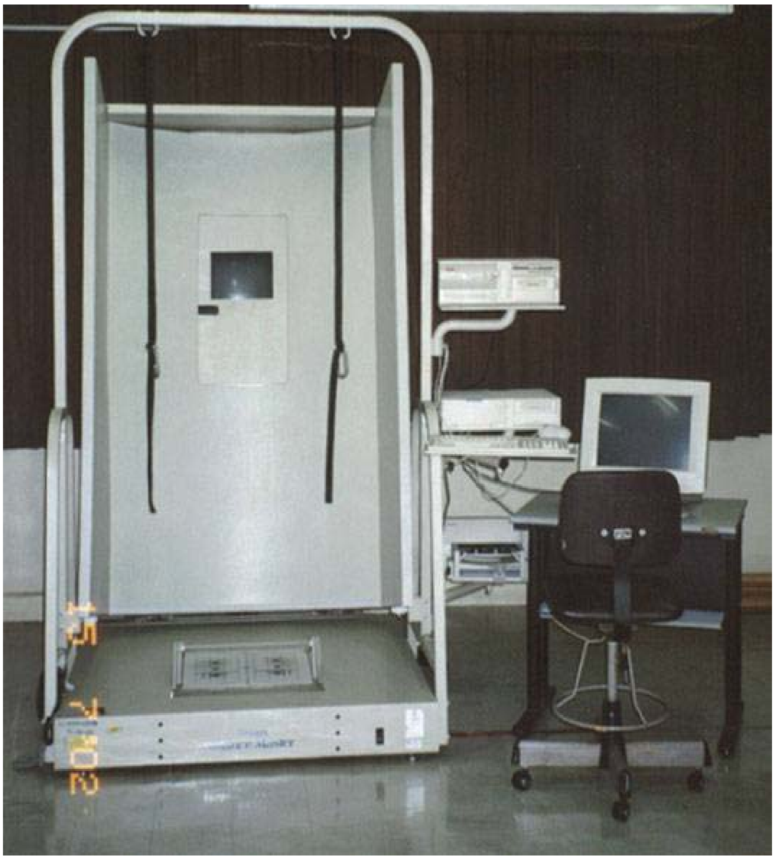


Figure 3.1 The SMART Balance Master System™; Neurocom® International, Inc.

2. Audiometer (Figure 3.2)
3. “X” form tape (Figure 3.3)
4. Blindfold (Figure 3.3)
5. Stop watch (Figure 3.3)
6. Vernier caliper (Figure 3.3)
7. Snellen’s chart (Figure 3.3)

Figure 3.2 Audiometer was used as the sound generator.

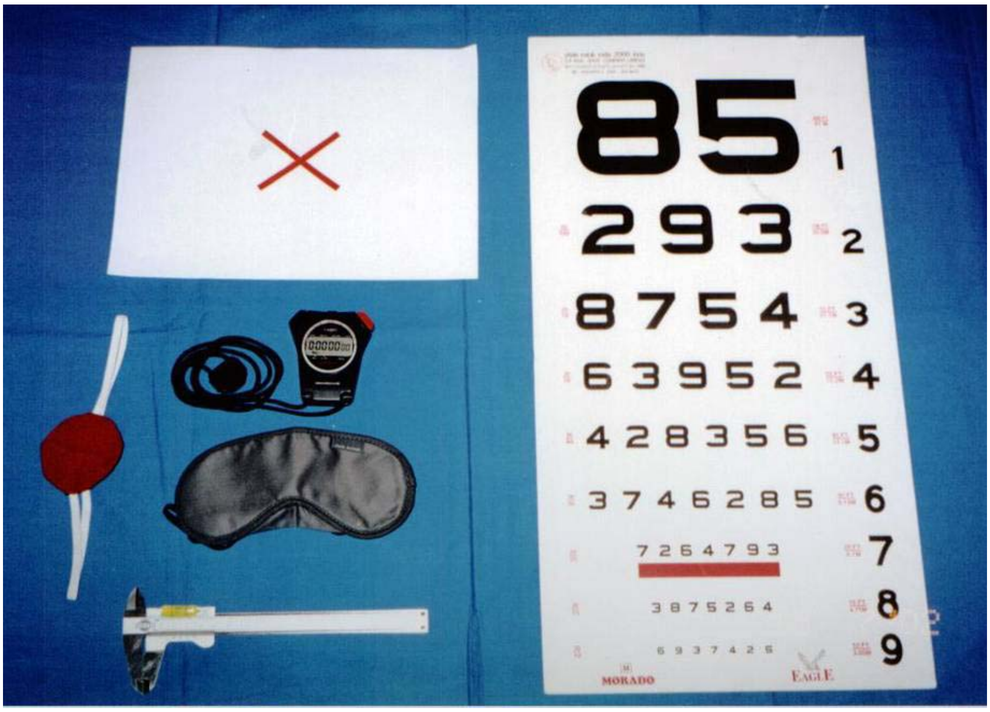


Figure 3.3 Other assessment instruments; an “X” form tape (A), Blindfold (B and D), a stop watch (C), a vernier caliper (E) and Snellen’s chart (F)

3.3 Procedure

3.3.1 Screening test

Visual and auditory systems were screened in each subject. The tests consisted of visual acuity, visual field, visual dominant screening test and hearing threshold level.

Visual acuity was assessed by Snellen's chart (Figure 3.3). Subject stood in front of the chart at a distance of six meters. Subjects were instructed to close an eye and then, they were allowed to pronounce the letters above the red line. If subject read more than two letters in error, she had abnormal visual acuity of that side.

Visual field for both the right and left eyes was assessed by the Confrontation test. Subject sat and faced with the researcher about 0.5 meters apart. When the right eye was tested, subject were instructed to close the left eye and looked directly into the researcher's left eye. The researcher wiggled an index finger in each of the quadrant of the eye field and asked the subject whether she could see it. If she could not see the finger, her visual field was abnormal.

For visual dominant screen test, there was a letter "X" placed on the wall at the subject's eye level. Subject stood 3 meters far from the wall and a "X" was in the middle front of the subject. Then, subject was instructed to make a circle by putting the tip of left or right thumb and index finger together. Next, subject held the circle and moved it forward and upward until reaching the eye level. Subject looked a "X" through the circle. To test the left eye, subject was instructed to close the right eye. After that subject reported the researcher whether she could see a "X" sign. The right eye test was done in the opposite way. The eye side which subject could see a "X" is the subject's dominant eye.

In a quiet room, the minimum level of hearing for each ear was assessed by an audiometer. Before the assessment, subject was instructed to respond to the sound signal by raising the index finger as soon as she heard the sound and drop the finger when she did not hear the tone.

The popular method of hearing threshold examination was known as ascending technique. The sound signal would be presented at the loudness approximately 30 decibels (dB) or higher if subject could not hear at 30 dB. After that the intensity would be decreased 10-dB step down until subject could not hear the sound. Next, the signal would be increased 5-dB step up until subject could hear it. This process was repeated three times until the subject responded to the same level for two of three times. This level would be considered to be the hearing threshold. The assessment would be first tested at sound frequency 1,000 Hertz (Hz) and then move to the frequencies 1,500, 2,000, 4,000 and 8,000 Hz. For the low frequencies the test was started at sound frequency 1,000 Hz and decreased the frequency to 500 and 250 Hz, respectively.

3.3.2 Testing procedure

The subjects who passed all visual and auditory screening tests were included in the study. Before signing the informed consent, subjects were introduced about the testing procedure. Then, subjects were interviewed about their demographic data and the general health status.

Static postural balance was recorded by SMART Balance Master system. The value of average sway velocity in degree per second (deg/sec.), the percentage of maximum stability (%), and the percentage of ankle strategy (%) was calculated from the software program version 5.0 of Smart Balance Master System. The path of COG sway excursion was traced on a printout for each subject. The anteroposterior (AP) and mediolateral (ML) COG sway excursion was measured manually on printout by using vernier caliper and the unit was millimeter.

Before testing, subject was instructed to take off her shoes and socks and put on a safety harness before standing comfortably with arms hanging beside the body and feet together at the center of the platform and looking straight ahead at the monitor. (Figure 3.4)

Figure 3.4 The position of the subject during the balance assessment.

The 12 conditions; eyes open, eyes open with sound on left ear, eyes open with sound on right ear, left eye-closed, left eye-closed with sound on left ear, left eye-closed with sound on right ear, right eye-closed, right eye-closed with sound on left ear, right eye-closed with sound on right ear, eyes-closed, eyes-closed with sound on left ear, eyes-closed with sound on right ear were tested in sequence. According to the work of Sakellari and Soames (37), the stabilizing effect of sounds at the loudness of 70 dB and frequency 1,500 Hz was chosen in the study. In the condition with the sound, the sound was generated by audiometer and was turned on for 5 seconds (sec) before recording postural behavior. In addition, the blindfold was applied in the condition of both eye closed and either left or right eye closed that subject's eyes was opened behind the blindfold. Each test was taken 20 seconds and was done twice. Subject was allowed to have 2-minute rest on chair after two tests already have been done.

Experimental Protocol

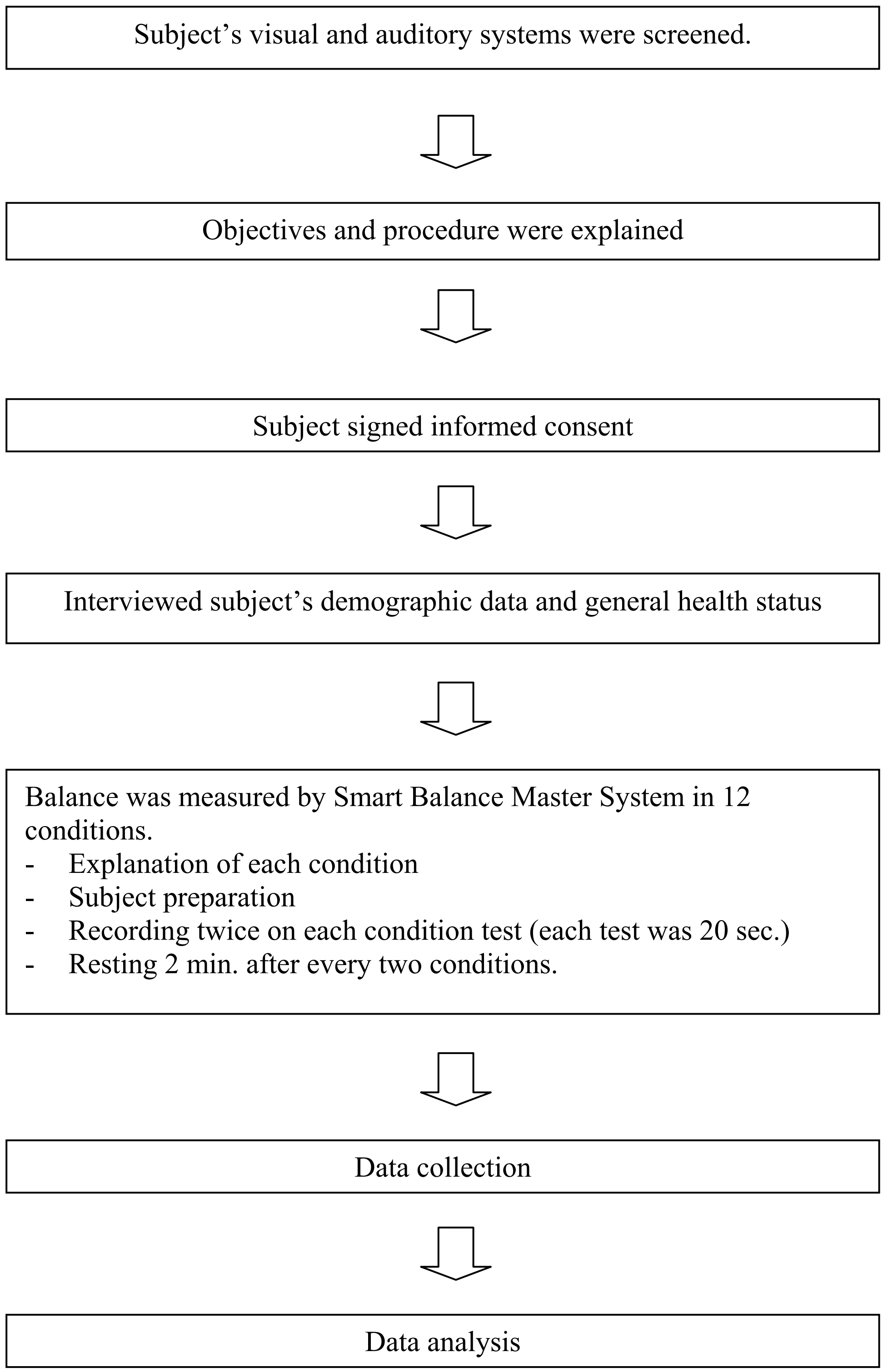


Figure 3.5 Flow chart of experimental protocol.

3.4 Data Analysis

The SPSS/PC for Microsoft Windows release 9.0 program was used for statistical analysis. The statistical significance was set at probability (p-value) level less than 0.05 ($p<0.05$).

1. Kolmogorov-Smirnov Goodness of Fit test was used to test the distribution of the data.

2. Two way analysis of variance for repeated measures was used to determine the interactive and individual effects of vision and sound on all postural balance variables. Bonferroni was used as post-hoc test to test the difference in each condition of visual and sound effect.

3. One way analysis of variance for repeated measures was used to test the simple effect of vision and sound that showed significant interaction.

CHAPTER IV
RESULTS

The present study investigated the effect of visual and auditory inputs on balance performance by using the SMART Balance Master system. The interaction effect of visual and auditory inputs on balance performance in healthy Thai women was determined.

4.1 Characteristics of Subjects

The study sample consisted of 50 healthy Thai women with age ranged from 20 to 35 years and all of them had right eye dominant. Means and standard deviations of age, weight, height and body mass index of the subjects are presented in Table 4.1.

Table 4.1 Characteristics of subjects (n=50)

	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
Mean	24.82	48.08	157.60	19.35
SD	3.25	4.53	5.26	1.68
Range	20-35	41-60	150-173	17.02-23.58

4.2 The Interaction Effect of Visual and Auditory Inputs on Balance Variables

The result of two way analysis of variance for repeated measures demonstrated significant interaction effect of vision and sound on COG sway excursion in the AP direction and the percentage of maximum stability. There were no interaction effects of vision and sound on COG sway excursion in the ML direction, average sway velocity and the percentage of ankle strategy as shown in Table 4.2.

COG sway excursion in AP direction

The simple effect of vision demonstrated that in the condition of no sound and sound on the left ear, COG sway excursion in the AP direction was significantly increased ($p \leq 0.001$) in eyes closed condition when compared with eyes open and the left or right eye closed. There was an increase in AP sway in the left or right eye closed when compared with eyes open ($P \leq 0.001$) in the conditions of no sound and sound on the left ear. No significant difference in COG sway excursion in the AP direction between the right and left eye closed was observed. When there was sound on the right ear, COG sway in the AP direction in eyes closed condition was significantly different ($p \leq 0.001$) from eyes open, left, and right eye closed as shown in Table 4.3.

The result of the simple effect of sound showed significant difference in sound on the right ear condition when compared with no sound ($p \leq 0.001$) and sound on the left ear ($p < 0.05$) condition during both eyes open. There was no significant difference between sound on the left ear and no sound, sound on the left ear and right ear condition. Furthermore, there was no significant difference between sound condition in other visual conditions (LEC, REC and EC) as shown in Table 4.4.

The percentage of the maximum stability

The result of the percentage of maximum stability was similar to the result of COG sway excursion in the AP direction. For the visual simple effect, there was significant decrease ($p \leq 0.001$) in the percentage of maximum stability in eyes closed when compared with eyes open, left or right eye closed during no sound and sound on the left ear. Furthermore, the percentage of maximum stability was decreased when loss of visual feedback from an eye compared to visual feedback from both eyes in the conditions of no sound and sound on the left ear. There was no significant difference between right and left eye closed in the percentage of maximum stability. In the right sound condition, the percentage of maximum stability of eyes closed was significantly decreased ($p \leq 0.001$) when compared to eyes open, left and right eye closed as shown in Table 4.3.

For the simple effect of sound, the percentage of maximum stability was decreased in sound on the right ear condition when compared with no sound ($p<0.05$) and sound on the left ear ($p<0.05$) conditions during both eyes open. No significant difference in the percentage of maximum stability between no sound and sound on the left ear, and also sound on the right ear and sound on the left ear was observed. Furthermore, there was no significant difference between sound condition in other visual condition as shown in Table 4.4.

Table 4.2 Interactive effect of vision and sound on all balance parameters

Parameters	Interaction of vision and sound (Vision* Sound)	NS		LS		RS		P-value [a]
		Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in AP (mm.)	EO	3.04	0.89	3.13	1.29	3.73	1.33	P=0.039*
	LEC	3.87	1.31	3.99	1.45	3.65	1.27	
	REC	3.97	1.54	3.81	1.58	3.91	1.64	
	EC	4.92	1.49	5.28	1.91	5.25	2.27	
COG sway excursion in ML (mm.)	EO	4.12	1.08	4.09	1.31	4.52	1.64	P=0.347
	LEC	4.88	1.50	5.00	1.49	4.97	1.50	
	REC	5.05	1.70	5.01	1.77	5.26	1.99	
	EC	5.80	1.74	6.15	1.95	6.57	2.16	
Average sway velocity (deg/sec)	EO	0.33	0.07	0.31	0.08	0.32	0.08	P=0.273
	LEC	0.37	0.12	0.37	0.11	0.37	0.10	
	REC	0.37	0.10	0.35	0.10	0.37	0.12	
	EC	0.50	0.15	0.52	0.17	0.52	0.18	
% maximum stability (%)	EO	95.22	1.61	95.18	2.27	94.14	2.34	P=0.047*
	LEC	93.56	2.32	93.72	2.57	94.22	2.14	
	REC	93.78	2.56	93.94	2.76	93.90	2.81	
	EC	92.18	2.52	91.46	3.25	91.58	3.89	
% ankle strategy (%)	EO	97.14	0.78	97.14	0.73	96.96	0.78	P=0.590
	LEC	96.98	0.80	96.66	1.19	96.50	2.50	
	REC	96.76	0.94	96.90	0.71	96.70	0.95	
	EC	96.32	1.08	96.18	1.26	96.00	1.56	

a = Two way analysis of variance for repeated measure

✶ = Statistically significant at $p<0.05$

Table 4.3 P-value of post hoc analysis of the simple effect of vision on COG sway excursion in the AP direction and the percentage of maximum stability

Parameters	Vision *sound†	NS			LS			RS		
		LEC	REC	EC	LEC	REC	EC	LEC	REC	EC
COG sway excursion in AP (mm.)	EO	.001✶	.001✶	.001✶	.001✶	.008+	.001✶	1.00	1.00	.001✶
	LEC	-	1.00	.001✶	-	1.00	.001✶	-	1.00	.001✶
	REC	-	-	.001✶	-	-	.001✶	-	-	.001✶
% maximum stability (%)	EO	.001✶	.001✶	.001✶	.001✶	.003+	.001✶	1.00	1.00	.001✶
	LEC	-	1.00	.001✶	-	1.00	.001✶	-	1.00	.001✶
	REC	-	-	.001✶	-	-	.001✶	-	-	.001✶

† = One way analysis of variance for repeated measure with Bonferroni adjustment ($p<0.05$)

+ = Statistically significant difference ($p<0.05$)

✶ = Statistically significant difference ($p\leq0.001$)

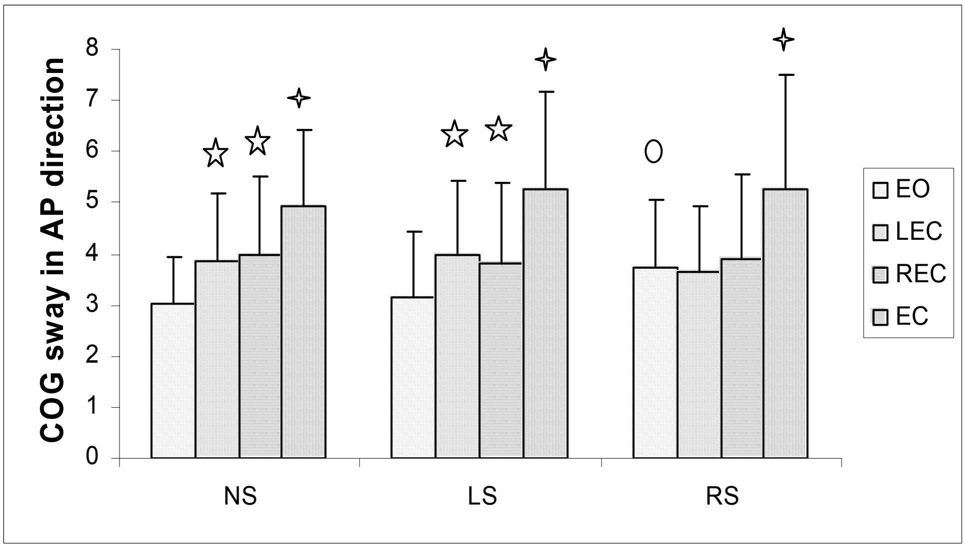
Table 4.4 P-value of post hoc analysis of the simple effect of sound on COG sway excursion in the AP direction and the percentage of maximum stability

Parameters	Vision *sound†	EO		LEC		REC		EC	
		LS	RS	LS	RS	LS	RS	LS	RS
COG sway excursion in AP (mm.)	NS	1.00	.001✶	1.00	1.00	1.00	1.00	.519	.850
	LS	-	.008+	-	.337	-	1.00	-	1.00
% maximum stability (%)	NS	1.00	.004+	1.00	1.00	1.00	1.00	.335	.661
	LS	-	.009+	-	.550	-	1.00	-	1.00

† = One way analysis of variance for repeated measure with Bonferroni adjustment ($p<0.05$)

+ = Statistically significant difference ($p<0.05$)

✶ = Statistically significant difference ($p\leq0.001$)

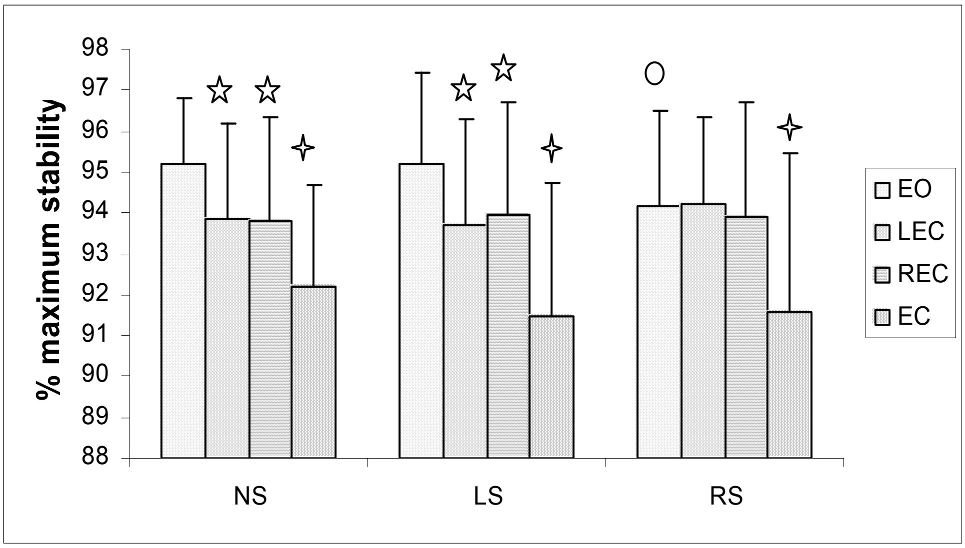


✧ = statistically significant difference from EO, LEC, REC

☆ = statistically significant difference from EO

○ = statistically significant difference from NS and LS during EO

Figure 4.1 Interaction effect of visual and auditory inputs on COG sway excursion in the AP direction (mean±SD). (EO = eyes open, LEC = left eye closed, REC = right eye closed, EC = both eyes closed, NS = no sound, LS = sound on left ear and RS = sound on right ear)



✧ = statistically significant difference from EO, LEC, REC

☆ = statistically significant difference from EO

○ = statistically significant difference from NS and LS during EO

Figure 4.2 Interaction effect of visual and auditory inputs on the percentage of maximum stability (mean±SD). (EO = eyes open, LEC = left eye closed, REC = right eye closed, EC = both eyes closed, NS = no sound, LS = sound on left ear and RS = sound on right ear)

4.3 The Main Effect of Visual Input on Balance Variables

This part focused on the effect of vision on static balance performance. Two way analysis of variance for repeated measure showed the significant difference in visual effect on COG sway in the AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy ($p<0.05$) that are presented in Table 4.5. Since significant interactions between vision and sound were found on the COG sway in the AP and the percentage of maximum stability (see previous section and Table 4.3), only the main effect of vision on COG sway excursion in the ML direction, average sway velocity and the percentage of ankle strategy are presented in this section.

Table 4.5 Mean and standard deviation of visual effect on COG sway in ML direction, average sway velocity and the percentage of ankle strategy. (EO = eyes open, LEC = left eye closed, REC = right eye closed and EC = Eyes closed)

Parameters	EO		LEC		REC		EC		P-value [a]
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in ML (mm.)	4.24	1.34	4.95	1.49	5.11	1.82	6.18	1.95	0.001*
Average sway velocity (deg/sec)	0.32	0.08	0.37	0.11	0.36	0.11	0.51	0.17	0.001*
% Ankle strategy (%)	97.08	0.76	96.71	1.49	96.79	0.87	96.17	1.30	0.001*

a = Two way analysis of variance for repeated measure

* = Statistically significant at $p<0.05$

The result of Post-hoc analysis of COG sway excursion in the ML direction demonstrated that there was significant increase in COG sway in the ML direction during eyes closed ($p<0.05$) when compared with eyes open and the left or right eye closed. In addition, when loss of visual input from one side of eyes it was showed significant increase ($p<0.05$) in sway excursion when compared to both eyes open. However, no significant difference in COG sway excursion in the ML direction between the left and right eye closed was observed, that are presented in Table 4.6 and Figure 4.3.

When loss of visual input, average sway velocity was significantly increased ($p<0.05$) when compared with visual input on both eyes and one eye. Visual feedback from one eye caused the significant increase ($p<0.05$) in average sway velocity when compared to both eyes open. There was no significant difference in average sway velocity between left and right eye closed, which are presented in Table 4.6 and Figure 4.4.

Post-hoc analysis test of the percentage of ankle strategy are presented in Table 4.6 and Figure 4.5. There was significant decrease ($p<0.05$) in the percentage of ankle strategy in the condition of without visual feedback from both eyes when compared with the condition of visual feedback from both eyes, right eye and left eye. In addition, when the right eye were closed, the percentage of ankle strategy were significantly decreased ($p<0.05$) when compared with both eyes open. The percentage of ankle strategy did not differ between left eye closed and both eyes open. No significant difference in the percentage of ankle strategy between the right eye closed and left eye closed was observed.

Table 4.6 P-value of post hoc analysis of visual effect on COG sway in the ML direction, average sway velocity and the percentage of ankle strategy. (EO = eyes open, LEC = left eye closed, REC = right eye closed and EC = Eyes closed)

Parameters	Conditions	LEC	REC	EC
COG sway excursion in ML (mm.)	EO	.001*	.001*	.001*
	LEC	-	1.000	.001*
	REC	-	-	.001*
Average sway velocity (deg/sec)	EO	.001*	.001*	.001*
	LEC	-	1.000	.001*
	REC	-	-	.001*
% Ankle strategy (%)	EO	.108	.002*	.001*
	LEC	-	1.000	.010*
	REC	-	-	.001*

✶ = Bonferroni, statistically significant difference ($p<0.05$)

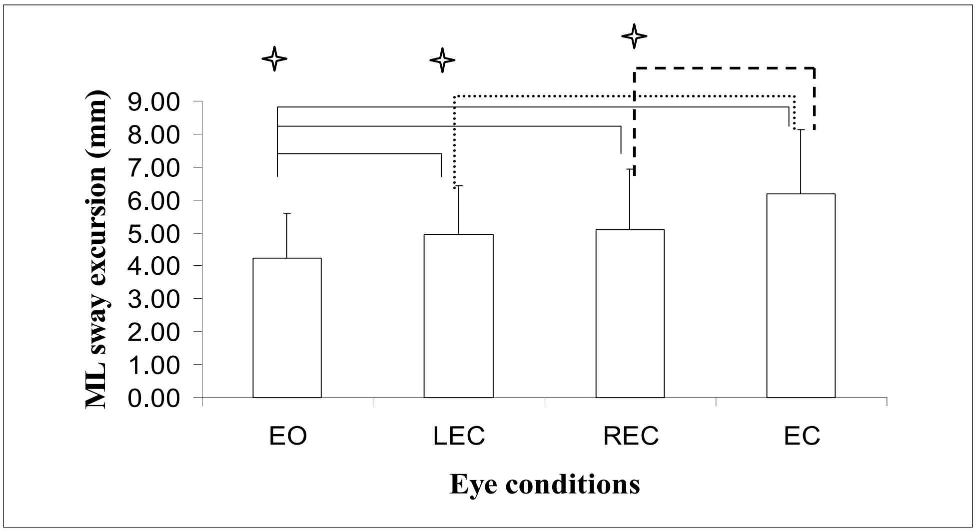


Figure 4.3 COG sway excursion in the mediolateral (ML) direction (mean±SD) in the condition of eyes open (EO), left eye closed (LEC), right eye closed (REC) and both eyes closed (EC)

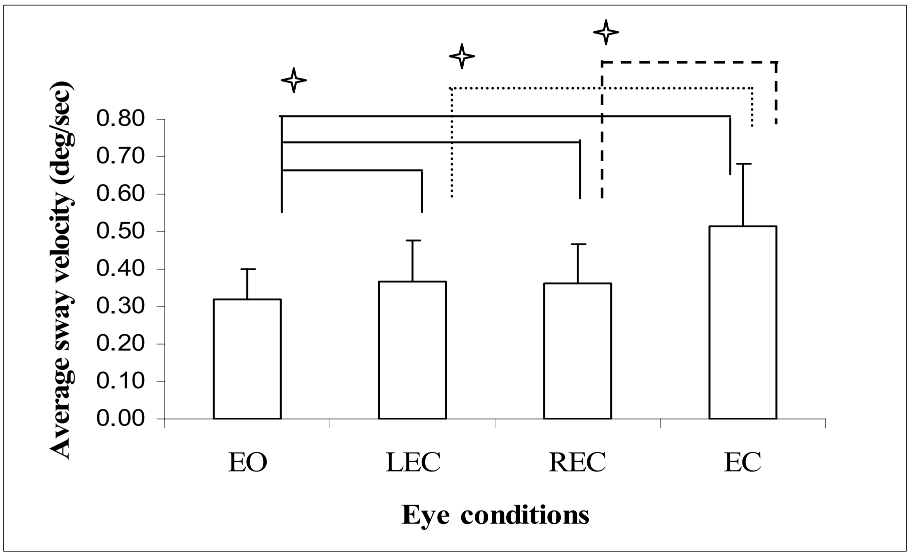


Figure 4.4 Average sway velocity (mean±SD) in the condition of eyes open (EO), left eye closed (LEC), right eye closed (REC) and both eyes closed (EC)

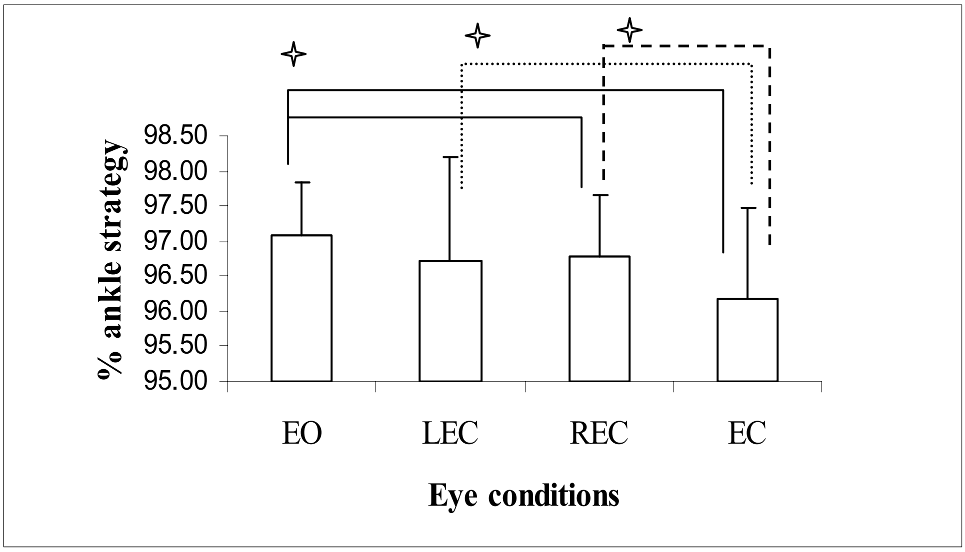


Figure 4.5 The percentage of ankle strategy (mean±SD) in the condition of eyes open (EO), left eye closed (LEC), right eye closed (REC) and both eyes closed (EC)

4.4 The Main Effect of Auditory Input on Balance Variables

The two way analysis of variance for repeated measure showed the significant sound effect in only COG sway excursion in the ML direction ($p<0.05$), that are presented in Table 4.7. There were no significant sound effect on COG sway excursion in the AP direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy. However, significant interactions between vision and sound were focus on COG sway excursion in the AP direction and the percentage of maximum stability. The main effects of sound on these two parameters were interpreted in light of these interactions which were presented in Table 4.4.

Further analysis, Bonferroni test, determined the effect of each sound condition. The result showed no significant difference in COG sway in the ML direction between any pair of sound conditions. However, COG sway excursion in the ML direction was nearly significant in the condition of sound on the right ear when compared with no sound condition ($p=0.056$) as shown in Table 4.8.

Table 4.7 Mean and standard deviation of sound effect on COG sway in ML direction, average sway velocity and the percentage of ankle strategy. (NS = no sound, LS = sound on left ear and RS = sound on right ear)

Parameters	NS		LS		RS		P-value[a]
	Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in ML (mm.)	4.96	0.31	5.06	0.28	5.33	0.30	0.024*
Average sway velocity (deg/sec)	0.39	0.03	0.39	0.04	0.39	0.04	0.588
% Ankle strategy (%)	96.8	0.14	96.72	0.29	96.54	0.78	0.089

a = Two way analysis of variance for repeated measure
✶ = Statistically significant at $p<0.05$

Table 4.8 P-value of post hoc analysis of sound effect on COG sway in the ML direction, average sway velocity and the percentage of ankle strategy. (NS = no sound, LS = sound on left ear and RS = sound on right ear)

Parameters	Conditions	LS	RS
COG sway excursion in ML (mm.)	NS	1.000	0.056
	LS	-	.150
	RS	-	-
Average sway velocity (deg/sec)	NS	1.000	1.000
	LS	-	0.771
	RS	-	-
% Ankle strategy (%)	NS	1.000	0.154
	LS	-	0.513
	RS	-	-

CHAPTER V
DISCUSSION

5.1 Characteristics of the Subjects

From the previous studies, age has influence on balance control in a negative way which means that advance in age shows increase in postural sway (73, 74, 76). The increase in postural sway may be due to the impairments in sensory system or reduction in sensory information; delayed or absent motor response; or incorrect patterns of muscle activation resulting in appropriate and noncompensatory response (73). Generally, the sensory systems decline after age 35 years (110). Degeneration of sensory systems influence on postural control. Therefore, in the present study subjects aged range 20 to 35 years were selected to study the effect of sound and vision on balance performance.

The effect of gender on postural balance is controversial. Hageman et al in 1995 stated that gender did not affect balance (74). However, Wolfson et al found that gender influence on postural control that women show greater sway more than men (66). Kollegger et al found that sex-associated difference were highly significant for all sway components in oldest age group (51-65 years) in which men exhibited more spontaneous postural sway than women in the condition of eyes open (76). The study of Hiengkaew demonstrated that there was sex difference in postural maintenance due to the dominant influence of specific sensory input in each gender. Vision control sway in mediolateral direction in males, while the auditory system has this role in female (109). Therefore, in the present study females was focused.

5.2 The Interaction Effect of Visual and Auditory Inputs on Balance Variables.

The present study found that the interaction of visual and auditory inputs affected on the COG sway excursion in the AP direction and the percentage of maximum stability. Further analysis revealed that when there was the auditory input at the left ear in the condition of opening an eye, the AP sway magnitude was increased when compared to the condition of both eyes open. In addition, when there was the auditory input at the right ear in the condition of both eyes open, the COG sway in the AP direction was observed to increase when compare to the auditory input at the left ear or without auditory input. The increase in the COG sway in the AP direction in such conditions caused the decrease in the percentage of maximum stability.

The interaction of visual and auditory inputs has been reported (26, 33, 37). It was revealed the interaction leading to increase sway behaviors (37). An auditory system is more dominant than the vision in postural maintenance in the ML direction, whereas vision is more dominant in postural control in the AP direction (37). The study of Hiengkaew showed the visual-auditory interaction appearing control the ML COG projection and mean sway velocity both in the ML and AP direction (111). Nevertheless, the result of the present study found the interaction effect on the COG sway in the AP direction, not the ML direction, and did not find the interaction effect on the sway velocity. The possible explanation about the difference between the previous result and the present result is the difference in the method. In the previous study sound was transmitted to both ears, whereas in the present study sound was transmitted to only either the left or right ear. Additionally, the frequency and the loudness of sound in the present study differs from those in the previous studies (37, 111). However, the present result agrees with the reports that the visual - auditory interaction play a role in postural control.

From the present result it is suggested that in controlling the COG sway in the AP direction the visual input is more dominant than auditory input at the left ear. In addition, the auditory input at the right ear seems to assist the visual feedback loss from an eye either the left or right eye. However, when there is full vision information, both eyes open condition, the auditory input at the right ear appears to disturbed postural maintenance in the AP direction.

Several areas within the central nervous system are integrating areas for sensory input. It is showed that the primate superior colliculus is the spatiotopic of visual and auditory space (35, 92). The interaction of visual and auditory system projects to the optic tectum or superior colliculus in the midbrain to form a bimodal visual-auditory map (90).

From the evidence in neurophysiological study and several previous studies about the visual-auditory interaction, the present study, therefore, confirming the interaction between visual and auditory input on postural maintenance. The auditory input at the right ear induces postural instability when there is full visual feedback.

5.3 The Main Effect of Visual Input on Balance Variables.

The present results showed that visual input affected on COG sway excursion in the ML direction, average sway velocity and the percentage of ankle strategy. The deprivation of visual feedback leads to increase in COG sway in the ML directions and average sway velocity. Consequently, the posture is destabilization. Thus, the mechanism for postural control is changed as it is seen a reduction in the percentage of ankle strategy.

The loss of visual feedback from both eyes leads to increase the AP and ML sway (76). However, in the present study it was found that both eyes closed led to an increase sway in the ML direction. In addition, the loss of visual input from an eye also increased sway in the ML directions. It is, therefore, suggested that visual input is also important in women in controlling in both the AP and ML sway. The study of Kollegger et al in 1992 (76) found that in all age groups vision was more important in men than in women. However, the present study could indicate that in young and middle age group vision is also crucial in women.

In patients with hemianopia an increase in lateral sway and COG projection shifting toward to the visual affected side were shown (23). The present study showed that in healthy women no visual input from either the left or right eye destabilized posture. Since the present study did not measure the sway magnitude in individual the left or right side, it can not indicate the COG projection shifting toward to the side of visual feedback loss. The finding of Fox (64) revealed that postural stability was better under binocular vision than under monocular vision, that is similar to the present result. However, the study of Isotalo (63) showed no difference in body sway area between binocular vision and monocular vision. The present study did not record the body sway area but record sway magnitude in the AP and ML direction. The magnitude in the ML directions was increased under monocular vision when compared to binocular vision. Moreover, the sway velocity was greater in monocular vision condition than the binocular. Thus, it is postulated that visual input loss from an eye causes postural instability. The postural instability resulting from monocular vision may be due to the partial loss of visual stimulation on visuo-motor pathway (23, 27).

During standing with feet together and eyes open, the strategy controlling posture is the ankle strategy (60). Visual information is more important for the AP sway stability (37). The sway amplitude and velocity was found to increase when closing eyes (60). When loss of visual input from both eyes or an eye, the increase in postural sway in the ML and AP directions as well as sway velocity was observed. Thus, it is possible that the strategy for postural control is changed to other strategy: hip strategy, stepping strategy. From the present result, it is observed the decrease in the percentage of ankle strategy when loss of visual feedback from both eyes or an eye. Since the ML sway magnitude was increased during standing with both eyes closed or an eye closed, it could be a mechanism to generate muscle around the hip. Consequently, the ankle strategy is reduced and the hip strategy is gradually substituted. Interestingly, in the present study, the loss of visual input from the left eye did not yield the change in the strategy controlling posture. It is suggested that visual input from the dominant eye can help the input from the non-dominant eye and then control the posture by the ankle strategy. The visual feedback is important for postural control in standing. The monocular vision leads to postural destabilization. The loss of visual feedback from both eyes leads to the worst in postural control.

5.4 The Main Effect of Auditory Inputs on Balance Variables.

The auditory system enables us to detect the frequency composition of sound source. Human with normal hearing can locate sound source with good precise, which is the basic for the use of diverse sound in daily life as warning signal or to facilitate orientation in space such as that found in blind people (28).

Sound appears to be an important factor influencing postural maintenance. The study of Juntunen and Kilburn showed postural destabilization in the subjects with more severe hearing loss (30, 31). In addition, the deaf children had poor balance when compared with normal children (91).

Several previous studies used the sound as auditory feedback to stabilize posture (28, 29). It was found that the auditory feedback reduced the AP sway in the healthy adults and stroke patients (28, 29). Additionally, in healthy subjects and congenital blindness auditory input from two speakers at the side of both ears can reduce sway magnitude in the ML and AP directions (17). However, the auditory input is reported to increase postural sway magnitude in the AP and ML directions (26, 33, 37). The result of the present study demonstrated influence of auditory input on the COG sway excursion in the ML direction. However, further analysis did not show the difference in any condition of the auditory input.

Due to the limitation of sound generator in the present study, the sound could not be simultaneously generated into both ears. Hence, the sound was transmitted to either the left or right ear that it was at the left side for the left ear and at the right side for the right ear. The study of Raper and Soames (26, 33) showed that the sound was generated at the lateral side of the body inducing the ML sway whereas the auditory input was come from the front or back of the body leading to the AP sway. However, the study of Eatson (17) showed that no change in the COP sway magnitude if there was sound input from a speaker at the front of the subject. Therefore, in the present study it is possible not to observe the effect of the auditory input on the AP sway excursion since the sound was generated at the side of the ear. In the present study it was not found the effect of auditory input on average sway velocity that is similar to the result of Sakellari (37).

From the present result, it is suggested that the auditory input at the side of the ear influence on the COG sway excursion in the ML direction. The input has no effect on the AP sway excursion, sway velocity, maximum stability and the strategy controlling posture.

5.5 Clinical Implication and Further Study

The successful maintenance of the upright posture requiring an intact sensory system, an integrating central nervous system and an effective motor system. The sensory system consists of visual, vestibular and proprioceptive system. In addition, auditory system also appears to be influence on postural control.

The present study showed that the interaction of visual and auditory input increased postural sway in the AP direction. The loss of visual feedback from both eyes or an eye led to postural destabilization. Furthermore, the auditory input is a factor inducing postural instability in the lateral direction. The result from the present study could be applied to design the rehabilitation program for patient who had postural balance problem.

Patients with postural balance problem should be trained in a quiet room. Trained postural maintenance with the visual input, the patients should open both eyes, then closed the left or right eye, and finally closed both eyes. If physiotherapists need to challenge the patients to induce postural destabilization, the auditory input at the right ear in the condition of both eyes open is recommended.

For further study, it is interesting to study the influence of the auditory feedback on postural maintenance in rehabilitation programs. Furthermore, the visual-auditory interaction on postural balance should be investigated in the patients with mid-brain dysfunction.

CHAPTER VI
CONCLUSION

The present study determined the interaction and individual effects of stationary auditory and visual inputs on balance performance in young Thai women by using SMART Balance Master System.

The results showed the significant interactive effect of visual and auditory input on COG sway excursion in the AP direction and the percentage of maximum stability. The visual input was more dominant than the auditory input at the left ear showing the increase in the COG sway excursion in the AP direction and the decrease in the percentage of maximum stability. In addition, in the condition of both eyes open the auditory input at the right ear showed an increase in the AP sway.

The result of the main effect of vision showed the increase in the COG sway in the AP and ML directions as well as average sway velocity when loss of visual feedback. Hence, the maximum stability was reduced and the strategy for controlling posture was change from the ankle strategy to hip strategy. Postural destabilization was observed when loss of visual feedback from either the left or right eye or the both. Postural destabilization is the worst in the condition that loss of visual feedback from both eyes.

The result of the main effect of the auditory input demonstrated that the sound influenced on COG sway excursion in the ML direction. However, the post hoc analysis did not showed the difference in any condition of sound.

In the conclusion, the present study demonstrated that the interaction of visual and auditory inputs leads to postural instability in the AP direction. Visual feedback is important to postural maintenance. In addition, the auditory input is a factor that influences to postural control, particularly in the COG sway in the ML direction. The result from the present study could be applied to plan rehabilitation program for the patient who had postural balance problem.

REFERENCES

1. Horak FB, Henry SM, Shumway-Cook A. Postural perturbations: new insights for treatment of balance disorders. Phys Ther. 1997;77(5):517-533.

2. Westcott SL, Lowes LP, Richardson PK. Evaluation of postural stability in children: current theories and assessment tools. Phys Ther. 1997;77(6):629-645.

3. Whipple R, Wolfson L, Derby C, Singh D, Tobin J. Altered sensory function and balance in older persons. J Gerontol 1993;48:71-6.

4. Shumway-Cook A, Woollacoot MH. Motor Control: Theory and practical applications. U.S.A.: Williams & Wilkins.; 1995.

5. Paulus WM, Straube A, Brandt TH. Visual stabilization of posture. Brain. 1984;107:1143-1163.

6. Redfern MS, Yardley L, Bronstein AM. Visual influences on balance. J of Anxiety Disorders. 2001;15:81-94.

7. Paulus WM, Straube A, Brandt TH. Visual postural performance after loss of somatosensory and vestibular function. J of Neurology, Neurosurgery, and Psychiatry. 1987;50:1542-1545.

8. Lord SR, Menz HB. Visual contributions to postural stability in older adults. Gerontology. 2000;46:306-310.

9. Wade MG, Jones G. The role of vision and spatial orientation in the maintenance of posture. Phys Ther. 1997;77(6):619-628.

10. Soechting JF, Berthoz A. Dynamic role of vision in the control of posture in man. Exp Brain Res. 1979;36:551-61.

11. Bronstein AM. Suppression of visually evoked postural responses. Exp Brain Res. 1986;63:655-8.

12. Dornan J, Fernie GR, Holliday PJ. Visual input: its importance in the control of postural sway. Arch Phys Med Rehabil. 1978;59:588-591.

13. Vuillerme N, Nougier V, Prieu JM. Can vision compensate for a lower limbs muscularfatigue for controlling posture in human? Neuroscience Letters. 2001;308:103-6.
14. Era P, Heikkinen E. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. J Gerontol 1985;40:287-95.
15. Brocklehurst JC, Robertson D, James-Groom P. Clinical correlates of sway in old age: sensory modalities. Age Ageing 1982;11:1-10.
16. Stones MJ, Kozma A. Balance and age in the sighted and blind. Arch Phys Med Rehabil. 1987;68:85-9.
17. Easton RD, Greene AJ, DiAZio P, Lackner JR. Auditory cues for orientation and postural control in sightedand congenitally blind people. Exp Brain Res. 1998;118:541-550.
18. Savino G, Dickmann A, Ottaviani F, Di nardo W, Scullica L, Di Girolamo S. The role of ocular oscillations upon visually dependent postural stabilization in patients affected by congenital nystagmus. J Vestib Res. 2000;10:201-6.
19. Guerraz M, Shallo-Hoffman J, Yarrow K, Thilo KV, Bronstein AM, Gresty MA. Visual control of postural orientation and equilibrium in congenital nystagmus. Invest Ophthalmol Vis Sci 2000;41(12):3798-804.
20. Di Girolamo S, Di nardo W, Cosenza A, Ottaviani F, Dickmann A, Savino G. The role of vision on postural strategy evaluated in patients affected by congenital nystagmus as an experimental model. J Vestib Res. 1999;9(6):445-51.
21. Jahn K, Strupp M, Krafezyk S, Schuler O, Glasauer S, Brandt T. Suppression of eye movements improve balance. Brain 2002;125:2005-11.
22. Butter CM, Kosslyn D, Mijovic-Prelec D, Riffle A. Field-specific deficits in visual imagery following hemianopia due to unilateral occipital infarcts. Brain 1997;120:217-228.
23. Rondot P, Odier F, Valade D. Postural disturbances due to homonymous hemianopic visual ataxia. Brain 1992;115:179-88.

24. Sveistrup H, Woollacoot MH. Practice modifies the developing automatic postural response. Exp Brain Res. 1997;114:33-43.

25. Horak FB. Postural adaptation to somatosensory loss. Proceeding of Peripheral and Central Somatosensory Control of Posture; 2001 Jan 4-5; Natcher Conference Center National Institutes of Health, United States. Maryland: 2001.

26. Soames RW, Raper SA. The influence of moving auditory fields on postural sway behaviour in man. Eur J Appl Physiol. 1992;65:241-245.

27. Kandel ER, Schwartz JH, Jessell TM. Principles of neural science.; 2000.

28. Petersen H, Magnusson M, Johansonsson R, Akesson M, Fransson P-A. Acoustic cues and postural control. Scand J Rehab Med. 1995;27:99-104.

29. Petersen H, Magnusson M, Johansonsson R, Fransson P-A. Auditory feedback regulation of perturbed stance in stroke patients. Scand J Rehab Med. 1996;28:217-223.

30. Kilburn KH, Warshaw RH, Hanscom B. Are hearing loss and balance dysfunction linked in construction iron workers? British Journal of Industrial Medicine. 1992;49:138-141.

31. Juntunen J, Ylikoski J, Ojala M, Matikainen E, Ylikoski M, Vaheri E. Postural body sway and exposure to high-energy impulse noise. The Lancet 1987;1:261-3.

32. Tanaka T, Kojima S, Takeda H, Ino S, Ifukube T. The influence of moving auditory stimuli on standing balance in healthy young adults and the elderly. Ergonomics 2001;44(15):1403-12.

33. Raper SA, Soames RW. The influence of stationary auditory fields on postural sway behaviour in man. Eur J Appl Physiol. 1991;63:363-367.

34. Lewald J, Ehrenstein WH. The effect of eye position on auditory lateralization. Exp Brain Res. 1996;108:473-485.

35. Cohen YE, Knudsen EI. Maps versus clusters: different representations of auditory space in the midbrain and forebrain. Auditory-space representations 1999;22(3):128-135.

36. Schaefer KP, Suss KJ, Fiebig E. Acoustic-Induced Eye Movements. Am. New york Acad. Science. 1981;118:674-688.

37. Sakellari V, Soames RW. Auditory and visual interactions in portural stabilization. Ergonomics 1996;39(4):634-48.

38. Bell F. Principle of mechanics and biomechanics. Cheltenham: Stanley Thornes; 1998.

39. Ragnarsdottir M. The concept of balance. Physiotherapy. 1996;82(6):368-375.

40. Slobounov SM, Moss SA, Slobounova ES, Newell KM. Aging and time to instability in posture. J Gerontol 1998;53A(1):B71-8.

41. Berg K. Balance and its measure in the elderly: a review. Physiotherapy Canada 1989;41:240-6.

42. Winter DA. Human balance and posture control during standing and walking. Gait Posture 1995;3:193-24.

43. Horak FB. Clinical assessment of balance disorders: Review article. Gait & Posture. 1997;6:76-84.

44. Pollock AS, Durward BR, Rowe PJ. What is balance? Clinical Rehabilitation 2000;14:402-6.

45. Rothwell J. Control of human voluntary movement. London: Chapman & Hall; 1994.

46. Swift CG. Postural instability as a measure of sedaive drug response. British Journal of Clinical Pharmacology. 1984;18:87S-90S.

47. Fitzpatrick R, McClosekey DI. Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in human. J Physiol. 1994;478:173-86.

48. Dichgans J, Diener HC. The Contribution of Vestibulo-spinal Mechanisms to the Maintanance of Human Upright Posture. Acta Otolaryngol (Stockh) 1989;107:338-345.

49. Shupert CL, Horak FB. Effects of vestibular loss on head stabilization in response to head and body perturbations. Journal of Vestibular Research. 1996;6(6):423-37.

50. Wu G, Chiang JH. The significance of somatosensory stimulations to the human foot in the control of postural reflexes. Exp Brain Res. 1997;114:163-169.

51. Kavounoudias A, Gilhodes JC, Roll R, Roll JP. From balance regulation to body orientation: two goals for muscle proprioceptive information processing? Exp Brain Res. 1999;124:80-8.

52. McChesney JW, Woollacoot MH. The effect of age-related declines in proprioception and total knee replacement on postural control. Journal of Gerontology. 2000;55A(11):M658-M666.

53. Kristinsdottir EK, Fransson P-A, Magnusson M. Changes in postural control in healthy elderly subjects are related to vibration sensation, vision and vestibular asymmetry. Acta Otolaryngol (Stockh) 2001;121:700-6.

54. Maki BE, Perry SD, Norrie RG, McIlroy WE. Effect of facilitation of sensation from plantar foot-surface boundaries on postural stabilization in young and older adult. J. Gerontol A Biol Sci Med Sci. 1999;54(6):M281-7.

55. Simmons RW, Richardson C, Pozos R. Postural stability of diabetic patients with and without cutaneous sensory deficit in the foot. Diabetes Res Cli Pract. 1997;36(3):153-60.

56.Oppenheim U, Kohen-Raz R, Alex D, Kohen-Raz A, Azarya M. Postural characteristicsof diabetic neuropathy. Diabetes Care 1999;22(2):328-32.

57. Allum JHJ, Bloem BR, Carpenter MG, Hulliger M, Hadders-Algra M. Propioceptive control of posture: a review of new concepts. Gait & Posture. 1998;8:214-42.

58. Pansky B, Allen DJ, Budd GC. Review of neuroscience. London: Macmillan Publishing Company; 1992.

59. Talbott RE, Brookhart JM. A predictive model study of the visual contribution to canine postural control. Am J Phlsiol 1980;239:R80-R92.

60. Day BL, Steiger MJ, Thompson PD, Marsden CD. Effect of vision and stance width on human body motion when standing: iplications for afferent control of lateral sway. Journal of physiol. 1993;469:479-99.

61. Lee DN, Lishman JR. Visual proprioceptive control of stance. J Human Movement Studies 1975;1:87-95.

62. Potvin AR, Syndulko K, Tourtellotte WW, Lemmon JA, Potvin JH. Human neurologic function and aging process. J Am Geriatr Soc. 1980;28:1-9.

63. Isotalo E, Kapoula Z, Feret P, CGauchon K, Zamfirescu F, Gagey P. Monocular versus binocular vision in postural control. Auris Nasus Larynx. 2004.
64. Fox CR. Some visual influences on human postural equilibrium: binocular versus monocular fixation. Percept Psychophys. 1990;47:409-22.
65. Nakata H, Yabe K. Automatic postural response systems in individuals with congenital total blindness. Gait & Posture. 2001;14:36-43.
66. Wolfson L, Whipple R, Derby CA, Amerman P, Nashner L. Gender differences in the balance of healthy eldery as demonstrated by dynamics posturography. Journal of Gerontology. 1994;49(4):160-167.
67. Hay L, Redon C. Feedforward versus feedback control in children and adults subjected to a postural disturbance. Exp Brain Res. 1999;125:153-162.
68. Ouchi Y, Okada H, Yoshikawa E, Nobezawa S, Futatsubashi M. Brain activation durings maintenance of standing postures in humans. Brain 1999;122:329-38.
69. Riemann BL, Guskiewicz KM, Shields EW. Relationship between clinical and forceplate measures of postural stability. J. Sport Rehabi 1999;8:71-82.
70. Horak FB. Clinical measurement of postural control in adults. Physical Therapy. 1987;67(12):1881-1885.
71. Winter D. A.B.C. (Anatomy, Biomechanics and Control) of balance during standing and walking. Ontorio Canada: University of Waterloo; 1995.
72. Gatev P, Thomas S, Kepple T, Hallett M. Feedforward ankle strategy of balance during quiet stance in adults. J Physiol. 1999;514:915-28.
73. Peterka RJ, Black FO. Age-ralated changes in human posture control: sensory organization tests. Journal of Vestibular Research. 1990;1:73-85.
74. Hageman PA, Leibowitz JM, Blanke D. Age and gender effect on postural control measures. Arch Phys Med Rehabil. 1995;76:961-5.
75. Colledge NR, Cantley P, Peaston I, Brash H, Lewis S, Wilson JA. Ageing and balance: The measurement of spontaneous sway by posturography. Gerontology. 1994;40:273-8.
76. Kollegger H, Baumgartner C, Wober C, Oder W, Deecke L. Spontaneous body sway as a function of sex, age, and vision: posturographic study in 30 healthy adults. Eur Neurol. 1992;32:253-9.

77. Berger W, Trippel M, Discher M, Dietz V. Influence of Subjects' Height on the Stabilization of Posture. Acta Otolaryngol (Stockh) 1992;112:22-30.

78. Carpenter MG, Frank JS, Slicher CP. Surface height effect on postural control: A hypothesis for a stiffness strategy for stance. Journal of vestibular Research-Equilibrium & Orientation. 1999;9(4):277-286.

79. Adkin Al, Frank JS, Carpenter MG, Peysar GW. Postural control is scaled to level of postural threat. Gait & Posture. 2000;12(2):87-93.

80. Shumway-Cook A, Woollacoot M. Attentional demands and postural control: the effect of sensory context. Journal of Gerontology. 2000;55A(1):10-16.

81. Rankin JK, Woollacott MH, Shumway-Cook A, Brown LA. Cognitive influence on postural stability: a neuromuscular analysis in young and older adults. Journal of Gerontology. 2000;55(3):112-119.

82. Voorhees RL, Washington S. Dynamic posturoraphy findings in central nervous system disorders. Otolaryngol Head Neck Surg. 1990;103(1):96-101.

83. Tianwu H, Watanabe Y, Asai M, Shimizu K, Takada S, Mizukoshi K. Effects of alcohol injestion on vestibular function in postural control. Acta Otolaryngol (Stockh). 1995;Suppl 519:127-131.

84. Wober C, Wober-Bingol C, Karwautz A, Nimmerrichter A, Deecke L, Lesch OM. Postural control and lifetime alcohol consumption in alcohol-dependent patients. Acta Neurol Scand 1999;99:48-53.

85. Uchida T, Hashimoto M, Suzuki N, Takegami T, Iwase Y. Smoking-induced body sway and its suppression by periodic saccades. Neuroscience Letters. 1980;18:219-24.

86. Iki M, Ishizaki H, Aalto H, Starck J, Pyykko I. Smoking habits and postural stability. American Journal of Otolaryngology. 1994;15:124-8.

87. Bonner AM, Loria Y, Saint-Hilaire MH. Does long-term aggravation of Parkinson's disease result from nondopaminergic lesion? Neurology. 1987;37:1539-42.

88. Cutson TM, Laub KC, Schenkman M. Pharmacological and nonpharmacological interventions in the treatment of Parkinson's disease. Phys Ther. 1995;75:363-73.

89. Lord SR, Anstey KJ, Williams P, Ward JA. Psychoactive medication use, sensori-motor function and falls in older women. J Clin Pharmac. 1995;39:227-34.

90. Alain C, Arnott SR, Hevenor S, Graham S, Grady CL. "What" and "where" in the human auditory system. Psyhology 2001;98:12301-6.

91. Siegel JC, Marchetti M, Tecklin JS. Age-related balance changes in hearing-impaired children. Phys Ther. 1991;71:183-189.

92. Lewald J, Ehrenstein WH. Auditory-visual shift in localization depending on gaze direction. NeuroReport. 1996;7(12):1929-1932.

93. Whitney SL, Poole JL, Cass SP. A review of balance instruments for older adults. The American Journal of Occupational Therapy. 1998;52(8):666-671.

94. Duncan PW, Weiner DK, Chadler J, Studenski S. Functional reach: a new clinical measure of balance. J Gerontol 1990;45:192-5.

95. Shumway-Cook A, Brauer S, Woollacoot M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys Ther. 2000;80(9):896-903.

96. Tinetti ME. Performance-oriented assessment of mobility problems in elderly patients. J Am Geriatr Soc. 1986;34:119-26.

97. Shumway-Cook A, Horak FB. Assessing the influence of sensory interaction on balance. Phys Ther. 1986;66(10):1548-1550.

98. Horak FB, Jone R, Black F, Shumwau-Cook A. Effects of vestibular rehabilitation on dizziness and imbalance. Otolaryngol Head Neck Surg. 1992;106.

99. El-Kashlan HK, Shepard NT, Asher AM, Snmith-Wheelock M, Telian SA. Evaluation of clinival measures of equilibrium. Laryngoscope. 1998;108(3):311-9.

100. Murray MP, Seireg AA, Sepic SB. Normal Postural Stability and Steadiness: Quantitative Assessment. The Journal of Bone and Joint Surgery. 1975;57-A(4):510-516.

101. Hoffman MA, Koceja DM. Dynamic balance testing with electrically evoked perturbation: A test of reliability. Arch Phys Med Rehabil. 1997;78:290-3.

102. Liston RA, Brouwer BJ. Reliability and validity of measures obtained from stroke patients using the Balance Master. Arch Phys Med Rehabil. 1996;77:425-30.

103. Lehmann JF, Bosswell S, Price R, Burleigh A, deateur BJ, Jaffe KM. Quantitative evaluation of sway as an indicator of functional balance in post-traumatic brain injury. Arch Phys Med Rehabil. 1990;71:955-62.

104. Brouwer B, Culham EG, Liston RAL, Grant T. Normal variability of postural measures: implications for the reliability of relative balance performance outcomes. Scand J Rehab Med. 1998;30:131-7.

105. Neurocom International I. SMART balance Master: operations manual software version 5. U.S.A.: Clackmas; 1997.

106. Hamid MA, Hughes GB, Kinney SE. Specificity and sensitivity of dynamic posturography: a retrospective analysis. Acta Otolaryngol. (stockh) 1991;481:596-600.

107. Wallmann HW. Comparison of elderly nonfallers and fallers on performance measures of functional reach, sensory organization, and limits of stability. Journal of Gerontology Series A: Biological Sciences and Medical Sciences 2001;56:M580-3.

108. Rine RM, Rubish K, Feeney C. Measurement of sensory system effectiveness and maturational changes in postural control in young chidren. Pediatr Phys Ther 1998;10:16-22.

109. Clark S, Rose DJ. Generalizability of the limits of stability test in the evaluation of dynamic balance among older adults. Arch Phys Med Rehabil. 1997;78:1078-84.

110. Jones DG, Lepley MK, Baker BA. Health assessment across the life span. Newyork: Mcgraw - Hill Book Company; 1984.

111. Hiengkaew V. Interaction of visual, vestibular, proprioceptive and auditory stimuli in the maintenance and control of postural sway behaviour. [Ph.D.]: Leeds university; 2000.

APPENDIX

APPENDIX A
CONSENT FORM

แบบฟอร์มยินยอมเข้าร่วมการศึกษา

วันที่..........เดือน...............พ.ศ...........

ข้าพเจ้า……………………………………………………………………………. อายุ……ปี อาศัยอยู่บ้านเลขที่…………ถนน……………………แขวง………………………เขต…………… จังหวัด……………………   ได้รับทราบรายละเอียดของโครงการวิจัยเรื่อง “ผลของเสียงและการมองเห็นต่อความสามารถในการทรงตัว” โดยผู้เข้าร่วมวิจัยจะได้รับการตรวจร่างกายอย่างง่ายเพื่อประเมินความสามารถในการมองเห็น และการได้ยิน และจะทำการทดสอบความสามารถในการทรงตัวในท่ายืนขณะเปิดตา ปิดตาทั้งสองข้าง ปิดตาข้างซ้าย ปิดตาข้างขวา ร่วมกับการให้เสียงด้วยเครื่อง Audiometer ที่หูข้างซ้ายและขวา ซึ่งวัดด้วยอุปกรณ์วัดการทรงตัวในท่ายืนด้วยเครื่องคอมพิวเตอร์ SMART Balance Master System โดยคาดว่าการวิจัยครั้งนี้จะมีประโยชน์อย่างยิ่งต่อการนำไปใช้ในทางคลินิกและข้อมูลที่ได้จะถูกนำไปใช้เป็นข้อมูลพื้นฐานเพื่อการศึกษาต่อไป ขบวนการเก็บข้อมูลครั้งนี้จะไม่มีผลเสียต่อสุขภาพแต่อย่างใด

ทั้งนี้ผู้เข้าร่วมวิจัยมีสิทธิที่จะขอยุติการวิจัยได้ในขณะทำการเก็บข้อมูล

หากผู้วิจัยมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์ และโทษที่เกี่ยวข้องกับการวิจัยจะแจ้งให้ข้าพเจ้าทราบอย่างรวดเร็วโดยปิดบัง

ข้าพเจ้าได้รับทราบจากผู้วิจัยว่าจะไม่เปิดเผยข้อมูลหรือผลการวิจัยของข้าพเจ้าเป็นรายบุคคลต่อสาธารณชน

ข้าพเจ้าได้รับทราบและได้ซักถามผู้วิจัยจนหมดข้อสงสัยโดยตลอดแล้ว และยินดีเข้าร่วมงานวิจัย จึงได้ลงลายมือชื่อไว้เป็นหลักฐาน

ลงชื่อ..ผู้ยินยอม

(..)

ลงชื่อ..หัวหน้าโครงการ

(..)

ลงชื่อ...พยาน

(..)

APPENDIX B
DATA COLLECTION FORM

แบบบันทึกข้อมูลสุขภาพ

วันที่…………………

1. ประวัติทั่วไป

ชื่อ-สกุล …………………………………………………. อายุ …… วัน เดือน ปี เกิด…………

ที่อยู่ปัจจุบัน ………………………………………………………………………………………..

เบอร์โทร ……………..…การศึกษา …………… อาชีพปัจจุบัน ..…………… สถานภาพ………...

น้ำหนัก ………. กิโลกรัม ส่วนสูง ……………. เซนติเมตร BMI …..………กิโลกรัม/เมตร^2

เท้าข้างที่ถนัด ❒ ขวา ❒ ซ้าย

1. เขียนเลข 8 ❒ ขวา ❒ ซ้าย
2. เตะลูกบอล ❒ ขวา ❒ ซ้าย
3. หยิบยางลบ ❒ ขวา ❒ ซ้าย

2. ประวัติความเจ็บป่วย

-โรคเกี่ยวกับหู (เช่น หูน้ำหนวก, หูอื้อ) ❒ไม่มี ❒มี โปรดระบุ__________

-โรคเกี่ยวกับระบบกระดูกและกล้ามเนื้อ ❒ไม่มี ❒ มี โปรดระบุ__________

-โรคเกี่ยวกับระบบประสาท ❒ ไม่มี ❒ มี โปรดระบุ__________

-โรคเกี่ยวกับระบบทางเดินหายใจ ❒ ไม่มี ❒ มี โปรดระบุ__________

- มีปัญหาเกี่ยวกับสายตาที่ไม่สามารถแก้ไขด้วยเลนส์ ❒ ไม่มี ❒ มี โปรดระบุ__________

-โรคประจำตัวอื่น ๆ ❒ ไม่มี ❒ มี โปรดระบุ__________

- มีอาการเมารถหรือเมาเรือ ❒ ไม่มี ❒ บางครั้ง ❒ บ่อยครั้ง

ในวันที่ทำการทดสอบท่านมีอาการหรือปฏิบัติตนดังต่อไปนี้หรือไม่

- มีอาการปวด, อ่อนแรงของกล้ามเนื้อ, หรือมีการจำกัด การเคลื่อนไหวของข้อต่อในส่วนล่างของลำตัว	❐ ไม่มี	❐ มี
- มึนงง, เวียนศีรษะ, คลื่นไส้	❐ ไม่มี	❐ มี
- คืนก่อนทดสอบนอนเพียงพอหรือไม่ (6-8 ชม.)	❐ ไม่เพียงพอ	❐ เพียงพอ
- รับประทานยาใดๆ เช่น ยาแก้หวัด, ยาคลายกล้ามเนื้อ	❐ ไม่มี	❐ มี
- สูบบุหรี่ก่อนทำการทดสอบ 1 ชั่วโมง	❐ ไม่มี	❐ มี
- ก่อนทำการทดสอบ ท่านดื่มเครื่องดื่มที่มี ส่วนผสมของแอลกอฮอล์ภายใน 24 ชั่วโมง	❐ ไม่มี	❐ มี
- ดื่มเครื่องดื่มที่มีส่วนผสมของคาเฟอีนภายใน 8 ชั่วโมง	❐ ไม่มี	❐ มี

หมายเหตุ ……………………………………………………………………………………………

APPENDIX C
RESULT OF PILOT STUDY

The aim of this study was to determine the effect of auditory and visual inputs on static postural balance. Ten healthy women were assessed balance performance by using SMART Balance Master System. Their characteristics were shown in Table C.1. The parameters of the static postural maintenance were COG sway excursion in anteroposterior (AP) and mediolateral (ML) direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy,

Table C.1 Characteristics of subjects. (n=10)

Characteristics	Age (yrs.)	Weight (kg.)	Height (cm.)	BMI (kg/m^2)
Mean	24.10	45.75	156	18.84
SD	4.36	2.37	5.03	1.23
Range	20-35	43-50	150-168	17.02-20.58

Two way analysis of variance for repeated measure showed the significant individual effect of vision on all parameters ($p<0.05$) and the individual effect of auditory on COG sway excursion in AP direction ($p<0.05$) and the percentage of maximum stability ($p<0.05$). However, there was no interaction effect of vision and auditory on postural balance.

The Interaction Effect of Visual and Auditory Inputs on Balance Variables.

Two way analysis of variance for repeated measure showed that there was no significant difference in the interaction effect of vision and sound on all parameters as shown in Table C.2

The Individual Effect of Visual Input on Balance Variables.

Two way analysis of variance for repeated measure demonstrated the significant difference in COG sway excursion in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy as shown in Table C.3

The result of post hoc analysis of COG sway excursion in AP direction showed that there was significant increase in AP sway ($p<0.05$) when loss of visual feedback from both eyes (EC) compared with EO. In the COG sway excursion in ML direction, postural sway was significant increase during EC when compared with EO and REC conditions. There was significant increase in average sway velocity on EC condition compared with EO, LEC and REC. In addition, there was significant difference in the percentage of ankle strategy on eye closed compared with EO, LEC and REC. Although, two way analysis of variance for repeated measure showed significant difference in the percentage of maximum stability, however, the post hoc analysis was not showed the significant difference in the visual condition as shown in Table C.4.

The Individual Effect of Auditory Input on Balance Variables.

The two way analysis of variance for repeated measure demonstrated the significant difference ($p<0.05$) in the path of COG excursion in anteroposterior direction and the percentage of maximum stability (Table C2). However, Bonferroni test was not showed the significant difference in each condition of sound.

Table C.2 Mean and standard deviation of interactive effect of visual and auditory inputs in all parameters.

Parameters	Interaction of visual and auditory inputs (Vision* Sound)	NS		LS		RS		P-value [a]
		Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in AP (mm.)	EO	3.22	0.84	3.73	1.74	3.61	1.83	P=0.371
	LEC	3.69	1.23	4.31	1.48	3.72	1.25	
	REC	3.41	1.80	3.44	1.28	4.34	2.23	
	EC	4.76	2.13	5.69	2.27	5.77	2.34	
COG sway excursion in ML (mm.)	EO	4.49	1.33	4.95	1.69	5.24	2.13	P=0.633
	LEC	4.73	1.66	4.99	1.89	5.24	1.50	
	REC	5.66	2.44	4.96	1.69	5.42	2.12	
	EC	6.20	1.54	5.90	1.99	6.92	3.13	
Average sway velocity (deg/sec)	EO	0.34	0.08	0.35	0.08	0.35	0.08	P=0.574
	LEC	0.39	0.11	0.38	0.15	0.39	0.11	
	REC	0.39	0.14	0.34	0.10	0.39	0.10	
	EC	0.53	0.19	0.55	0.19	0.58	0.23	
% maximum stability (%)	EO	94.80	2.12	94.10	2.92	94.40	3.31	P=0.422
	LEC	94.20	2.20	93.00	2.49	94.10	2.13	
	REC	94.60	2.91	94.60	2.01	93.10	3.06	
	EC	92.30	3.77	90.90	3.54	90.80	4.02	
% ankle strategy (%)	EO	97.20	0.79	96.80	0.63	96.90	0.74	P=0.312
	LEC	97.10	0.74	96.70	0.95	96.70	0.82	
	REC	96.90	0.74	97.10	0.74	96.70	0.48	
	EC	96.40	1.35	95.50	1.84	95.50	1.35	

a = Two way analysis of variance for repeated measure.

Table C.3 Mean and standard deviation of visual effect on COG sway in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy. (EO = eyes open, LEC = left eye closed, REC = right eye closed and EC = Eyes closed)

Parameters	EO		LEC		REC		EC		P-value [a]
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in AP (mm.)	3.52	1.18	3.91	1.06	3.73	1.62	5.34	2.20	0.002✶
COG sway excursion in ML (mm.)	4.89	1.46	4.99	1.36	5.35	1.80	6.34	2.02	0.001✶
Average sway velocity (deg/sec)	0.35	0.07	0.39	0.11	0.37	0.10	0.55	0.19	0.001✶
% Maximum stability (%)	94.43	2.01	93.77	1.83	94.10	2.57	91.33	3.53	0.003✶
% Ankle strategy (%)	96.67	0.55	96.83	0.65	96.90	0.39	95.80	1.26	0.001✶

a = Two way analysis of variance for repeated measure

✶ = Statistically significant at $p<0.05$

Table C.4 P-value of post hoc analysis of visual effect on COG sway in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy. (EO = eyes open, LEC = left eye closed, REC = right eye closed and EC = Eyes closed)

Parameters	Conditions	EO	LEC	REC	EC
COG sway excursion in AP (mm.)	EO	-	0.125	1.00	0.040*
	LEC	-	-	1.00	0.071
	REC	-	-	-	0.081
	EC	-	-	-	-
COG sway excursion in ML (mm.)	EO	-	1.00	1.00	0.014*
	LEC	-	-	1.00	0.050
	REC	-	-	-	0.002*
	EC	-	-	-	-
Average sway velocity (deg/sec)	EO	-	0.441	0.724	0.009*
	LEC	-	-	1.00	0.003*
	REC	-	-	-	0.004*
	EC	-	-	-	-
% Maximum stability (%)	EO	-	0.69	1.00	0.052
	LEC	-	-	1.00	0.094
	REC	-	-	-	0.103
	EC	-	-	-	-
% Ankle strategy (%)	EO	-	1.00	1.00	0.020*
	LEC	-	-	1.00	0.014*
	REC	-	-	-	0.035*
	EC	-	-	-	-

* = Bonferroni, statistically significant different ($p<0.05$)

Table C.5 Mean and standard deviation of auditory effect on COG sway in AP and ML direction, average sway velocity, the percentage of maximum stability and the percentage of ankle strategy. (NS = no sound, LS = sound on left ear and RS = sound on right ear)

Parameters	NS		LS		RS		P-value[a]
	Mean	SD	Mean	SD	Mean	SD	
COG sway excursion in AP (mm.)	3.77	1.11	4.30	1.42	4.36	1.44	0.016✶
COG sway excursion in ML (mm.)	5.27	1.49	5.14	1.65	5.71	1.96	0.328
Average sway velocity (deg/sec)	0.42	0.12	0.41	0.12	0.43	0.11	0.473
% Maximum stability (%)	93.98	1.92	93.15	2.26	93.08	2.44	0.043✶
% Ankle strategy (%)	96.90	0.78	96.53	0.94	96.45	0.52	0.105

a = Two way analysis of variance for repeated measure

✶ = Statistically significant at $p<0.05$

APPENDIX D
SAMPLE SIZE

The sample size for the present study aimed to examination the interactive and individual effect of vision and sound that was calculated with the following equation (105).

$$N = \left\{ \frac{(Z\alpha + Z\beta)/\sigma_d}{\triangle} \right\}^2$$

N	=	sample size
$Z\alpha$	=	Z value when set the confident level equal to 95% of significance level at 0.05 (α = 0.05) = 1.96
$Z\beta$	=	Z value when set the power testing equal to 80% = 0.84
σ_d	=	standard deviation of mean difference
$\triangle$	=	The difference of mean of the parameter when compare EO condition with the other conditions.

From the sample size calculation, the average sway velocity and the COG sway in AP and ML direction are considered to be important parameters in this study. The sample size values of these parameters are ranging from 4 to 502 subjects. However, two third of the sample size values from the average sway velocity, the COG sway in AP and ML direction are ranging from 4 to 44 subjects. Therefore, in order to cover the majority of the interested parameters, the appropriate sample size for this study is 50 subjects.

APPENDIX E
RESULT OF TEST-RETESR RELIABILITY

The purpose of this test was to determine the test-retest reliability of balance testing from SMART Balance Master system.

Procedure

Ten healthy women aged 20 to 35 years participated in the study. Static postural balance of all subjects was measured by SMART Balance Master System. The parameters were average sway velocity, the percentage of maximum stability, and the percentage of ankle strategy, all of which were calculated from the software program version 5.0 of SMART Balance Master system. In addition, the paths of COG excursion in antero-posterior and medio-lateral direction were manually measured on printout by using a vernier caliper.

The protocol consisted of 12 conditions and each condition was tested three times. The first trial was used as the practical trial. The score of the second and the third trial were the test for determining the reliability of three balance parameters; the average sway velocity, the percentage of maximum stability, and the percentage of ankle strategy. The intra-tester and inter-tester reliability of the path of COG excursion was assessed, which the second score of measurement was used to determine the reliability. Two master degree students of Physical Therapy participated in the study of inter-tester reliability. Before the measurement, the researcher explained the method of measurement to the tester.

Data Analysis

Intraclass correlation coefficient (ICC 3,1) was used to determine the test-retest reliability, intra-tester and inter-tester reliability of the parameters.

Result

The result of test-retest reliability demonstrated as followed:

1. Average sway velocity (deg/sec) of balance testing in 12 conditions; ICC (3,1) value showed moderate to good reliability, which had ranging from 0.40-0.92. (Table E1)
2. The percentage of maximum stability (%) in 12 conditions of the testing demonstrated poor to moderate reliability. Most values of ICC (3,1) were higher than 0.5. The value of poor reliability was lower than 0.37, while most of the difference values of raw data between the second and the third trial were less than 6. (Table E.2, Table F.2)
3. The percentage of ankle strategy (%) of balance testing found that nine of twelve conditions showed moderate to good reliability which ICC (3,) ranged from 0.54 to 0.88, while three conditions had poor reliability. The maximum difference value of raw data between the second and the third trial was 2 in three conditions. (Table E.3, Table F.3)
4. The path of COG sway excursion in antero-posterior direction (mm.) showed good reliability for both intra-tester and inter-tester of the measurement. ICC (3,1) value was 0.99 of both test. (Table E4, E5)
5. The path of COG sway excursion in medio-lateral direction (mm.), ICC (3,1) value of intra-tester and inter-tester showed good reliability, which had range from 0.99 to 0.9997. (Table E.6, E.7)

Table E1 Intratester reliability of the measurement of the average sway velocity (trial 2,3) in ten subjects.

Conditions	ICC (3,1)
Eyes open	0.85
Eyes Open with sound on left ear	0.62
Eyes Open with sound on right ear	0.40
Eyes-closed	0.85
Eyes-closed with sound on left ear	0.92
Eyes-closed with sound on right ear	0.74
Left eye-closed	0.71
Left eye-closed with sound on left ear	0.72
Left eye-closed with sound on right ear	0.83
Right eye-closed	0.83
Right eye-closed with sound on left ear	0.87
Right eye-closed with sound on right ear	0.54

Table E2 Intratester reliability of the measurement of the percentage of maximum stability (trial 2,3) in ten subjects.

Conditions	ICC (3,1)
Eyes open	0.06
Eyes Open with sound on left ear	0.37
Eyes Open with sound on right ear	0.71
Eyes-closed	0.85
Eyes-closed with sound on left ear	0.59
Eyes-closed with sound on right ear	0.66
Left eye-closed	0.11
Left eye-closed with sound on left ear	0.53
Left eye-closed with sound on right ear	0.65
Right eye-closed	0.69
Right eye-closed with sound on left ear	0.12
Right eye-closed with sound on right ear	0.18

Table E3 Intratester reliability of the measurement of the percentage of ankle strategy (trial 2,3) in ten subjects.

Conditions	ICC (3,1)
Eyes open	0.70
Eyes Open with sound on left ear	0.68
Eyes Open with sound on right ear	0.22
Eyes-closed	0.82
Eyes-closed with sound on left ear	0.88
Eyes-closed with sound on right ear	0.54
Left eye-closed	0.66
Left eye-closed with sound on left ear	0.46
Left eye-closed with sound on right ear	0.70
Right eye-closed	0.59
Right eye-closed with sound on left ear	0.80
Right eye-closed with sound on right ear	-0.37

Table E4 Intra-tester reliability of the measurement of distance of sway in antero-posterior direction (trial 2) in ten subjects.

Conditions	ICC (3,1)
Eyes open	0.9840
Eyes Open with sound on left ear	0.9993
Eyes-closed	0.9992
Eyes-closed with sound on left ear	0.9999
Eyes-closed with sound on right ear	0.9996
Left eye-closed	0.9976
Left eye-closed with sound on left ear	0.9989
Left eye-closed with sound on right ear	0.9977
Right eye-closed	0.9996
Right eye-closed with sound on left ear	0.9980
Right eye-closed with sound on right ear	0.9999

Table E5 Intra-tester reliability of the measurement of distance of sway in medio-lateral direction (trial 2) in ten subjects.

Conditions	ICC (3,1)
Eyes open	0.9940
Eyes Open with sound on left ear	0.9995
Eyes Open with sound on right ear	0.9997
Eyes-closed	0.9982
Eyes-closed with sound on left ear	0.9989
Eyes-closed with sound on right ear	0.9996
Left eye-closed	0.9997
Left eye-closed with sound on left ear	0.9993
Left eye-closed with sound on right ear	0.9983
Right eye-closed	0.9900
Right eye-closed with sound on left ear	0.9980
Right eye-closed with sound on right ear	0.9992

Table E6 Inter-tester reliability of the measurement of distance of sway in antero-posterior direction (trial 2) in ten subjects.

Conditions	ICC (3,1)
Eyes open	.9969
Eyes Open with sound on left ear	.9989
Eyes Open with sound on right ear	.9990
Eyes-closed	.9989
Eyes-closed with sound on left ear	.9994
Eyes-closed with sound on right ear	.9977
Left eye-closed	.9963
Left eye-closed with sound on left ear	.9989
Left eye-closed with sound on right ear	.9972
Right eye-closed	.9987
Right eye-closed with sound on left ear	.9971
Right eye-closed with sound on right ear	.9993

Table E7 Inter-tester reliability of the measurement of distance of sway in medio-lateral direction (trial 2) in ten subjects.

Conditions	ICC (3,1)
Eyes open	.9962
Eyes Open with sound on left ear	.9990
Eyes Open with sound on right ear	.9955
Eyes-closed	.9984
Eyes-closed with sound on left ear	.9983
Eyes-closed with sound on right ear	.9937
Left eye-closed	.9993
Left eye-closed with sound on left ear	.9981
Left eye-closed with sound on right ear	.9967
Right eye-closed	.9996
Right eye-closed with sound on left ear	.9980
Right eye-closed with sound on right ear	.9990

APPENDIX F
RAW DATA OF THE STUDY

Table F.1 The COG sway excursion in anteroposterior direction (mm)

NO	Eyes open			Left eye closed			Right eye closed			Eyes closed		
	NS	LS	RS	NS	LS	RS	NS	LS	RS	NS	LS	RS
1	2.8	2.2	3	3.3	3.5	2.7	3.5	2.6	3.3	2.9	5	3.3
2	3.9	6.3	4	3.8	6.2	5	8.2	5.9	10	7.6	8.8	8.3
3	2.6	4.3	3.4	2.7	4.4	4.5	2.4	5.1	5.2	3.6	3.8	5
4	3.9	5.2	8.3	6.7	5.6	3.2	3.1	2.7	5.3	2.9	7.8	5.9
5	2.8	4	3.1	3.3	5.5	3.9	3.2	2.9	2.5	5.9	5.6	6.7
6	3.6	6.2	3.6	4.5	5.8	5.7	4.1	3.1	3.9	7	6.8	7.5
7	3.6	2.9	2.6	4	4	2.6	2.8	3.7	3.5	7.6	8.5	8.9
8	3.1	1.6	1.7	2.3	1.6	2.5	2.2	1.4	3.2	2.2	3.6	1.9
9	3.2	2.7	4.7	5.1	5.3	5	4.5	3.6	4.4	4.6	6.4	5.7
10	1.5	2.6	2.1	3.3	2.7	2.2	2	3.3	2.2	2.9	1.9	3.3
11	3.7	3.1	4.2	5.2	3.8	3.3	2.9	4.4	4.4	5.4	4.6	5.3
12	3.3	3.7	4.4	5.6	5.2	3.2	4.5	2.6	2.3	5.2	5.6	5.4
13	2.8	3.7	3.1	5.3	3.6	4.4	6	3.9	3.3	4.5	5.8	5.1
14	2.3	2.2	3.5	3.1	3.7	2.5	6.2	2.8	4	5.4	5.3	2.9
15	2.5	4.4	3	2.7	4.8	4.9	6.4	4.4	3.4	5.7	3.4	5.1
16	4.8	3.3	4.8	2.9	3.2	3.7	3	7.4	5.9	5.8	5.8	7
17	5.3	5.1	5.5	6.8	6.2	8	6.7	3.4	6.7	4.7	4.7	8
18	2.7	4.7	5.1	5.4	4.4	4.7	3.3	7.6	4.1	5.6	5.5	7.5
19	2.8	2.1	2.8	2.6	3.5	4	3	3.5	3	6.7	6.4	5.1
20	1.8	2.2	3.9	3.7	3	3.9	4.3	3.5	2.3	7.7	5.8	4.3
21	2.8	2	3.5	4.3	2.9	5.6	5.7	3.9	4.6	6	5.9	4.8
22	2.9	2.3	2.9	3.3	3	4.6	4.6	5.4	2.7	7.1	3.2	5.6
23	2.6	2.1	4.7	2.1	3.1	3.9	5.7	3.3	7.2	2.7	5.3	4.6
24	2.2	2.7	2.5	3.7	4.7	3.3	3	3.9	4.6	4.1	4.2	6.5
25	3.2	3.6	5.9	4.3	4.5	3.5	5.2	6	4.4	4.1	9.2	12.5
26	2.3	1.8	3.9	3.2	3.8	3	2.7	2.1	2.3	2.8	3	2
27	2.5	2.8	3.2	3.5	3.3	3.6	5.4	2.5	3.6	4.8	3.3	4
28	3.3	2.5	3	5.4	3.7	3.5	2.8	6.8	3	5	5.3	5.4
29	2.6	2.8	3.9	4.3	5.6	3	4.2	3.8	3.9	4.5	5	4.2
30	2.2	2	1.8	3	2.6	3.2	2.7	2.2	2.4	3	3.4	2.9
31	4.8	4.6	5	5.9	4.9	4	7.2	6.1	8.6	6.4	7.8	5.9
32	2.5	3	6.2	6.3	4.8	3.4	6.7	4.8	5.7	5.6	8.9	7.3
33	3.7	3.1	4.9	3	4.5	5.4	4.7	4.2	4.4	3.8	6.4	4.8
34	2.2	2.2	5	3.3	2.8	3.4	2.7	2.2	2.9	4.5	6	3.2
35	2.7	3	2	2.6	4.7	5.1	5.1	3.4	3.3	6.2	3.4	3.3
36	3	3.3	4.7	7.3	7.5	3.4	4.4	5.5	3.3	7.1	9.8	11.8
37	1.9	1.7	3.4	3.2	2.2	1.8	2	2.3	2.7	2.8	2	2.2
38	2.3	2.9	2.2	3	1.8	2.6	2.2	2.2	2.1	5.2	4.2	3.5
39	2.4	1.5	1.4	2.3	1.7	2.1	2.1	2.1	1.8	2.7	3.1	1.9
40	3.5	2.3	3.5	2.6	3.2	2.3	2.8	2.6	3.9	4.7	8.8	5.6
41	5.5	7.2	6.3	2.7	6	3.7	4.5	8.6	5.4	5.7	6.1	7.1
42	4.8	4.2	4	3.6	6.6	5.9	3.5	3.4	4.4	6.3	5.3	4.5
43	3.1	2	3.4	2.8	1.9	1.8	4.9	2.3	3	5.1	3.9	2.4
44	2.9	2.8	2.5	2.5	2.3	5	2.7	2.7	2.3	5.3	4.6	4.6
45	3.3	2.3	3	4.1	5.3	3	4.1	4.9	3.3	5.1	3.8	5.3
46	2.7	2.8	3.1	4	3	2.5	3.7	3.4	4	6.2	5.5	5.8
47	2.5	1.7	3.5	3.7	1.9	3.9	2.2	3.1	3.2	5.5	4	2.8
48	2.8	2.4	2.8	2	2.5	2.4	2.9	2.6	2.6	3.5	2.9	2.9
49	1.8	2	4.5	3.8	2.9	2.6	2.6	2.8	2.5	2.5	4.5	7.1
50	4.2	4.3	2.9	5.3	5.8	1.3	3.3	3.8	4.4	4	4	5.7

Table F.2 The COG sway excursion in mediolateral direction (mm)

NO	Eyes open			Left eye closed			Right eye closed			Eyes closed		
	NS	LS	RS	NS	LS	RS	NS	LS	RS	NS	LS	RS
1	4.7	6.3	7.1	7.9	5	7	7.2	5.1	4.9	6.8	7.2	6.2
2	6.4	5.6	4.2	5	3.3	4.6	6.3	6.3	4.5	7	7.4	5.7
3	4.5	6.1	4.5	4.5	7.5	4.8	3.4	4.5	5.5	4.5	4.2	7.1
4	3.1	6.8	8.4	5.2	6.7	5.3	7.4	5.7	10.2	8.2	8.6	10.5
5	4.1	3.7	3.2	3.9	6.5	3.9	5.8	4.4	3.7	6.1	6	5.3
6	6.6	7.3	8.5	6.5	5.3	7.5	10.7	7.6	6.2	7.1	7.1	13.5
7	4.1	4.5	5	5.4	6.7	7	5.9	6.9	7.6	7.7	7.5	8.1
8	2.4	2.4	2	2.2	4.2	3.3	2.8	2.4	3.8	3.5	2.6	2.6
9	6.5	4.1	3.6	5.2	7.1	5.4	5.7	3.1	5	6.4	6.4	7.4
10	3.7	3.2	5	3.2	2.1	3.6	3.3	2.9	4.6	4.5	3.6	4.5
11	4.1	3.2	4.3	6.2	4.9	4.6	4.5	4.7	4.1	7.3	4.9	5.1
12	3.6	2.8	4.5	5.5	5.7	5	7.8	5	5.4	7.3	8.8	8.5
13	4.6	5.5	3.4	4.5	4.7	5.8	3.5	6.3	5.2	4.5	8.2	7.5
14	3.9	2.6	3.7	3.6	2.6	5.3	4.5	3	3.9	5.4	2.7	7.1
15	5.2	5.8	4	4.4	4.9	7	5.3	4.8	5.7	6.4	9.4	7.2
16	4.4	6.2	6.5	6.4	5.1	4.6	5	6.9	5.1	7.8	5.5	6.9
17	4.7	6	4.7	6.9	6	3.8	4.6	7	4.5	6.2	6.5	7.1
18	5.1	5.2	4.9	5.5	7.6	6.7	4.7	8.6	6	6.4	8.3	10.6
19	2.4	2.1	2	3.1	3.2	3.8	3.2	3.2	3	3.7	2.7	3.6
20	4.5	2.4	3.6	3.4	2.8	3.8	4	3.7	4.9	6	4.1	8.2
21	5	6	6	6.6	7.2	6.7	4.7	3.2	4.8	4.9	6.5	5.7
22	5.2	4.8	5.2	7.3	5.9	4.9	7.3	5.3	4.3	6.1	5.8	8.3
23	3.2	3.6	5.1	3.3	5.7	3.9	4	3.8	5	4.3	3.3	6.6
24	2.7	3.3	3.6	5.4	5	4.7	5.4	4.9	3.9	8.6	6.3	6.1
25	6.3	5	10	6	7.5	10.1	5	8.2	8.7	7	7.1	8.6
26	3.5	2.2	2.3	4.8	3.1	2.7	3.2	1.8	2.2	3.2	2.5	2.3
27	3.2	2.9	3.7	5	4	4.8	6.9	4.2	4.6	5	6.2	7.5
28	3.2	4.8	3.6	7.6	4.1	5.6	4.4	3.3	7.9	6.5	6.8	5.8
29	3.9	4.5	5.8	5.5	4.7	5.4	5.8	4.2	5.9	5.9	8.1	7.5
30	3.8	3.1	3	3.1	3.5	4.3	2.5	2.7	3.5	3.2	6.2	3.9
31	4.5	4.4	6.8	6.5	5.2	7	4.5	8.1	7.1	7.9	9.4	8.2
32	4.3	4.1	4.8	5.4	3.9	4.4	6.8	6.4	4.6	6.7	6.5	4.7
33	4.5	3.3	4.8	3.6	5.1	4	3.8	3.9	5.3	4.2	7.7	6.8
34	4.7	5	4.1	4.3	5.2	5.8	8.7	6.7	5.5	6.5	6.8	6.3
35	3.1	3	2.5	2.3	4.9	5.5	5.1	5.1	4.6	5.3	4.5	4.9
36	4	3.8	3.7	7.1	6	6	7.9	8.4	12.5	9	9.4	9.3
37	2.3	2.9	3.3	2.9	2.7	4	2.4	2.4	2.8	3.3	2.7	3.6
38	2.6	3.2	3.3	3.7	3.4	4.3	2.9	2.9	4.8	6.1	5.4	6.3
39	3.7	3.2	2.4	2.5	4	2.5	3.7	5.2	2.8	2.7	3.1	2.8
40	3.7	3.3	4.9	4.6	6.3	5.7	3.8	5.5	7.1	4.8	8.2	5.5
41	3.7	3.8	4.3	4.9	6.5	3.8	6.1	5.6	4.5	4.9	5.7	5.3
42	5.6	3.5	5	5.5	6.5	4.9	5	5.4	5.2	8.4	7.5	4.7
43	4.2	2.9	3.5	4.1	4.2	2.7	5	4.3	3.2	4.8	6.9	8.6
44	3.5	4.3	3.5	2.4	6.3	6.3	4.5	4.7	5.8	5.1	6.2	6.5
45	3.3	4.4	4.2	7.1	6.7	5.4	3.6	6.1	4.7	4.8	6.5	8.1
46	3.9	4.3	6.8	4.4	4.9	4	6.6	5.1	10.5	5.4	7.2	6.5
47	3.2	3.2	4.1	4.3	3.2	6.5	4.9	5	6	6	5.7	7.8
48	5.5	2.4	5.2	3.1	3.1	3	4.1	2.3	3.6	3.4	4.7	3.1
49	2.4	3	4	6.3	3.1	2	4.2	8.2	3.8	2.8	4.4	7
50	4.7	4.3	3.5	5.9	6.4	4.8	4.3	5.7	4.2	10.6	8.6	7.5

Table F.3 Average sway velocity (deg/sec)

NO	Eyes open			Left eye closed			Right eye closed			Eyes closed		
	NS	LS	RS	NS	LS	RS	NS	LS	RS	NS	LS	RS
1	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.3	0.6	0.5	0.5
2	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.4	0.5	0.6	0.7	0.7
3	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.4	0.6
4	0.2	0.4	0.5	0.4	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.4
5	0.4	0.4	0.3	0.5	0.7	0.4	0.5	0.4	0.4	0.7	0.8	0.9
6	0.4	0.4	0.4	0.5	0.4	0.6	0.5	0.4	0.4	0.7	0.7	0.7
7	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.8	0.9
8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2
9	0.4	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.4
10	0.3	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.4	0.3	0.4
11	0.4	0.3	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.7	0.5	0.4
12	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.6	0.7	0.6
13	0.5	0.5	0.3	0.4	0.5	0.5	0.4	0.4	0.5	0.6	0.7	0.6
14	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4
15	0.3	0.3	0.3	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.5	0.4
16	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.6	0.8	0.7	0.9
17	0.4	0.4	0.5	0.8	0.6	0.5	0.6	0.5	0.6	0.6	0.5	0.9
18	0.3	0.3	0.3	0.4	0.4	0.5	0.3	0.4	0.2	0.5	0.5	0.6
19	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.5	0.5	0.4
20	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.5	0.4	0.4
21	0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.3	0.4	0.6	0.6	0.5
22	0.3	0.3	0.3	0.5	0.5	0.4	0.4	0.5	0.4	0.6	0.5	0.6
23	0.4	0.3	0.3	0.2	0.4	0.4	0.3	0.3	0.3	0.3	0.4	0.5
24	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.7	0.5	0.6
25	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.4	0.7	0.5	0.9	0.8
26	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.2
27	0.4	0.3	0.3	0.4	0.3	0.4	0.5	0.4	0.4	0.5	0.5	0.6
28	0.3	0.3	0.3	0.5	0.3	0.3	0.3	0.3	0.3	0.5	0.4	0.5
29	0.4	0.4	0.3	0.4	0.5	0.4	0.5	0.4	0.5	0.6	0.7	0.6
30	0.3	0.3	0.3	0.3	0.3	0.4	0.2	0.2	0.3	0.3	0.5	0.4
31	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.8	0.8
32	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.3	0.4	0.5	0.6	0.5
33	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.6	0.5
34	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.5	0.6	0.4
35	0.2	0.3	0.1	0.2	0.3	0.4	0.3	0.3	0.3	0.4	0.3	0.3
36	0.4	0.4	0.3	0.5	0.4	0.5	0.5	0.5	0.5	0.7	0.9	0.8
37	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.3
38	0.3	0.3	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.5	0.5	0.5
39	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.3
40	0.3	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.4	0.4	0.6	0.5
41	0.3	0.4	0.4	0.3	0.4	0.4	0.3	0.5	0.3	0.5	0.4	0.5
42	0.3	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.5	0.6	0.5	0.5
43	0.4	0.3	0.3	0.2	0.3	0.3	0.4	0.3	0.3	0.5	0.6	0.5
44	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.5	0.4	0.4
45	0.4	0.3	0.4	0.3	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5
46	0.3	0.3	0.4	0.5	0.4	0.3	0.4	0.4	0.5	0.6	0.7	0.5
47	0.3	0.2	0.3	0.3	0.2	0.4	0.3	0.3	0.3	0.4	0.4	0.4
48	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.4	0.3
49	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.4	0.5
50	0.4	0.3	0.3	0.4	0.5	0.2	0.4	0.4	0.4	0.5	0.5	0.5

TableF.4 The percentage of maximum stability (%)

NO	Eyes open			Left eye closed			Right eye closed			Eyes closed		
	NS	LS	RS	NS	LS	RS	NS	LS	RS	NS	LS	RS
1	95	97	96	95	95	96	95	96	95	95	92	95
2	94	90	94	94	90	92	87	91	84	88	88	87
3	96	93	95	96	93	93	97	92	92	95	94	93
4	94	92	86	89	91	95	95	96	92	96	88	91
5	95	93	95	95	91	93	95	95	96	90	91	89
6	94	90	94	93	90	91	93	95	93	88	89	88
7	94	95	96	93	93	96	95	94	94	87	85	85
8	95	98	98	97	97	96	96	98	95	97	94	97
9	95	96	92	92	91	92	93	94	93	93	89	91
10	98	96	97	95	96	97	97	95	97	95	97	95
11	95	95	93	93	95	95	96	93	94	92	94	92
12	95	94	93	91	91	95	93	96	97	92	91	91
13	96	94	95	91	94	93	90	94	95	93	91	92
14	96	97	95	95	94	96	90	96	93	91	91	95
15	96	93	95	96	93	92	91	93	95	91	95	92
16	92	95	92	95	95	94	95	88	90	90	90	88
17	91	93	91	88	90	87	89	95	89	92	92	87
18	96	92	92	91	93	92	95	87	94	91	91	88
19	96	97	96	96	94	94	95	94	96	89	90	92
20	98	97	93	94	96	94	93	95	97	94	90	93
21	95	97	95	93	96	91	91	94	92	90	90	92
22	95	97	96	95	95	93	93	92	96	88	94	91
23	96	97	92	97	95	94	91	95	88	96	91	93
24	96	96	96	94	92	95	95	94	93	94	93	89
25	95	94	91	93	93	94	92	90	93	93	85	79
26	96	98	94	95	96	95	96	97	97	96	95	97
27	96	96	95	94	95	94	92	96	94	93	95	94
28	95	96	95	91	94	94	95	89	95	92	92	91
29	96	96	94	93	91	95	93	94	94	93	92	93
30	97	97	97	95	96	95	96	97	97	95	95	96
31	92	92	92	90	92	93	88	90	86	89	87	90
32	96	95	90	90	92	95	89	92	91	91	85	88
33	94	95	92	96	93	92	92	93	93	94	89	92
34	97	97	92	95	96	95	96	97	96	93	90	95
35	96	96	97	96	93	92	92	95	95	90	95	95
36	95	95	93	88	87	95	93	91	95	88	84	80
37	98	98	95	95	97	97	97	96	96	95	97	97
38	97	96	97	95	97	96	97	97	97	91	93	94
39	96	98	98	97	98	96	97	97	97	96	95	98
40	95	96	95	96	96	97	96	96	94	93	85	91
41	91	88	89	96	90	94	93	85	91	91	90	88
42	92	93	94	94	89	90	95	94	93	90	92	93
43	95	97	95	95	97	97	92	96	96	92	94	96
44	96	96	96	97	97	92	96	96	96	91	93	93
45	95	96	95	93	92	96	94	92	95	92	94	92
46	96	96	95	94	95	96	94	94	94	90	90	91
47	96	98	94	94	97	94	97	95	95	91	94	95
48	96	96	96	97	96	96	96	96	96	94	96	95
49	97	97	93	94	96	96	96	96	96	96	93	89
50	93	93	96	92	91	99	95	94	93	93	93	91

TableF.5 The percentage of ankle strategy (%)

NO	Eyes open			Left eye closed			Right eye closed			Eyes closed		
	NS	LS	RS	NS	LS	RS	NS	LS	RS	NS	LS	RS
1	97	97	97	96	97	97	97	97	97	96	96	96
2	97	97	96	97	96	97	97	97	96	96	95	93
3	98	97	97	98	97	97	98	97	97	98	97	95
4	98	97	96	98	98	98	97	98	96	98	97	97
5	97	96	97	97	95	97	97	96	97	94	94	94
6	96	96	97	97	96	96	96	97	97	96	96	96
7	97	96	96	96	96	96	96	96	97	96	91	95
8	98	98	98	98	98	97	98	98	97	98	97	97
9	97	97	97	97	97	97	96	97	97	97	96	96
10	98	97	98	97	97	97	97	98	96	97	96	97
11	96	97	97	96	97	97	98	97	97	94	96	96
12	97	97	97	96	96	97	96	97	97	96	96	96
13	96	97	97	97	97	97	97	96	97	95	95	96
14	98	98	98	98	97	98	96	97	98	97	97	97
15	98	98	97	98	98	97	97	97	98	98	97	97
16	97	97	98	97	97	97	97	97	96	96	96	95
17	97	97	96	95	95	80	95	97	95	95	96	94
18	98	97	97	98	96	96	97	97	93	95	95	95
19	98	97	97	97	97	97	98	98	97	96	96	96
20	97	98	97	97	96	97	97	97	97	97	96	96
21	97	98	97	97	97	96	97	97	97	97	97	97
22	97	98	97	97	97	96	97	97	97	95	97	96
23	97	98	97	98	98	98	97	98	96	98	97	97
24	96	96	97	96	96	97	96	97	97	95	96	97
25	96	97	96	97	96	95	96	96	96	96	94	88
26	96	98	96	96	94	97	94	96	94	96	96	96
27	95	98	98	96	97	96	95	96	96	96	96	96
28	97	97	97	96	97	97	97	97	97	96	97	96
29	96	97	97	97	91	96	96	96	96	96	95	96
30	96	97	97	97	97	96	97	97	97	97	96	97
31	97	95	94	97	96	96	96	96	95	95	94	94
32	96	97	97	96	96	96	96	96	97	95	96	96
33	97	96	96	97	97	97	96	97	97	97	95	96
34	98	98	97	98	98	97	97	98	97	96	96	97
35	98	98	96	97	97	96	97	97	97	96	97	97
36	97	96	97	96	96	96	96	96	96	95	95	95
37	98	98	97	97	97	98	98	98	97	98	98	97
38	97	98	98	97	97	97	97	97	98	96	98	96
39	98	98	98	98	98	98	98	98	98	96	98	98
40	98	97	97	97	97	97	97	97	97	97	96	97
41	98	97	96	98	96	97	98	96	98	97	97	95
42	97	96	98	98	97	97	97	97	96	96	97	96
43	97	97	96	98	97	98	95	97	97	96	97	96
44	98	97	98	98	97	97	98	96	97	96	96	97
45	97	97	97	96	96	97	98	96	97	96	97	97
46	98	97	98	96	98	98	97	97	97	96	96	97
47	98	98	98	97	98	98	98	98	97	98	97	98
48	98	98	97	98	98	98	96	96	97	98	98	98
49	97	97	97	97	97	96	98	98	97	98	98	97
50	97	97	97	96	97	95	96	96	98	97	97	96

APPENDIX G

๒ ถนนพรานนก บางกอกน้อย กรุงเทพฯ ๑๐๗๐๐
โทร. (๖๖-๒) ๔๑๑-๑๔๒๐, ๔๑๑-๓๒๕๓
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Faculty of Medicine Siriraj Hospital
Mahidol University

The Ethical Committee on Research Involving Human Subject
Faculty of Medicine Siriraj Hospital, Mahidol University

No. 218/2002

Protocol Title	Effect of Sound and Vision on Balance Performance
Protocol Number	--------
Principal Investigator	Miss. Ratchanoke Raungrojvichai
Name of Department	Orthopedic Surgery

The aforementioned project and informed consent have been reviewed and approved by the Ethical Committee, Faculty of Medicine Siriraj Hospital, Mahidol University, based on the Declaration of Helsinki on December 24, 2002

Signature of Chairman ....
(Prof. Sumalee Nimmannit)

Signature of Dean P. Sakol ....
(Clin. Prof. Piyasakol Sakolsatayadorn)

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