Postural control: Visual and cognitive manipulations

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POSTURAL CONTROL: VISUAL AND COGNITIVE MANIPULATIONS

by

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Bachelor of Science
Montana State University, Bozeman
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A thesis submitted in partial fulfillment
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ABSTRACT

Postural Control: Visual and Cognitive Manipulations

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Numerous questions exist regarding the utilization of sensory information for postural control. Past research establishes the possibility that cognitive tasks requiring visual perception may affect the processing of visual information for postural control. The purpose of this study was to investigate the effects of varying demands of visual perception associated with a concurrent cognitive task on postural control in healthy, young adults (N=30). The postural sway of each participant was tested in six conditions, 2 [Eye Movement] x 3[Cognitive (none, visual, auditory)] on a Kistler force platform. Significant differences were observed between the No Cognitive condition and one or both of the other cognitive conditions. No differences were present between the Visual and Auditory Cognitive tasks. Significant differences were also observed between Eye Movement and No Eye Movement conditions. In conclusion, specific visual and cognitive manipulations can effect postural control in young healthy adults.
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CHAPTER 1

INTRODUCTION

The high number of falls observed in the elderly population has sparked a great deal of interest regarding the postural control system (Grabiner & Enoka, 1995; Horak, Shupert, & Mirka, 1989). Investigation of the general underlying mechanisms of postural control in young and older adults is important in the attempt to understand the reasons behind such falls. Research spanning all age groups contributes to the general understanding of the postural control system and possible changes in the system across the lifespan.

The postural control system functions to position and maintain the body’s center of gravity (COG) over the base of support (Nashner, 1989). Postural control has been described as a highly complex behavior in humans and requires contributions from several systems of the body (Horak et al., 1989). Specifically, it requires detection of stimuli by the sensory systems, integration of information within the central nervous system (CNS), and production of responses by the musculoskeletal system (Nashner, 1989). The postural control system uses overlapping neural feedback from multiple sensory systems to maintain postural stability (Grabiner & Enoka, 1995). Due to the complexity of the integration of sensory information, this component of postural control is not well understood. Primarily three sensory systems provide information to the CNS.
concerning the position of the body's COG at any given time; the visual, somatosensory, and vestibular. The importance of each system was initially established through observations of individuals with known deficits to one of the three systems. Additionally, experimental manipulations involving the removal or degradation of sensory information have aided in establishing each system's importance. In such situations, an overall lack of input, or lack of accurate input, generally decreases a person's postural stability (Grabiner & Enoka, 1995; Woollacott & Shumway-Cook, 1990; Horak et al., 1989; Nashner, 1989; Nashner, Shupert, Horak, & Black, 1989; Woollacott, Shumway-Cook, & Nashner, 1986). Postural stability requires a continuous regulation and integration of sensory inputs (Lajoie, Teasdale, Bard, & Fleury, 1993), as no one sensory system directly specifies the position of the body's COG (Horak et al., 1989). The CNS uses a variable ratio of the three inputs depending on the demands of a situation (Nashner, 1989). Therefore, the relative importance of the information gained from the visual, somatosensory, and vestibular systems continually changes. The mechanism(s) responsible for these changes remain unclear.

Manipulations of vision are more common than those of somatosensory and vestibular information, due to the relative ease of manipulating visual input. Several authors have clearly documented the importance of vision to postural control (Nashner, 1989; Horak et al., 1989; Woollacott et al., 1986; Doman, Femie, & Holliday, 1978). Postural stability generally decreases in the absence of visual input, such as experimental conditions with the eyes closed. Similarly, altering the quality or type of visual inputs affects postural control. For example, several experiments employed a "moving room" apparatus in which the visual surroundings moved in relation to the standing participant (Sundermier, Woollacott, Jensen, & Moore, 1996; Lee & Lishman, 1975). In these
studies, postural control decreased with movement of the visual surroundings. The authors suggested that the moving surroundings provided inaccurate information to the postural control system. Specifically, moving surroundings disrupted the participant's reference to the external environment, thereby decreasing postural control. Other more subtle types of visual manipulations may also affect postural control, such as a manipulation primarily directing the use of vision toward another task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997) or involving eye movement (Stelmach, Zelaznik, & Lowe, 1990). Such manipulations may interfere with the quality and/or quantity of visual information available specifically for the control of posture, or possibly with the processing of visual information for postural control. The effect of such manipulations on postural control has yet to be thoroughly investigated.

Under normal circumstances, postural control rarely requires conscious effort. However, several authors suggest that certain cognitive tasks interfere with the control of posture (Shumway-Cook et al., 1997; Maylor & Wing, 1996; Lajoie et al., 1993; Teasdale, Bard, LaRue, & Fleury, 1993; Kerr, Condon, & McDonald, 1985). Maylor & Wing (1996) investigated the effects of five different cognitive tasks on postural control. The two tasks thought to require the greatest amount of spatial processing resulted in decreased postural control for older adults and demonstrated significant increases in age-related differences. The remaining three tasks did not significantly affect postural control. This finding corroborates a previous hypothesis that proposed spatial tasks can interfere with postural control (Kerr et al., 1985). Furthermore, this hypothesis was based on the possibility that a link exists between spatial tasks and postural control due to their common reliance on the visual system.
Additional research in this area demonstrated that visual perception, defined here as the use of vision for the completion of another task, can interfere with performance on spatial imagery tasks (Brooks, 1967). It was demonstrated that performance on a spatial imagery task declined during the concurrent performance of a separate task involving the use of vision. Therefore, the use of vision to complete a task (visual perception) may require similar mechanisms or processing used in the completion of spatial tasks. Thus, it is apparent that visual perception can interfere with spatial tasks and that spatial tasks can interfere with postural control. The remaining link to be investigated is the relationship between visual perception and postural control. Shumway-Cook et al. (1997) put forth such a hypothesis, postulating that the visual presentation of a task may in itself place demands on visual processing pathways common to the postural control system. The majority of studies concerned with the cognitive demands of postural control have employed spatial imagery tasks, with no visual perception requirement. The relationship between visual perception and postural control has yet to be thoroughly investigated. It is possible that tasks requiring visual perception may interfere with postural control to a different degree than those requiring little or no visual perception.

In 1991, Bardy and Laurent studied the effects of visual perception on cognitive demands involved with locomotion. They reported that walking toward a small target required more attention than walking toward a large target. Specifically, they suggest that variable requirements of visual perception can have different effects on locomotion. The effect observed in this study could possibly be due to increased demands associated with increased visual perception demands (smaller target). Such demands may in some
way interfere with the processing of general visual information for locomotion. A similar interaction may also exist between visual perception and postural control.

An investigation of processing interference between two tasks typically involves the simultaneous performance of both tasks, termed a dual-task paradigm. Detriments in performance of one or both tasks during their concurrent performance is referred to as dual-task interference (Pashler, 1994; Abernethy, 1988). Numerous explanations of the phenomenon have been developed due to its complexity and the inability to measure it directly (Pashler, 1994). It is beyond the scope of the present study to explain how or why any observed dual-task interference occurs. It should, however, be noted that tasks used to study the effects of concurrent cognitive tasks on postural control present problems as they are typically not equated in terms of cognitive load. Most studies have focused primarily on changes in postural control, not adequately addressing the cognitive performance associated with such changes. This represents a limitation in previous postural control studies, along with the present study. The focus of this study, however, remains on postural control, and not on the elucidation of mechanisms responsible for dual-task interference. For practical purposes, it is first important to uncover the types of tasks and situations that interfere with postural control. Later research may be conducted in an attempt to then understand how or why they interfere. Bardy & Laurent (1991) described the dual-task paradigm as an interesting basis for investigating visuolocomotor coordination. Likewise, it appears to be an effective way to investigate the relationship between visual perception and postural control.

The study of postural control in young, healthy adults allows for the investigation of basic postural control mechanisms. The majority of past research has involved only older adults, or a direct comparison of young and older adults. It is possible that certain
differences in postural control observed between old and young adults may reflect

generalized age-related slowing of information processing in older adults (Maylor &
Wing, 1996). Therefore, it is important to thoroughly investigate postural control in
healthy, young adults as well as older adults to formulate broad conclusions concerning
age-related effects.

Statement of Problem

The study of postural control is vital to addressing the high incidence of
falls observed in the elderly population. Perhaps the least understood problem
surrounding postural control involves the regulation and integration of visual, vestibular,
and somatosensory inputs. The role of vision in postural control is of specific interest
due to its notable importance to humans in the control of posture and countless other
daily activities. Recently, researchers have revealed that spatial cognitive tasks can
interfere with postural control (Shumway-Cook et al., 1997; Maylor & Wing, 1996;
Lajoie et al., 1993; Teasdale et al., 1993; Kerr et al., 1985). A link between spatial tasks
and postural control has been proposed through their common reliance on the visual
system (Kerr et al., 1985). It has further been demonstrated that visual perception, or the
use of vision to accomplish a task, can interfere with certain spatial imagery tasks
(Brooks, 1967). Additionally, Shumway-Cook et al. (1997), postulated that the visual
presentation of a task may interfere with postural control. Such relationships provide a
basis for investigating a possible relationship between specific visual perception
manipulations, cognitive tasks, and postural control.
Statement of Purpose

The purpose of this study was to investigate the effect of visual and cognitive manipulations on postural control in healthy, young adults. Specifically, the study addressed the effect of varying demands of visual perception associated with a concurrent cognitive task on postural sway.

Significance of Study

The high incidence of falls in the elderly population likely relates to effects of aging on postural control (Perrin, Jeandel, Perrin, & Bene, 1996; Grabiner & Enoka, 1995; Lord & Ward, 1994; Woollacott & Shumway-Cook, 1990; Horak et al., 1989; Woollacott et al., 1986; Stelmach & Worringham, 1985). Information regarding the mechanisms underlying the regulation and integration of sensory information for the control of posture remains unclear. Manipulations of vision have been repeatedly shown to affect postural control (Nashner, 1989; Horak et al., 1989; Woollacott et al., 1986; Doman et al., 1978). Recently, it has also been demonstrated that certain cognitive tasks interfere with postural control (Shumway-Cook et al., 1997; Maylor & Wing, 1996). Due to the importance of vision in the maintenance of postural control, tasks requiring varying amounts of visual perception may produce different effects on postural control. The elucidation of general mechanisms involved in the control of posture and situations which may result in decreased postural control may be important in investigating the reasons underlying the high number of falls in the elderly. Investigations involving younger adults are important in the understanding of the general mechanisms and changes in the postural control system across the lifespan.
Hypotheses

The present study was designed to test the following null hypotheses:

1. Participation in a visually presented cognitive task does not affect postural control in healthy, young adults.

2. Participation in a verbally presented cognitive task does not affect postural control in healthy, young adults.

3. Participation in eye movement tasks does not affect postural control in healthy, young adults.

4. There is no interaction between presentation of a cognitive task (verbally or visually) and an eye movement task on postural control in healthy, young adults.

Delimitations

The following are delimitations to the present study:

1. Participants had no history of disorders that would affect their performance in the study. A questionnaire was used to examine each participant's general medical history.

2. Participant ages ranged from 18 to 34 years.

3. Participants volunteered from a university student population.

4. A force platform was used to measure postural sway.

5. The cognitive tasks were consistently presented to each participant.

6. A Tandem Romberg stance (heel-to-toe) was used to provide a degree of difficulty to the postural task.
Limitations

The current study had the following limitations:

1. Math skill levels may have differed between individuals, affecting the relative difficulty of the cognitive task.
2. The cognitive loads of the math tasks were not necessarily equated.
3. Participant motivation could not be controlled.

Assumptions

The present investigation was designed under the following assumption:

1. The cognitive tasks and balance task were sufficiently demanding to demonstrate any existing interference.
2. Any changes in postural control observed between the Cognitive Manipulation conditions are a result of the manipulations.
3. Any changes in postural control observed between the Eye Movement conditions are a result of the manipulation.
4. No observed interaction between the Cognitive Manipulation conditions and the Eye Movement conditions is evidence that interference does not exist between the two types of manipulations.

Definitions of Terms

The following operational definitions describe the specific use of the terms in the present study:

Attention demanding: Requiring a limited capacity, or pools of capacity, to process information (Schmidt, 1988).
**Center of Pressure (COP):** COP is the center of the pressure distribution pattern on the surface of the force platform. It corresponds to the vertical projection of the body's center of gravity (COG) when there is no horizontal acceleration (Goldie, Bach, & Evans, 1989).

**Force Platform:** The force platform is a piezoelectric device for measuring forces applied to the platform. The device provides a means of computing movements of the center of pressure (COP) on the platform over time (Goldie et al., 1989). These measurements are used to quantify postural control.

**Healthy, Young Participant:** Participant between the ages of 18 and 35 years, having no known history of lower extremity musculoskeletal disorders, vestibular disturbances, visual disorders not corrected by lenses, hearing disorders, and learning disorders associated with mathematics.

**Imagery:** The use of imaginary visualization to accomplish a task, without the use of vision.

**Postural Control:** The process of maintaining the body's center of gravity (COG) over a base of support, for the purpose of maintaining an upright stance (Nashner, 1989).

**Postural Sway:** The normal movement of the body's COG, as measured by variability of forces and center of pressure (COP) movement, as a description of postural control.

**Spatial Task:** A task thought to require a degree of visual processing (visual imagery or visual perception).

**Visual Perception:** The use of vision to accomplish a task.
Summary

Postural control requires utilization of sensory inputs regarding the position of the body's COG and the ability to make appropriate musculoskeletal responses (Nashner, 1989). Postural control has recently received a significant amount of attention due to the proposed link between postural control and the high incidence of falls among the elderly (Grabiner & Enoka, 1995; Woollacott & Shumway-Cook, 1990; Horak et al., 1989). The elucidation of the mechanisms underlying postural control will aid in the development of preventative and rehabilitative techniques needed for lowering the number of falls among older adults.

Potentially the least understood aspect of postural control involves the integration of sensory information from the visual, vestibular, and somatosensory systems by the CNS. No single sense completely regulates COG position, therefore postural control requires continual monitoring and coordination of sensory inputs (Horak et al, 1989). Research surrounding the use of vision is of particular interest because it is a dominant sense of humans and is relatively easy to experimentally manipulate. It has been repeatedly demonstrated that a lack of vision or manipulations of external visual surroundings can negatively affect postural control. Therefore, the importance of vision to postural control is well-established (Nashner, 1989; Horak et al., 1989; Woollacott et al., 1986; Dorman et al., 1978).

It has further been revealed that spatial cognitive tasks have the potential to interfere with postural control (Kerr et al., 1985). It has been hypothesized that spatial tasks and postural control may be linked through their common reliance on the visual system. Interference between visual perception and spatial imagery tasks is also documented (Brooks, 1967). Therefore, the relationships between spatial tasks and
postural control, and spatial tasks and visual perception have been investigated. The specific relationship between visual perception and postural control, however, has not been directly investigated. It is possible that visual perception may interfere with the normal use of visual input for the control of posture.

The purpose of this study was to investigate the relationship between varying demands of visual perception associated with and without a concurrent cognitive task on postural control. It is possible that cognitive tasks requiring visual perception may affect the quality or amount of visual information available specifically for postural control or interfere with the normal processing of sensory information for postural control. Visual perception demands may be manipulated through the visual presentation of a task and the addition of eye movements. It is also possible that the use of visual perception in a concurrent task has no effect on the postural control system.

The establishment of specific situations adversely affecting postural control is important in determining circumstances in which postural control is compromised. Such knowledge may be important in the development of preventative and rehabilitative techniques to address declines in postural control.
CHAPTER 2

REVIEW OF LITERATURE

The purpose of the current study was to investigate the effects of visual and cognitive manipulations on postural control. This chapter presents literature related to the effects of visual and cognitive manipulations on postural control. General information concerning the mechanisms underlying the control of posture is presented foremost, followed by a review of literature directly investigating the relationship between vision and postural control. The next section of the chapter is devoted to research involving spatial tasks and their relationship with vision, followed by a section addressing research involving the relationship between spatial tasks and postural control. A final section addresses current and popular dependent measures of postural stability. A summary concludes the chapter.

Postural Control

The postural control system is responsible for the coordination of the several components of motor control for the maintenance of balance, or posture (Grabiner & Enoka, 1995). Posture is maintained through a complex combination of sensory detection, integration of information within the central nervous system (CNS), and
appropriate musculoskeletal responses (Nashner, 1989). The goal of the postural control system is to position and maintain the body's center of gravity (COG) over the base of support (Nashner, 1989). Postural control involves not only the ability to detect changes in the COG resulting from external perturbations, but also to correctly predict postural adjustments prior to voluntary movements (Horak et al., 1989). Therefore, the postural control system clearly operates through both closed-loop and open-loop mechanisms. Closed-loop control of posture involves the use of feedback to monitor COG position, where as open-loop control involves feedforward strategies to generate anticipatory commands (Grabiner & Enoka, 1995).

The continuous control of posture depends on the integration of overlapping sensory input from visual, somatosensory, and vestibular sources (Grabiner & Enoka, 1995; Woollacott et al., 1986). The process of postural control requires continuous regulation and integration of sensory inputs (Lajoie et al., 1993), as no one sensory system directly specifies the position of the body's COG (Horak et al., 1989). The CNS does not use a fixed ratio of the information from the three sources in all situations (Nashner, 1989). Interaction with a continuously changing and unpredictable environment often creates situations where sensory information from one or more source is degraded. Even in such situations relatively stable posture can be maintained. This adaptability suggests that the nervous system possesses the ability to discriminate and disregard inaccurate information in favor of more accurate information from another source or sources (McCollum, Shupert, & Nashner, 1996). The process by which the CNS properly integrates the overlapping sensory information from the visual, somatosensory, and vestibular systems remains a poorly understood aspect of postural control.
The importance of each system has been well-established by placing individuals in situations where sensory information from one or more of the three sources is either degraded or removed. In such situations, an overall lack of input, or lack of accurate input, generally decreases a person's postural stability (Lord & Ward, 1994; Woollacott & Shumway-Cook, 1990; Horak et al., 1989; Nashner, 1989; Nashner et al., 1989; Woollacott et al., 1986).

Vision and Postural Control

Extensive documentation of the reliance of the postural control system on vision exists in the literature (Nashner, 1989; Horak et al., 1989; Woollacott et al., 1986; Dornan et al., 1978). Manipulations involving vision are common, partly because vision is relatively easy to manipulate compared to somatosensory and vestibular information, and in part due to the dominant sensory role vision plays in countless daily activities for humans.

Postural control generally decreases in the absence of visual input, such as eyes closed. In 1851, Romberg first made the observation that patients with disorders affecting proprioception demonstrated increased postural sway with no vision (Dornan et al., 1978). Since Romberg's observation, the removal of visual input, such as closing of the eyes, has been used in testing possible proprioceptive deficits of patients. Similar methods have more recently been employed to investigate the integration of sensory information with more sensitive measures of postural control. In 1978, Dornan et al. suggested that a ratio between sway values with eyes open to eyes closed provides a simple method to describe the extent to which people are dependent upon vision.
More recently, Yardley, Lerwill, Hall, & Gresty (1992) investigated visual destabilization of posture in normal subjects. Eyes open and eyes closed represented two of the conditions. Sway was found to increase with eyes closed, compared to the eyes open condition. Likewise, Nougier, Bard, Fleury, and Teasdale (1997) reported that participants were more stable with vision, even if it was only partial (i.e. only central or peripheral), than without vision.

Visual manipulation have also represented a popular means of investigating effects of aging associated with postural control. In one such study, Baloh, Fife, Swerling, Socotch, Jacobson, Bell, and Beykirch (1994), investigated sway velocity during static and dynamic posturography, with and without vision, in young versus older adults. Based on these results, the authors concluded that sway velocity was significantly higher with eyes closed than eyes open in both young and older participants, although older were affected to greater extent than young. In a similar study, Perrin et al. (1997) compared static and dynamic tests with eyes open and closed and demonstrated that anterior-posterior oscillations were significantly higher with eyes open than eyes closed for both young and older adults.

Based on the aforementioned research, the detrimental effect of removing visual input is well established and generally accepted in the area of postural control. However, the complete removal of visual input is not the only means of demonstrating its importance to postural control. Numerous studies have manipulated a person's visual surroundings to investigate the effect on postural control. A classic paradigm was used by Lee and colleagues (1974, 1975). Participants stood on a stable floor surrounded by a three-sided moveable chamber. The chamber, or "room," was moved in relation to the participant. Therefore, the visual information gained by the person to control his/her
posture was only available from the motion of the chamber. Lee and colleagues observed that the response for normal adults was to sway in relation to the room. For example, when the wall approached the participants, they tended to sway backward, and when the wall moved away, the participants tended to sway forward. Lee et al. explained the observed phenomenon by suggesting that participants exhibited such behavior to keep visually referenced in relation to their "eternal environment. Without such sway, the changing size of the image on the retina would be identical to that if the person was falling forward or backward. By swaying accordingly, the person counteracts such an illusory fall (Rosembaum, 1991).

Linear and rotational manipulations of the visual scene were further used by Nashner and Berthoz (1978). The experiment allowed for simultaneous perturbations of anterior-posterior sway and motion of the surrounding visual scene. The participant stood on a rail mounted cart inside a suspended visual scene capable of moving independently of the cart. Therefore, the participant could be moved in one direction while the visual environment moved in the opposite direction. Nashner and Berthoz measured electromyograph activity in response to the translations and concluded that visual inputs influence involuntary postural adjustments within 100 msec, and that rapid and slow movements of the visual surroundings affect postural control differently.

Further experiments involving the movement of visual surroundings, or "moving room" have been conducted. Nashner used this paradigm to develop the Sensory Organization Test (SOT) (Nashner, 1989). Specifically, the SOT serves to examine the contributions to posture from all three types of sensory input, visual, somatosensory, and vestibular, through manipulations of different inputs. During this test, patients stand on a moveable force plate facing into a moveable visual enclosure. Like Lee and colleagues
(1974, 1975), the visual enclosure is allowed to move. In the SOT, however, the visual enclosure can move at a frequency equal to the patient's anterior-posterior sway. Under this condition, the participant does not obtain visually referenced sway information as the movement of the visual surrounding is synchronized to sway of the body (Nashner & McCollum, 1985). Therefore, the person does not receive accurate visual information from the environment concerning sway. In 1986, Woollacott, Shumway-Cook, and Nashner, used a similar experimental apparatus. A servo control system was developed in which the support surface and visual enclosure precisely followed the anterior-posterior sway motions of the participant. The servoed visual condition, in which sway-related visual inputs were eliminated, resulted in an observed decrease in postural control.

Using a similar moving room protocol, Sundermier et al. (1996) investigated the sensitivity of postural control to visual flow in young adults, as well as older adults with and without balance problems. This experimental protocol used a 3-sided visual surround that could be moved in the anterior-posterior direction aligned with the force platform. Results revealed that overreliance on visual input is more likely to occur in adults with balance problems, but that sensitivity of postural control to visual flow can also occur in healthy older and young individuals as well (Sundermier et al., 1996).

Other visual manipulations have been used to investigate the contributions of static versus dynamic visual cues for postural control. Amblard, Cremieux, Marchand, and Carblanc (1985) investigated this question with respect to lateral orientation and stabilization of human posture. In four stances differing in the level of difficulty, a visual pattern was illuminated with either a stroboscopic bulb or a normal bulb. Amblard et al. demonstrated that static visual cues, available under the stroboscopic condition, make a contribution to postural control. The study also replicated findings that dynamic visual
cues play a major role in the control of lateral body sway. It was concluded that static visual cues may play a role in slower movements such as re-orientation of the upper body, whereas dynamic visual cues may contribute to rapid stabilization of the whole body.

The importance of specific visual cues was further investigated by Isableu, Ohlmann, Cremieux, and Amblard (1997). Isableu et al. suggested that a link may exist between an individual's perceptive visual field dependence or independence and the visual contribution to postural control. They hypothesized that individuals who use mainly visual cues in a spatial orientation task (Rod and Frame Test) may also mainly use these cues for body orientation and stability. The results demonstrated that all participants leaned toward a tilted frame of reference on the basis of static visual cues alone. Also, individuals classified as visual-field dependent were less stable and required the use of dynamic visual cues. Visual-field independent individuals, on the other hand, were more stable and used static visual cues to complement posture regulation. Therefore, individuals' visual field dependence may interact with visual contributions to postural control.

Using a new paradigm to assess reliance on vision for postural control, Yardley et al. (1992) employed a head-mounted mirror device to reverse left and right peripheral vision and a prism to create a lateral reversal of central vision by means of a prism. Such reversals evoked mismatches between body sway and visual information, just as movement of the visual surroundings did in previously described moving room studies. The visual manipulations did invoke a decrease in postural control. Spatial and non-spatial tasks were performed concurrently with the postural tasks. This aspect of the study is discussed in detail in the third section of this chapter.
The relationship between visual cues and locomotion was investigated by Bardy and Laurent (1991). The initial aim of the study was to determine what visual cues are primarily used to assess the time-to-contact with a stationary target during locomotor positioning. The protocol involved restricting central visual cues and also assessing the attentional demands involved in the use of visual cues. Attention demands were measured through the use of an auditory probe reaction time test during walking. The results suggested that walking toward a small target requires more attention than walking toward a large target. Bardy and Laurent note that the results obtained in the study for locomotor positioning are consistent with those found for visual-manual tasks. It was concluded that the increased reaction time during walking toward the small target indicates a lesser amount of information in the condition or at least qualitatively different information for locomotor positioning. While this study did not investigate postural control, it did further demonstrate the importance of specific visual cues in motor tasks that rely on vision.

A significant amount of literature exists describing various manipulations of visual input and their effect on postural control across the lifespan. In general, the broad conclusion drawn from such research illustrates a large contribution of visual input to the control of posture. Further, different aspects of vision may affect postural control in different ways. Vision does not have to be completely removed for its effect on postural control to be apparent, as the quality of visual input can be as, or more, important than the overall quantity. The multitude of ways in which visual manipulations can interact with postural control remain to be revealed.
Vision and Spatial Tasks

The previous section of this chapter established the important relationship between vision and postural control. This section explores the proposed relationship between visual perception and spatial tasks. As mentioned in the previous chapter, it is not within the scope of this study to put forth a hypothesis as to how or why interference may exist between two tasks. The primary interest of the current study is to investigate whether interference does exist and the effect it may have on postural control. Therefore, the purpose of the following section is to report past observations of dual-task interference between tasks pertinent to the present study. Such a relationship between visual perception and spatial imagery tasks was described by Brooks (1967). Brooks demonstrated lower performance on memory tasks requiring spatial imagery and visual monitoring, as opposed to spatial imagery and audition. In the experiment, messages were presented verbally in one condition and visually in another. The participant was asked to imagine the spatial relations described by the messages in both cases. Comparison of performance scores revealed that listening to the messages did not produce the interference observed with visualization of the messages. Brooks proposed that visualization and reading compete for the use of neural pathways specialized for visual perception and/or spatial imagery.

A similar question was addressed by Byrne (1974). In this investigation, Byrne sought to compare the effects of item concreteness versus spatial organization on visual imagery. Byrne concluded that visually guided responses interfered with recall of a list of items learned under conditions requiring spatial imagery. Visual conflict was most evident when the items were spatially organized. This study provided further evidence for the hypothesis proposed by Brooks, that spatial imagery and visual monitoring
interfere with one another. Additionally, experiments performed by DiVesta and Bartoli (1982) and Segal and Fusella (1970) revealed that sensitivity to visual signals is reduced during concurrent visual spatial imagery tasks. Therefore, the overlap between visual perception and visual imagery used in spatial cognitive tasks is documented in the literature.

Spatial Tasks and Postural Control

Postural control rarely requires conscious effort under normal circumstances. However, recent research revealed that certain cognitive tasks can interfere with the control of posture (Shumway-Cook et al., 1997; Maylor & Wing, 1996; Lajoie et al., 1993; Teasdale et al., 1993; Kerr et al., 1985). The previous sections of this chapter established the relationship between vision and postural control along with the relationship between vision and spatial tasks. The present section addresses the relationship between spatial cognitive tasks and postural control. A link between spatial tasks and postural control may be based on their common reliance on vision or visual processing (Kerr et al., 1985).

The hypothesized link between cognition and postural control was investigated by Kerr et al. (1985). Kerr et al. selected the spatial task used by Brooks (1967), which relies on visual imagery though auditory means. Participants were asked to perform the spatial task or non-spatial verbal task while either sitting or performing a concurrent difficult balance task (one-leg stance). In this first experiment, balance performance was not directly measured. As hypothesized, the concurrent balance task did interfere with the spatial memory task but not the analogous verbal memory task. In a second experiment within the same study, Kerr et al. slightly changed the protocol to directly
measure postural control. The stance used in this experiment was the Tandem Romberg position (heel-to-toe), and steadiness was measured on a force platform in all conditions. Balance steadiness, as measured in this study, did not significantly differ between the two memory tasks. Also, conditions involving a cognitive task surprisingly indicated less sway than balance-alone conditions. This was explained due to an order effect, described as a significant interaction between the order the conditions were presented and the outcome of the condition. This study established that maintaining a difficult postural task while performing a spatial memory task can interfere with performance on the cognitive task.

More recently, Maylor and Wing (1996) conducted a study to investigate the effects of five different cognitive tasks on postural control. In contrast to earlier work, Maylor and Wing used sensitive measures for both postural control and cognitive performance. The five cognitive tasks used in the experiment were thought to involve at least one component of working memory as described by Baddeley and colleagues. This model of working memory comprises a central executive and two slave systems. One slave system, the phonological loop, is related to speech, while the other, the visuo-spatial sketchpad, is responsible for setting up and manipulating visuo-spatial images (Maylor & Wing, 1996). The five specific tasks were (1) random digit generation (2) Brooks' spatial memory (3) backward digit recall (4) silent counting, and (5) counting backward in threes. Participants were split into two age groups, younger (mean age 57.1) and older (mean age 77.2). The authors concluded that age differences in postural stability were significantly increased when performing Brooks' spatial memory task and the backward digit recall. Both of these tasks have been described to rely on visual-spatial representation. Maylor and Wing offered a broader interpretation of the results in
stating that the use and processing of visuo-spatial information may reduce the ability of the system to use external visual information in the control of posture. The authors suggested that the effects of performing tasks requiring spatial processing can be explained in the same way previous studies have explained the effect of reducing and/or manipulating visual input. The study did, however, have possible significant limitations. One, only anterior-posterior sway measures were recorded, resulting in an incomplete, unidimensional investigation and description of sway behavior. Two, the tasks were presented in the same order each time, which could have led to an order effect. Also, the stance used by Maylor and Wing was relatively easy, requiring participants to stand on a flat surface, eyes open, arms by side, and feet apart. The authors postulated that the results of the study may have been more exaggerated under a more demanding stance or even dynamic condition. Further, as previously mentioned, the cognitive loads of the different tasks may have differed preventing a simple, direct comparison of their effects on postural control.

A study by Stelmach et al. (1990) used a more dynamic manipulation of balance to investigate the effects of two concurrent tasks. They did not, however, measure cognitive performance. The conditions of the study consisted of a cognitive (math task) and a motor (hand-squeeze) task during a stable stance and a stance task involving self-induced perturbations through arm swinging. Stelmach et al. tested eight young adults and eight older adults. After arm swinging, the older adults demonstrated a marked increase in recovery time to normal stance when concurrently performing an arithmetic task as compared to the other conditions. It was hypothesized that the motor task might interfere to a greater extent than the purely cognitive math task because both postural control and the squeezing task are motor in nature. Interestingly, the squeeze task did not
interfere with postural control in either age group. The authors propose two possible explanations for the effect of the math task on postural control: (1) eye movements associated with the cognitive demands of the math task produced changes in the postural control system or (2) the mathematics task drew attention away from the postural control system. This study used only postural control measures to investigate the effects of the cognitive tasks on postural control. A difference between young and older adults was observed. The young group was not significantly affected by any of the tasks. However, due to the small sample size, the premise deserves further research.

The relationship between the difficulty of a postural stance and the degree to which concurrent cognitive tasks interfere with postural control has been addressed in additional studies. Teasdale et al. (1993) investigated such a relationship by submitting young and older participants to an auditory reaction time task while standing on a force platform in four different visual/support surface conditions. A control postural condition was completed and used to calculated a mean COP for each subject. Central (close to the mean) and eccentric (farther from the mean) positions of the COP were then calculated. The auditory stimuli were presented at times when the COP was in a central position versus an eccentric position for each visual/surface condition. The eccentric condition represented a position closer to the participant's sway limit, and therefore, a more difficult or demanding position. Based on the results of the experiment, the authors revealed that the number of times participants' COPs were in an eccentric position increased with decreased sensory information. The primary dependent measure in the experiment, however, was reaction time to an auditory stimulus. Analysis of the reaction time data revealed that, for the elderly group, as the postural task became increasingly difficult reaction times increased. The authors note that this supports the importance of central
processes in postural control, and provides basis for further research on the relationship between the sensorimotor and the cognitive systems in the control of posture.

In a similar study, Lajoie et al. (1993) demonstrated reaction time (measured as in the aforementioned study) increased as the balance requirements of a task increased. The study compared sitting to standing and walking conditions.

An earlier investigation by Maki and McIlroy (1991) examined the influence of arousal and attention on the control of postural sway. Sway was quantified using displacements of the center of pressure. Each participant was asked to perform four conditions while standing with feet comfortably spaced and hands clasped in front. The four conditions were (1) no task (control) (2) listen to white noise (3) listen to a spoken-word book excerpt and (4) count backward from 1000 by serial 7's. Questions were asked concerning content after the listening task and the final number was checked in the math task condition. Task-related differences were observed in the participants with higher autonomic/somatic state-anxiety scores. These participants demonstrated a significantly higher anterior-posterior mean COP location during the math task compared to the control condition, indicating the participants leaned farther forward. These findings provide evidence that concurrent math tasks can affect postural control in young, healthy adults. However, the authors note that a person's physiological arousal should be further considered in postural control research, especially in studies involving cognitive tasks.

A study discussed in the first section of this chapter, Yardley et al. (1992), also demonstrated an interference between spatial tasks and postural control. Yardley et al. manipulated available visual input through the use of head-mounted mirrors. Spatial (Brooks' spatial task) and non-spatial tasks were concurrently employed in an attempt to differentiate between specific interference due to competition for visuo-spatial
processing. Performance of verbal or visuo-spatial memory tasks did not affect sway in this study, however error rates for the visuo-spatial task with manipulated (reversed) visual input were significantly higher than those during sitting and those during eyes closed trials.

Most studies investigating the relationship between spatial tasks and postural control have done so in terms of age-related effects on postural control. Another such study examined the effects of cognitive tasks on postural stability in older adults with and without a history of falls, compared to a younger group (Shumway-Cook et al., 1997). The study compared the effects of two types of cognitive tasks on postural stability, a language task and a visual spatial task. The authors sought to investigate whether the visual pathways used for information processing were the same for both tasks based on the established premise that both postural control and spatial orientation required visual processing. The cognitive tasks were performed on normal and compliant foam surfaces. The results demonstrated that the greatest interference was between the sentence completion task and the compliant surface. This was contrary to what was expected, as it was hypothesized that the visual spatial orientation task would interfere with postural control to a greater extent than the sentence completion task due to proposed competition for visual processing pathways. The authors suggest that the findings may be due to the fact that the while the sentence completion task was primarily a language task, it was presented visually. The visual presentation may have placed demands on visual processing pathways. From this, it was further suggested that had auditory pathways alone been used for the processing of the task, less interference with postural control may have resulted. This proposes an interesting question as to the effects of using vision for another concurrent task while attempting to maintain postural stability.
Shumway-Cook et al. further demonstrated in this study that during the concurrent performance of cognitive and postural tasks, a decline in postural stability rather than cognitive measures can result. Throughout the literature, studies show differences in whether the cognitive measure is affected or the postural measure is affected. Therefore, as Shumway-Cook et al. suggested, the effect on each type of task during dual-task protocols is complex and dependent upon many factors including the nature of the tasks, the goal of the participant, and the specific instructions given. It is possible such discrepancies could account for the varied findings of studies using different experimental protocols.

Several of the aforementioned studies have used verbal versus spatial cognitive tasks in the investigation of postural control. It should be mentioned that evidence exists for different processing associated with verbal and spatial tasks. In 1990, Davidson, Chapman, Chapman, and Henriques, compared brain electrical activity during the performance of a verbal task and spatial task that were carefully matched on psychometric properties and required motor activity. The findings indicated significant differences in asymmetrical brain physiology produced by the two types of cognitive tasks. This study, therefore, gives physiological evidence for differences in the two types of tasks. Once again, however, the scope of the present study does not cover an investigation of how and/or why interference occurs, merely an investigation of what may interfere with postural control.

Measures of Postural Control

Throughout postural control literature, the variables used to measure postural control are extremely varied and inconsistent. There are a multitude of opinions on the
most reliable and valid measures for investigating postural control. The "best"
variable to describe postural stability likely depends on the specific interest of the study.
For example, variables accurately describing dynamic postural control may not
accurately describe static postural control (Goldie et al., 1989). Goldie et al. also
demonstrated differences in reliability and validity of measures between different static
stances. Since the study done by Goldie et al (1989), numerous other postural control
measures have been developed and implemented. Measurements of postural control are
intrinsically variable, which creates difficulties in the comparison of postural control
between different individuals and even the same individuals in different trials (Tarantola,
Nardone, Tacchini, & Schieppati, 1997). In the following section, the dependent
variables used in several studies similar to the present investigation are briefly described.

Maylor and Wing (1996) measured anterior-posterior sway on a low-cost platform
(Sway Weigh), which measures weight distribution using electronic weighing scales.
Readings were obtained as percentage weight distribution (WD) which, according to the
authors, directly relate to the center of pressure (COP). Changes in the WD reflect the
combined effects of the body's center of mass position variation and active forces
producing that variation. Maylor and Wing recorded only anterior-posterior WD.

Maki and McIlroy (1991) used center of pressure displacements in the anterior-
posterior and medial-lateral direction measured by two custom made force plates. The
COPs were described in terms of mean location and root-mean-square displacement
relative to the mean. Secondary variables of peak-to-peak range, average speed, and
mean frequency of the COP were also recorded. Of the four primary COP measures,
only the a-p location showed significant task-related differences between conditions.
The variable of total sway path was used as a measure of postural stability in experiments performed by Shumway-Cook et al. (1997) and Yardley et al. (1992). Total sway path describes the displacement of the center of pressure exerted on the force platform presented as the total distance traveled in mm during the sampling time. Shumway-Cook et al. sampled for a 30 second interval, whereas Yardley et al. sampled for 20 seconds on each trial.

In another study, Perrin et al. (1997) used a force platform to record the location of maximal vertical pressure. This position was recorded for each foot during the test, and displacements of the position were recorded over time. This data was then used to calculate the distance and surface area covered by the position over the course of each trial. Tarantola et al. (1997) also recorded oscillations of the center of pressure (COP) during quiet upright stance. Stabilograms of the data calculated three measures: (1) sway path over a given time interval, (2) the mean position of the COP, and (3) the surface covered by the instantaneous COP moving around its mean position (sway area).

Kerr et al. (1985) used a Kistler force platform to measure components of forces during 12 second trials. For analysis, COPs in m-l and a-p directions were used to compute four values: (1) the average absolute distance of COP from the mean COP location, (2) the standard deviation of the absolute distances from the mean COP location, (3) the average absolute distances of the separate m-l and a-p COPs from their respective means, and (4) the ranges of the a-p and m-l COP values.

A study performed by Teasdale, Stelmach, Breunig, and Meeuwsen (1991) used a force platform to measure range and standard deviation of sway behavior in both a-p and m-l planes. The authors point out that the range of sway behavior can be misleading due to the fact it does not provide information about the distribution of the COP within the
specified range. Hay, Bard, Fleury, and Teasdale (1996) again used range of COP displacements. In addition, the mean COP velocity was calculated. The COP velocity indicated the mean speed of the displacements of the COP over the given sampling time. This is the calculated sum of the displacement vectors divided by the sampling time (Hay et al., 1996). This measure was also used by Geurts, Mulder, Nienhuis, & Rijken (1991) and Baloh et al. (1994). Baloh et al. proposed that sway velocity should be a better indicator of the effort to maintain balance during platform perturbations than the amplitude of sway. To obtain the measure of the average velocity, the investigators calculated the root mean square of sway velocity in a-p and m-l directions for each ten second trial. A frequency analysis was then performed to generate histograms.

Stelmach et al. (1990) used the dependent measures of mean sway velocity, range, and variability of range of the center of foot pressure (COP) from an Advanced Mechanical Technology force platform. Each measure was calculated over a 1-second interval. Mean velocity was defined as the velocity with which the COP changes within each 1 second interval. The range represented the difference between the two extreme-position values, and the variability of range was the mean standard deviation of the individual range values. Measures were calculated for both the anterior-posterior (a-p) and medial-lateral (m-l) directions.

Teasdale et al. (1993) did not directly record postural stability measures for each trial, however they used a novel measure to accomplish part of the experimental protocol. Based on preliminary trials recording COP on a force platform, the authors calculated a central area (inside approximately one standard deviation around the mean COP) and an eccentric area (outside the central area). Teasdale et al. observed that the number of times participants' COP's were in an eccentric position increased with decreased available
sensory information. More time spent in an eccentric position would indicate decreased postural control. Therefore, the classification of central and eccentric areas was based on movements of the COP, and specifically, the amount of time spent in an area close to the mean COP versus in an area farther from the COP.

Summary

Postural control requires continuous regulation and integration of sensory information from the visual, somatosensory, and vestibular systems (Lajoie et al., 1993). No one sensory system directly specifies the position of the body's COG, therefore, the integration of sensory information must continually change (Horak et al., 1989). The mechanisms behind these changes remain unclear. Situations in which there is an overall lack of input, or lack of accurate input, generally result in decreased postural stability (Grabiner & Enoka, 1995; Woollacott & Shumway-Cook, 1990; Horak et al., 1989; Nashner, 1989; Nashner et al., 1989; Woollacott et al, 1986).

The importance of vision to postural control is well established in the literature. Numerous studies have demonstrated its importance through the exclusion of vision and manipulation of visual input in "moving room" protocols (Perrin et al., 1997; Sundermier et al., 1996; Yardley et al., 1992; Nashner & McCollum, 1985; Dornan et al., 1978; Lee & Lishman, 1974; Lee & Aronson, 1975).

It has also been demonstrated that vision can interfere with spatial tasks. This has been suggested on the basis that the both may compete for visual processing capabilities. Brooks (1967) described such a relationship, along with following researchers, Byrne (1974), Podgorny and Shepard (1978), and Finke (1980).
Not only can spatial tasks and vision interfere with one another, it has additionally been illustrated that spatial cognitive tasks can interfere with postural control. This interference has been explained through the common reliance of both postural control and spatial tasks on visual processing (Shumway-Cook et al., 1997; Maylor & Wing, 1996; Teasdale et al., 1993; Maki & McIlroy, 1991; Stelmach et al., 1990).

The relationships between visual processing, spatial tasks, and postural control have been investigated through separate investigations of two of the three. The interaction between specific visual perception manipulations associated with cognitive tasks and postural control has not previously been investigated. That is, the effect of having to use vision, with and without eye movements, to perform another task while maintaining postural stability. It is possible that the visual processing needed for a visual task may interfere with postural control in much the same way certain spatial tasks have been demonstrated to. Woollacott et al. (1997) touched on this hypothesis by stating that a sentence completion task presented visually may have placed demands on visual processing pathways, thereby interfering with postural control.

In conclusion, previous studies have established the possibility that using visual perception and eye movements for a concurrent postural task may interfere with postural control mechanisms. The present study was developed to investigate this possibility.
CHAPTER 3

METHODS

The purpose of this study was to investigate the effects of visual and cognitive manipulations on postural control in healthy, young adults. Specifically, the study addressed the effect of varying demands of visual perception associated with a concurrent cognitive task on postural sway.

This chapter provides a description of the study's methodology. The chapter initially addresses participant selection, followed by a description of the experimental protocol and specific conditions of the study. Finally, the chapter concludes with an explanation of the instrumentation and procedures used to collect and analyze the data.

Participants

Participants included 30 young, adult volunteers (mean age 24.4 years, range 18-34 years) recruited from the student population at the University of Nevada, Las Vegas (Table 1 and Table 2). This population was selected to represent healthy, young adults. Approval was provided by the University of Nevada, Las Vegas Office of Sponsored Programs for research involving human subjects (Appendix I).
Participants were required to give informed consent (Appendix II) after reading a general description of the experimental procedures. No information was given regarding the theoretical questions of the study. Additionally, participants were asked to complete a general health questionnaire (Appendix III) prior to involvement in the study. The questionnaire served as a screening device to exclude participants on the basis of health conditions that may have interfered with their performance during the study. The questionnaire also asked the participant to indicate the highest level of math class completed. This information was used to assess participant math skills. All participants had at least completed a high school level Algebra class. Participants were excluded from the study if the results of the questionnaire indicated any disorders related to postural control, vision, or audition.

Table 1

Participant Descriptive Statistics

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<td>26.0 ±4.33</td>
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<td>23 to 34</td>
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<tr>
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<td>15</td>
<td>22.8 ±3.34</td>
<td>±3.34</td>
<td>18 to 34</td>
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<tr>
<td>Total</td>
<td>30</td>
<td>24.4 ±4.71</td>
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<td>18 to 34</td>
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Table 2

Participant Characteristics

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Experimental Protocol

Participants first read and signed a human subject informed consent form. Following this, each participant completed the general health questionnaire if the participant agreed to be involved in the study. A general overview of instructions was given verbally by the same investigator prior to the start of the experiment, and any questions related to the protocol were answered. Participants were informed that they could terminate their involvement at any time with absolutely no negative consequences.

Participants were directed to stand barefoot in a Tandem (heel-to-toe) Romberg stance (Kerr et al., 1985) during each trial. Instructions were given directing the participant when to step on and off the Kistler Force Platform, along with specific instructions at the start of each trial describing the demands of the specific condition. Each trial began after a verbal cue from the participant that he/she felt comfortable in a quiet, static stance and was ready to begin the trial. Consistent instructions were given to each participant.

All participants were tested in six conditions, the order of which was counterbalanced. Each condition consisted of five trials, each of a 22 second duration.

Description of Conditions

The six conditions tested in the present study were combinations of eye movement manipulations with or without the concurrent performance of a cognitive task. The study was a 2 (Eye Movement) x 3 (Cognitive Task) within-subject design. Each level of the cognitive manipulation (No Cognitive, Visual Cognitive, and Auditory Cognitive) was performed in conjunction with each level of the eye movement manipulation (No Eye Movement and Eye Movement) (Table 3).
Table 3
Experimental Design

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<th>Auditory Cognitive</th>
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<tr>
<td>No Eye Movement</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

The three levels of the cognitive task were No Cognitive task, visually presented cognitive task (Visual), and verbally presented cognitive task (Auditory). In the No Cognitive task condition this condition, participants stood as stationary as possible for the duration of the trial while remaining focused on the visual target(s) presented directly in front of them. The Visual Cognitive condition involved the projection of the visual targets with numbers inside of them (Appendix IV). A number was presented in every two seconds, for a total of ten numbers. The math task, as described below, involved calculating a running additive total of ten numbers. In the Auditory Cognitive condition numbers used in the mathematical task were presented verbally and synchronized to visual targets without numbers in them. Therefore, the difference between the Visual and Auditory conditions was the mode presentation of the numbers.

Each of the cognitive conditions described above was performed in conjunction with the two levels of eye-movement condition: No Eye Movement and Eye Movement. In the No Eye Movement conditions participants were asked to stand on the force
platform and focus on a stationary visual target projected on the wall directly in front of
them. Instructions were given in all conditions to stand as stationary as possible for the
duration of the trial. Eye Movement conditions, on the other hand, required participants
to follow moving visual targets presented at a rate of one per second, without movement
of the head. Therefore, during the visual and auditory cognitive tasks, numbers were
presented in every other visual target at a rate of one every other second.

The cognitive task consisted of a mathematical addition problem. Specifically, it
involved calculating a running total of ten, single digit numbers. Each cognitive task trial
used a different ten number array. The difficulty levels of the task between trials were
equated through the use of a predetermined classification system. The numbers 1 through
9 were divided into three levels of difficulty: easy (1-3), medium (4-6), and difficult (7-
9). The following pattern of difficulty levels was used for every trial: medium, hard,
easy, medium, easy, hard, easy, medium, easy, medium. For each difficulty level in the
pattern, a number was randomly drawn to fill the slot. For example, if the specified level
was medium, either 4, 5, or 6 was randomly selected for the number array.

Depending on the condition, the numbers were presented either visually or
verbally. Power Point® was used to create the visual targets presented to the participant
and to synchronize the visual and verbal presentations of the numbers. One number was
presented every 2 seconds for the duration of the trial. The participant was asked to
report the final total at the end of each trial. Answers were recorded to describe
performance on the cognitive test.

Testing took approximately one-half hour for each participant. After testing, any
questions were answered for the participant regarding the theoretical question of the
study.
Instrumentation

The postural sway measuring device used in the present study was a Kistler® Force Platform. The force platform uses four piezoelectric sensors located in the corners of the platform. When a force is applied to the platform, piezoelectric signals are generated. These signals are then amplified and transmitted to an A/D board. Kistler Bioware® software was used to analyze the resulting digital signals. For each trial, the system collected 22 seconds of data at a frequency of 50 Hz. The first two and last two seconds of data were removed prior to analysis of the data to eliminate sampling error (Hoffman, 1995). Therefore, the middle 18 seconds (900 data points) were used in the analysis. The dependent measures recorded directly from the Bioware® software were variability of shear forces in the medial-lateral (FxSD) and anterior-posterior (FySD) directions, along with the variability of center of pressure (COP) movement in the medial-lateral (AxSD) and anterior-posterior (AySD) directions.

The force platform was mounted inside a three-sided "pod" (Figure 1). A computer projector projected the images from the computer onto the back wall of the pod directly in front of the participant. Images were projected at eye level. Both the force platform and power point presentation were controlled by the primary investigator from a location behind and to the right of the participant and the pod.
Analyses

Variability (standard deviation) for each of the four dependent sway measures (FySD, FxSD, AySD, and AxSD) was obtained for each trial and averaged across each condition for use in the analysis. The ratio of medial-lateral variability to anterior-posterior variability was calculated for both the force and COP movement variables. A 2(Eye Movement) x 3(Cognitive condition) analysis of variance (ANOVA) was performed on each dependent measure of force (FySD and FxSD), COP movement (AySD and AxSD), and ratio of medial-lateral to anterior-posterior variability (FxSD/FySD and AxSD/AySD). Due to the six separate ANOVA's, the alpha level was adjusted to 0.017 according to the modified Bonferroni adjustment. In the presence of significant main effects a Tukey's post hoc test was utilized to determine the location of any significant differences between the three Cognitive conditions.

Figure 1. Experimental Setup (overhead view)
Summary

The purpose of this study was to investigate the effects of visual and cognitive manipulations on postural control. Specifically, the study addressed the effect of varying demands of visual perception associated with a concurrent cognitive task on postural sway.

Participants were young, healthy adults from a student population at the University of Nevada, Las Vegas. They were required to sign an informed consent and to be free of any disorders possibly affecting their performance in the study.

Postural sway of participants was measured on a Kistler Force platform during six different conditions. The conditions required different visual demands associated with and without a cognitive math task. Conditions were presented at eye level in front of the participant through the use of Power Point. Six dependent measures (FxSD, FySD, AxSD, AySD, ratio FxSD/FySD, and ratio AxSD/AySD) were statistically analyzed. An average variability of sway was calculated for each participant in each condition. An ANOVA was applied to the average values for each dependent measure for each condition. A Tukey's post hoc test was performed to identify the location of any significant main effects of the Cognitive conditions.
CHAPTER 4

RESULTS

Introduction

The purpose of the current study was to investigate the effects of visual and cognitive manipulations on postural control in healthy, young adults. Specifically, the study addressed the effect of varying demands of visual perception associated with a concurrent cognitive task on postural sway. Postural sway was quantified through the use of a Kistler® force platform. Six measures of sway were calculated for each subject in each of the six conditions: (1) mean anterior-posterior force variability (FySD), (2) mean medial-lateral force variability (FxSD), (3) mean anterior-posterior center of pressure (COP) movement variability (AySD), (4) mean medial-lateral COP movement variability (AxSD), (5) ratio of medial-lateral force variability to anterior-posterior force variability (FxSD/FySD), (6) ratio of medial-later COP movement variability to anterior-posterior COP movement variability (AxSD/AySD). Performance scores (number of correct totals) were also recorded for each cognitive condition for each participant. Zero order correlations were calculated to determine the strength of the relationships between the six dependent variables. A 2 (Eye Movement) x 3 (Cognitive) repeated measures Analysis of Variance (ANOVA) was applied to each dependent measure. Alpha level of .05 was
used in all analyses. A post hoc Tukey's Test was used to identify the location of significant differences where appropriate. An additional correlation was calculated to investigate the relationship between the performance scores and the variables of AxSD, FxSD/FySD, and AxSD/AySD.

Measurement of Postural Sway

Postural sway was measured for each subject during five trials under six experimental conditions (total trials = 30). Four posture related variables (standard deviations of Fy, Fx, Ay, and Ax) were calculated from each trial. From these variables, the ratios of FxSD/FySD and AxSD/AySD were calculated. Anterior-posterior force (Fy) is a measure of sheer forces exerted on the force platform in the anterior-posterior direction, while medial-lateral force (Fx) is a measure of sheer forces exerted on the platform in the medial-lateral direction. Anterior-posterior COP movement (Ay) is a measure of COP location in the anterior-posterior direction over time. Likewise, medial-lateral COP movement (Ax) describes COP location in the medial-lateral direction over time. Standard deviations of these measures represent variability around the mean for a trial.

The FySD ANOVA revealed no significant Cognitive Manipulation effect, Eye Movement effect, or Eye Movement by Cognitive Manipulation interaction (see Table 4 and Table 5).
### Table 4

**Anterior-Posterior Force Variability (FySD) Means and Standard Deviations**

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None</th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Eye Movement</td>
<td>10.39</td>
<td>9.91</td>
<td>10.09</td>
</tr>
<tr>
<td></td>
<td>3.04</td>
<td>2.71</td>
<td>2.59</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>10.55</td>
<td>10.08</td>
<td>10.23</td>
</tr>
<tr>
<td></td>
<td>3.08</td>
<td>3.42</td>
<td>3.64</td>
</tr>
</tbody>
</table>

### Table 5

**ANOVA Summary Table for Anterior-Posterior Force Variability (FySD)**

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>1.12</td>
<td>1</td>
<td>1.12</td>
<td>.49</td>
<td>.487</td>
</tr>
<tr>
<td>Subject</td>
<td>1482.84</td>
<td>29</td>
<td>51.12</td>
<td>22.68</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>65.38</td>
<td>29</td>
<td>2.25</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cognitive</td>
<td>6.96</td>
<td>2</td>
<td>3.48</td>
<td>3.34</td>
<td>.042</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>60.39</td>
<td>58</td>
<td>1.04</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>.01</td>
<td>2</td>
<td>.00</td>
<td>.00</td>
<td>.997</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td>64.51</td>
<td>58</td>
<td>1.11</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
The FxSD ANOVA revealed a significant effect for Eye Movement, $F(1.29) = 7.61, p = .010$ (see Table 6, Table 7, Figure 2). The Cognitive Manipulation effect and Eye Movement by Cognitive Manipulation interaction were not statistically significant.

<table>
<thead>
<tr>
<th></th>
<th>Cognitive Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>No Eye Movement</td>
<td>X 13.17</td>
</tr>
<tr>
<td></td>
<td>SD 4.32</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>X 14.13</td>
</tr>
<tr>
<td></td>
<td>SD 5.11</td>
</tr>
<tr>
<td></td>
<td>X 13.65</td>
</tr>
<tr>
<td></td>
<td>SD 4.72</td>
</tr>
</tbody>
</table>

Table 6

Medial-Lateral Force Variability (FxSD) Means and Standard Deviations
### ANOVA Summary Table for Medial-Lateral Force Variability (FxSD)

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>41.37</td>
<td>1</td>
<td>41.37</td>
<td>7.61</td>
<td>.010</td>
</tr>
<tr>
<td>Subject</td>
<td>3969.67</td>
<td>29</td>
<td>136.89</td>
<td>25.17</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>157.70</td>
<td>29</td>
<td>5.44</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cognitive</td>
<td>10.04</td>
<td>2</td>
<td>5.02</td>
<td>3.24</td>
<td>.046</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>89.74</td>
<td>58</td>
<td>1.55</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>.01</td>
<td>2</td>
<td>.01</td>
<td>.00</td>
<td>.996</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td>76.60</td>
<td>58</td>
<td>1.32</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

**Figure 2.** Medial-Lateral Force Variability (FxSD) Eye Movement Effect

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The AySD ANOVA revealed a significant Cognitive Manipulation main effect,

$$F(2,58) = 6.13, p=.004$$ (see Table 8 and Table 9). The Eye Movement main effect and
the Eye Movement by Cognitive Manipulation interaction were not statistically
significant. The follow up Tukey's Test (Tukey's critical value = 0.419) indicated
significantly more variability of sway in the No Cognitive condition than the Auditory
Cognitive condition. The differences between the remaining means were not statistically
significant (see Table 10 and Figure 3).

Table 8

Anterior-Posterior COP Movement Variability (AySD) Means and Standard Deviations

<table>
<thead>
<tr>
<th></th>
<th>Cognitive Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>No Eye Movement</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td></td>
<td>5.12</td>
</tr>
<tr>
<td></td>
<td>SD</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td></td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>SD</td>
</tr>
</tbody>
</table>

$\bar{X}$ 4.96 4.55 4.37 4.62
SD 1.27 1.74 1.39 1.49
Table 9

ANOVA Summary Table for Anterior-Posterior COP Movement Variability (AvSD)

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>2.68</td>
<td>1</td>
<td>2.68</td>
<td>2.39</td>
<td>.133</td>
</tr>
<tr>
<td>Subject</td>
<td>268.88</td>
<td>29</td>
<td>9.27</td>
<td>8.27</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>32.51</td>
<td>29</td>
<td>1.12</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cognitive</td>
<td>11.18</td>
<td>2</td>
<td>5.59</td>
<td>6.13</td>
<td>.004</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>52.90</td>
<td>58</td>
<td>0.91</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>0.56</td>
<td>2</td>
<td>0.28</td>
<td>.55</td>
<td>.582</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td>29.50</td>
<td>58</td>
<td>0.52</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Table 10

Tukey's Test for AvSD Cognitive Manipulation Effects (Critical Difference = 0.419)

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None</th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X=4.96)</td>
<td>----</td>
<td>Significant (.41)</td>
<td>Significant (.59)</td>
</tr>
<tr>
<td>None (X= 4.96)</td>
<td>----</td>
<td>NS (.18)</td>
<td></td>
</tr>
<tr>
<td>Visual (X= 4.55)</td>
<td>----</td>
<td>----</td>
<td></td>
</tr>
<tr>
<td>Auditory (X= 4.37)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The AxSD ANOVA revealed significant Eye Movement, $F(1,29) = 11.52$, $p=.002$, and Cognitive Manipulation, $F(2,58) = 14.60$, $p<.0001$, main effects (see Table 11, Table 12, Figure 4, and Figure 5). The Eye Movement by Cognitive Manipulation interaction was not statistically significant. Tukey's Test (Tukey's critical value = 0.244) revealed significantly more variability of sway in the No Cognitive condition than both the Visual Cognitive and Auditory Cognitive conditions (See Table 13). The means of the Visual Cognitive and Auditory Cognitive conditions did not display a statistically significant difference.
Table 11

Medial-lateral COP Movement Variability (AxSD) Means and Standard Deviations

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None</th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Eye Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>6.45</td>
<td>6.09</td>
<td>6.05</td>
</tr>
<tr>
<td>SD</td>
<td>1.07</td>
<td>1.13</td>
<td>0.99</td>
</tr>
<tr>
<td>Eye Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>6.90</td>
<td>6.33</td>
<td>6.34</td>
</tr>
<tr>
<td>SD</td>
<td>1.00</td>
<td>0.96</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Table 12

ANOVA Summary Table for Medial-Lateral COP Movement Variability (AxSD)

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>4.83</td>
<td>1</td>
<td>4.83</td>
<td>11.52</td>
<td>.002</td>
</tr>
<tr>
<td>Subject</td>
<td>134.88</td>
<td>29</td>
<td>4.65</td>
<td>11.08</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>12.17</td>
<td>29</td>
<td>0.42</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cognitive</td>
<td>9.01</td>
<td>2</td>
<td>4.50</td>
<td>14.60</td>
<td>.001</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>17.88</td>
<td>58</td>
<td>0.31</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>0.38</td>
<td>2</td>
<td>0.19</td>
<td>0.68</td>
<td>.512</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 13

Tukey’s Test for AxSD Cognitive Manipulation Effects (Critical Difference = 0.244)

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None (X=6.67)</th>
<th>Visual (X=6.21)</th>
<th>Auditory (X=6.19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (X=6.67)</td>
<td></td>
<td>Significant (0.46)</td>
<td>Significant (0.48)</td>
</tr>
<tr>
<td>Visual (X=6.21)</td>
<td></td>
<td></td>
<td>NS (0.02)</td>
</tr>
<tr>
<td>Auditory (X=6.19)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Medial-Lateral COP Movement Variability (AxSD) Eye Movement Effect

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The force variability ratio (FxSD/FySD) ANOVA revealed significant Eye Movement, $F(1,29) = 14.64, p=.001$, and Cognitive Manipulation, $F(2.58) = 16.21, p<.0001$, main effects (see Table 14, Table 15, Figure 6, and Figure 7). The Eye Movement by Cognitive Manipulation interaction was not statistically significant. The follow up Tukey's test performed on the three Cognitive means indicated significant differences between the No Cognitive and Visual Cognitive conditions, along with the No Cognitive and Auditory Cognitive conditions (see Table 16). The No Cognitive condition had the smallest FxSD/FySD ratio in both comparisons. The difference between The Visual Cognitive and Auditory Cognitive means was not statistically significant.
Table 14

**Force Variability Ratio (FxSD/FySD) Means and Standard Deviations**

<table>
<thead>
<tr>
<th></th>
<th>Cognitive</th>
<th>Manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Visual</td>
</tr>
<tr>
<td>No Eye Movement</td>
<td>$\bar{x}$</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.19</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>$\bar{x}$</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>$\bar{x}$</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 15

**ANOVA Summary Table for Force Variability Ratio (FxSD/FySD)**

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>0.20</td>
<td>1</td>
<td>0.20</td>
<td>14.64</td>
<td>.001</td>
</tr>
<tr>
<td>Subject</td>
<td>6.67</td>
<td>29</td>
<td>0.23</td>
<td>17.10</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>0.39</td>
<td>29</td>
<td>0.01</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cognitive</td>
<td>0.50</td>
<td>2</td>
<td>0.25</td>
<td>16.21</td>
<td>.0001</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>0.89</td>
<td>58</td>
<td>0.02</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>0.01</td>
<td>2</td>
<td>0.00</td>
<td>0.24</td>
<td>.788</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td>0.81</td>
<td>58</td>
<td>0.01</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Table 16

Tukey's Test for FxSD/FySD Main Effects (Critical Difference = 0.062)

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None (X=1.30)</th>
<th>Visual (X=1.42)</th>
<th>Auditory (X=1.40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None (X= 1.30)</td>
<td>---</td>
<td>Significant (.12)</td>
<td>Significant (.10)</td>
</tr>
<tr>
<td>Visual (X= 1.42)</td>
<td>---</td>
<td>---</td>
<td>NS (.02)</td>
</tr>
<tr>
<td>Auditory (X= 1.40)</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** Force Variability Ratio (FxSD/FySD) Eye Movement Effect

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The COP movement variability ratio (AxSD/AySD) ANOVA revealed significant Eye Movement main effect, $F(1, 29) = 19.13$, $p < .0001$. (see Table 17, Table 18, Figure 8). The Cognitive Manipulation effect and Eye Movement by Cognitive Manipulation interaction were not statistically significant. The difference between the Visual Cognitive and Auditory Cognitive means was also not statistically significant.
### Table 17

**COP Movement Variability Ratio (AxSD/AySD) Means and Standard Deviations**

<table>
<thead>
<tr>
<th>Cognitive Manipulation</th>
<th>None</th>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Eye Movement</td>
<td>1.32</td>
<td>1.41</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>0.32</td>
<td>0.39</td>
<td>0.41</td>
</tr>
<tr>
<td>Eye Movement</td>
<td>1.50</td>
<td>1.61</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>0.45</td>
<td>0.43</td>
</tr>
</tbody>
</table>

### Table 18

**ANOVA Summary Table for COP Movement Variability Ratio (AxSD/AySD)**

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye Movement</td>
<td>1.45</td>
<td>1</td>
<td>1.45</td>
<td>19.13</td>
<td>.0001</td>
</tr>
<tr>
<td>Subject</td>
<td>18.46</td>
<td>29</td>
<td>0.64</td>
<td>8.41</td>
<td>.0001</td>
</tr>
<tr>
<td>Eye Movement x Subject</td>
<td>2.20</td>
<td>29</td>
<td>0.08</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cognitive</td>
<td>0.42</td>
<td>2</td>
<td>0.21</td>
<td>3.31</td>
<td>.044</td>
</tr>
<tr>
<td>Cognitive x Subject</td>
<td>3.72</td>
<td>58</td>
<td>0.06</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Eye-Movement x Cognitive</td>
<td>0.02</td>
<td>2</td>
<td>0.01</td>
<td>0.22</td>
<td>.801</td>
</tr>
<tr>
<td>Eye Movement x Cognitive x Subject</td>
<td>2.53</td>
<td>58</td>
<td>0.04</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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A Pearson's correlation was performed on the six postural sway variables, FySD, FxSD, AySd, AxSD, FxSD/FySD ratio, and AxSD/AySD ratio, to investigate the strength of the relationships between the variables. The correlation coefficients are displayed in Table 22. Eleven of the fifteen combinations of variables were significantly correlated (p<.05). Six of those ten were revealed moderate to high correlations and are as follows: FxSD and FySD, r=.8572; AxSD/AySD ratio and AySD, r=-.8253; AySD and FySD, r=.6320; AxSD and FySD, r=.5580; AxSD and FxSD, r=.5068; and FxSD/FySD ratio and AxSD/AySD ratio, r=.4756. Table 23 displays a direct comparison of the correlation coefficients revealed in the current study compared to those reported by Goldie et al. (1989) in the same stance, using the same four basic measures of postural sway.
<table>
<thead>
<tr>
<th></th>
<th>Fy</th>
<th>Fx</th>
<th>Ay</th>
<th>Ax</th>
<th>F-ratio</th>
<th>A-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fy</td>
<td>1.0000</td>
<td>.8572</td>
<td>.6321</td>
<td>.5580</td>
<td>-.0990</td>
<td>-.3740</td>
</tr>
<tr>
<td></td>
<td>p=.0001</td>
<td>p=.0001</td>
<td>p=.0001</td>
<td>p=.186</td>
<td>p=.0001</td>
<td></td>
</tr>
<tr>
<td>Fx</td>
<td>1.0000</td>
<td>.3571</td>
<td>.5068</td>
<td>.4020</td>
<td>-.1128</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=.0001</td>
<td>p=.0001</td>
<td>p=.0001</td>
<td>p=.132</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ay</td>
<td>1.0000</td>
<td>.4397</td>
<td></td>
<td>-.4394</td>
<td>-.8253</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p=.0001</td>
<td>p=.0001</td>
<td></td>
<td>p=.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ax</td>
<td></td>
<td></td>
<td></td>
<td>1.0000</td>
<td>-.0247</td>
<td>.0393</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p=.742</td>
<td>p=.601</td>
</tr>
<tr>
<td>F-ratio</td>
<td></td>
<td></td>
<td></td>
<td>1.0000</td>
<td>.4819</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p=.0001</td>
<td></td>
</tr>
<tr>
<td>A-ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

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Table 20

Comparison of Correlation Coefficients to those Reported by Goldie et al. (1989)
(Goldie et al. values in bold face)

<table>
<thead>
<tr>
<th></th>
<th>FySD</th>
<th>FxSD</th>
<th>AySD</th>
<th>AxSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>FySD</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.86</td>
<td>0.55</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>FxSD</td>
<td>0.82</td>
<td>1.000</td>
<td>0.41</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.86</td>
<td>0.36</td>
<td>0.51</td>
</tr>
<tr>
<td>AySD</td>
<td></td>
<td></td>
<td>1.000</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>AxSD</td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

The Pearson’s correlation for AxSD, FxSD/FySD ratio, AxSD/AySD ratio and
Score on the cognitive task was performed to investigate the relationship between
cognitive performance and postural sway (see Table 24). No correlation coefficient
between a math score and a dependent measure, however, was statistically significant.

Table 21

Correlation Coefficients of Math Score to AxSD, F-ratio, and A-ratio

<table>
<thead>
<tr>
<th></th>
<th>Math Score</th>
<th>AxSD</th>
<th>F-ratio</th>
<th>A-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Score</td>
<td>1.0000</td>
<td>-0.0706</td>
<td>0.1465</td>
<td>0.0740</td>
</tr>
<tr>
<td></td>
<td>p=0.443</td>
<td>p=0.110</td>
<td>p=0.422</td>
<td></td>
</tr>
</tbody>
</table>
The purpose of the present study was to investigate the effects of cognitive and visual manipulations on postural control in healthy, young adults. Specifically, the study addressed the effects of varying the demands of visual perception associated with a concurrent cognitive task on postural sway. Cognitive Manipulations consisted of three conditions: no cognitive task, visual presentation of the cognitive task, and auditory presentation of the cognitive task. The Cognitive Manipulations were designed to investigate (1) the effect of the visual presentation of the task versus the auditory presentation, and (2) the general effect of a secondary (math) task on postural sway in young adults. Based on previous research, it was hypothesized that the secondary cognitive task would negatively affect postural control. It was further hypothesized that a visual presentation would interfere with postural control to a greater extent than an auditory presentation, due to possible interference between the processing of visual information for the task and for the control of posture (Shumway-Cook et al., 1997).

The Eye Movement manipulation consisted of 2 conditions: no eye movement and eye movement. This manipulation served to investigate the effect of deliberate eye
movements on postural control in young adults. It was hypothesized that eye movements would promote an increase in sway variability (Kerr et al., 1985), and that a possible interaction would exist between the three cognitive conditions and the eye movement or no eye movement. The results of the study are discussed in detail in the present chapter.

Dependent Measures

The dependent measures used in the present study were selected based on pilot work and their common use in postural control research. Analysis of the strength of association between the six dependent measures revealed correlation coefficients consistent to those reported by Goldie et al. (1989) (see Table 23). The relatively low observed correlation coefficients between many of the variables were expected. Although all dependent measures were chosen to describe postural sway variability, each describes different aspects of postural sway behavior. For example, AySd describes anterior-posterior sway variability, while AxSD describes medial-lateral sway variability. Therefore, while the majority of the correlation coefficients were statistically significant, few approached a coefficient of 1. The correlation served to describe the extent to which the two measures overlap in their measurement of postural sway. The observed coefficients are evidence for the need to combine dependent measures to develop a more thorough conclusion regarding changes in postural control.

Due to the arrangement of the feet in the Tandem stance, the medial-lateral plane is inherently provides less stability than does the anterior-posterior plane. Therefore, more variability of sway was expected in the medial-lateral direction. The data supported this expectation, as medial-lateral force and COP movement variability were generally greater than anterior-posterior force and COP movement variability.
The medial-lateral to anterior-posterior sway variability ratios (FxSD/FySD and AxSD/AySD) serve to describe sway behavior in two dimensions, as opposed to the one dimensional measures described above. Such ratios represent the relative relationship between medial-lateral and anterior-posterior sway, creating a description of overall sway behavior, or sway profile. Such a sway profile is important in determining how sway may change between conditions. In the Tandem stance, the ratio is expected to be greater than one. Specifically, more sway is observed in the medial-lateral direction than the anterior-posterior direction. A greater number corresponds to greater medial-lateral sway variability relative to anterior-posterior sway variability. Changes in ratios may result from increases in sway variability in the medial-lateral direction not accompanied by proportional increases in the anterior-posterior direction, or vice-versa.

It is possible that other dependent measures of postural sway may have better described sway behavior and therefore, any differences present between the conditions. Alternate variables to consider for future studies include total sway path, sway velocity, and amount of time spent in area close to the mean COP location versus in an area farther from the COP.

Effect of No Cognitive Task versus Cognitive Conditions

As previously mentioned, it was hypothesized that the performance of a secondary task on postural sway in the Tandem heel-to-toe stance would negatively affect postural control, thus increasing the variability of postural sway. Interestingly, statistical analyses revealed greater sway variability in the No Cognitive task condition compared to
one or both of the Cognitive conditions for the variables of anterior-posterior COP movement variability (AySD), medial-lateral COP movement variability (AxSD).

The finding that variability of sway was actually less in conditions involving a secondary cognitive task than balance alone is contrary to the majority of previous research. Two aspects of the present study may have contributed to this: (1) the specific cognitive task was novel, and (2) the population consisted of young adults, as opposed to the older adult populations used in the majority of similar postural control studies. One study that did report similar findings to the current study was conducted by Kerr et al. (1985). The study revealed that young adult participants actually demonstrated less sway in the cognitive (memory task) conditions than during balance-alone conditions. The experiment used the same stance and similar dependent measures as the current study, although the cognitive task differed. Kerr et al., however, explained the phenomenon through a significant order effect (Order X Condition interaction). That is, the order in which the participants were tested effected the outcome of the study. For example, only participants who balanced alone first displayed more sway in the balance-alone condition. In the present study, however, the order of all conditions were counterbalanced and the order effect described by Kerr et al. was not observed, yet more sway in the No Cognitive (balance alone) condition was still observed.

Maylor & Wing (1996) also observed a similar trend for the young adult participants, as participants tended to be more stable in dual-task conditions compared to the balance-alone condition. However, the authors conclude that the trend may be misleading due to several factors of the experiment. Participants' body-weight generally shifted forward during trials, termed "slow-drift." The degree of "slow-drift" was influenced by the specific condition, possibly from factors such as attending to a
metronome or experimenter situated behind the experimenter in dual-task conditions. Therefore, it is difficult to determine the degree to which the results were influenced by the lesser degree of "slow-drift" observed in the dual-task conditions than under single task conditions. This experiment used a different apparatus and dependent measure to describe postural sway from the present study. Also, all conditions in the present study were presented automatically in front of the participant, thus keeping attention directed in the same area with every condition. Therefore, the unexpected results of the present experiment cannot be accounted for with a similar explanation.

There are possible explanations for the unexpected larger variability of sway observed in the No Cognitive condition. It is a relatively common occurrence that performance on tasks that are extremely automatic can actually be hindered by "thinking" about it or directing attention to it. It is possible that attending specifically to postural sway in young adults has a negative impact on performance, interfering with its normal automaticity. In the No Cognitive trials, the participant had little else to attend to except postural sway, as they were only instructed to remain as stationary as possible while looking at the visual target. In contrast, the Visual and Auditory Cognitive conditions gave the participants something else to directly attend to, presumably taking attention away from postural control itself. This diversion of attention may allow the normal automatic and successful control of posture. It is important to note that it is not possible to determine whether postural sway increased in the No Cognitive condition or whether it decreased in the Cognitive task conditions. It can only be concluded that a difference does exist between the two.

This explanation may to some degree account for the opposite trend observed between the sway behavior of the young adults in the current study and that of older
adults described in previous research while performing a concurrent cognitive task. If postural control becomes less automatic due to factors associated with aging, then the secondary task could have a negative impact on postural control, taking resources away from it. This would explain the contrasts observed throughout postural control research between the two age groups.

Another factor that may have influenced the current results lies in the fundamental characteristics of the postural control system. The system normally allows movements of the center of gravity during quiet standing within certain limits (Collins, 1994). The amount the system is allowed to vary, or limits, may be affected by the presence or absence of concurrent tasks. In the No Cognitive condition, where there is little else to attend to and no concurrent task to accomplish, it may be safe to let the system vary to a greater degree than in the situation imposed by the Cognitive conditions. A secondary task may in effect constrain the amount of acceptable postural sway. Such a phenomenon could act as a type of safety mechanism during the time that attention is given to the other task. This possibility would explain that while most participants felt the cognitive conditions were more difficult from a postural control perspective, they actually exhibited less sway than in the "easier" No Cognitive condition. The different trend exhibited in previous studies of older adults could possibly be due to age-related effects on the postural control system leading to a decline in the ability to fine tune the postural control system that exists in young adults.

The ratios of medial-lateral to anterior-posterior variability of sway provided an interesting insight into the overall sway behavior and profile. Analysis of the ratios of force variabilities (FxSD/FySD) revealed that both the Visual Cognitive and Auditory Cognitive conditions had significantly larger medial-lateral compared to anterior-
posterior variability, than the No Cognitive condition. Therefore, the variability of forces in the medial-lateral direction was larger relative to the anterior-posterior direction when a cognitive task was employed. This is an interesting finding considering that the three measures FySD, AySD, and AxSD all showed greater sway variability in the No Cognitive condition than those involving a secondary cognitive task. This reveals that the proportion of medial-lateral to anterior-posterior sway differed between the conditions. As previously mentioned, it is not feasible to conclude which sway ratio, No Cognitive or Cognitive, represents normal sway variability. It is only possible to conclude that a difference in sway behavior exists between the two. There are two possibilities to account for the observed changes in sway ratios across conditions. One, anterior-posterior sway variability decreased more than medial-lateral in the Cognitive conditions, or two, anterior-posterior sway variability increased less than medial-lateral in the No Cognitive condition. In either situation, the sway profile of the Visual Cognitive and Auditory Cognitive conditions significantly differed from that of the No Cognitive condition. It is possible that the trend represents the use of different postural control strategies between the No Cognitive and Cognitive conditions. Thus, the difference in sway profiles between conditions may be a more practically significant finding than the other dependent measures describing only unidirectional sway variability.

Effect of Visual versus Auditory Conditions

The statistical analysis revealed no significant differences between the visual presentation of the secondary math task and the verbal (auditory) presentation of the task in any dependent measure. Therefore, using vision to accomplish the task did not affect
postural control differently than using audition. In the present experiment, the use of vision in the cognitive task did not appear to interfere with visual processing used in the control of posture.

It is possible that limitations of the present study contributed to this finding. One, the visual demands of the task were possibly relatively low, as compared to reading an entire word or sentence. A low visual demand, therefore, may not have been sufficient to produce an observable interference with postural control, if one does in fact exist. Along this same line, it should be noted that the cognitive load was not fully equated across the two conditions. The visual condition required the participant to use only one modality, vision, while the auditory condition required the participant to use two modalities, audition to hear the number and vision to keep gaze directed on the visual target. It is possible, therefore, that the difficulty levels of the two cognitive conditions masked any different effects of the two conditions on postural sway.

Another explanation for the observed results lies in the possibility that even if the Visual or Auditory Cognitive condition does interfere in some way with postural control, healthy, young adults are capable of fully compensating for that interference. Older adult populations have demonstrated less of an ability to compensate for interference within the postural control system than younger adults in previous studies. Therefore, replication of the protocol with a population of older adults would address this possibility and provide an interesting comparison between the control of posture in young versus older adults.

Effect of Eye Movement

It was hypothesized that deliberate eye movements would affect postural sway. This was proposed based on a hypothesis mentioned by Stelmach et al. (1990), stating
that eye movements may reflexively produce changes in the postural control system. The results of the present study support such a hypothesis.

Analysis of the medial-lateral force variability (FxSD) and the medial-lateral COP movement variability (AxSD) variable revealed significantly more sway variability in the Eye Movement condition compared to the No Eye Movement condition. Also, both the sway ratio of forces (FxSD/FySD) and of COP movement (AxSD/AySD) were significantly higher in the Eye Movement condition than the No Eye Movement condition. As described earlier the ratios describe greater variability in medial lateral sway in relation to anterior posterior sway. It is therefore evident from the current study that deliberate eye movements can affect sway behavior in young, healthy adults. Unlike the Cognitive Manipulation, the sway ratios increased as unidirectional measures of medial-lateral sway variability also increased. From this, it is reasonable to conclude that deliberate eye movements increased medial-lateral sway variability, negatively affecting postural control. Participants were observed to ensure that they were following the visual target and, therefore, making eye movements. However, the eye movements themselves were not measured, preventing a direct comparison of how specific eye movements affect postural control. The effect of eye movements, deliberate and involuntary, on postural control does deserve further investigation.

Analyses of anterior-posterior force variability (FySD) and COP movement (AySD) values, did not reveal a significant effect of Eye Movement. Based on the stance used, this finding was not expected. This, however, is not surprising due to the stance used. Once again, it may be most important to make conclusions based on the sway ratios, revealing that there is a significant change in sway profile between Eye Movement and No Eye Movement conditions.
Cognitive and Eye Movement Interactions

It was hypothesized that an interaction may exist between Eye Movement and Cognitive Manipulation. The addition of eye movement to the visual or auditory presentation of the secondary task could affect any interference with postural control already present as a result of the task. The same was possible for the No Cognitive condition. Contrary to this hypothesis, no interaction was revealed between Cognitive condition and Eye Movement condition for any dependent variable. Therefore, the effects of the Cognitive conditions were the same across both No Eye Movement and Eye Movement conditions, and the effects of Eye Movement were independent of the type of cognitive task employed.

Correlation of Cognitive Score, AxSD, F-ratio, and A-ratio

For each Cognitive Manipulation condition, a score was obtained for the mathematical addition task. The score was simply the number of trials with a correct answer (0-5). A significant positive correlation revealed that an increase in the amount of sway accompanied a decrease in performance on the math task. A negative correlation revealed that an increase in the amount of sway accompanied an increase in performance on the math task. The analysis, however, revealed no statistically significant correlation coefficients between the math score and either of the three dependent measures, AxSD, F-ratio (FxSD/FySD), and A-ratio (AxSD/AySD).
Implications

The present study is one of few that describes the effect of secondary cognitive tasks on a healthy, young adult population. The finding of increased sway in the No Cognitive condition versus the two cognitive conditions contrasts the findings of previous studies. The only studies that corroborate the finding disclaimed or raised questions concerning the effect due to a significant order effect of the conditions (Kerr et al., 1985) or to characteristics of the instrumentation and measurement used (Maylor & Wing, 1996). Therefore, the effect of a cognitive task on postural control in healthy, young adults should be further investigated before drawing broad conclusions as to the effect of secondary cognitive tasks on postural control of healthy, young adults. The sway ratios provide further evidence that a difference exists between sway behavior in a condition with no cognitive task compared to that with a concurrent cognitive task.

The effect of eye movements on postural control also deserves further attention. The current study further establishes that eye movements effect postural control in young, healthy adults. One possible limitation to the present study is that eye movements were not precisely measured. Therefore, the exact effect of eye movements on postural control cannot be detailed.

The present study can be extended in two important ways. First, develop a protocol with increased control over the secondary (cognitive) tasks. This would serve to describe the effect of the dual-task protocol on both the cognitive task and the posture task (Pashler, 1994). Second, it is of interest to extend the study to include an older adult population. This would provide an interesting comparison of age-related changes in postural control, especially related to visual information processing. Ellis, Goldberg, &
Detweiler (1996) recently suggested that younger adults are capable of developing parallel processing capabilities with regard to processing visual information, while older adults tend to remain serial processors. They further suggested that perceptual encoding had a large impact on age-related differences in performance on tasks requiring visual information processing. Such suggestions create interesting questions surrounding the effects of aging on the processing of visual information for the control of posture. The effect of using vision and/or eye movements to accomplish a secondary task on postural control may be of significant importance to older adults, as the use of vision is required in countless daily activities, from reading signs to watching television. If such tasks do in fact interfere with the ability to control posture, preventative or rehabilitative techniques could possibly be developed to train the system to better handle such overwhelming situations.
APPENDIX I

HUMAN SUBJECTS APPROVAL
DATE: April 27, 1998

TO: Megan Dailey
M/S 3034 (KIN)

FROM: Dr. William E. Schulze, Director
Office of Sponsored Programs (X1357)

REF: Status of Human Subject Protocol Entitled:
"The Effects of Visual Versus Verbal Presentation of a Math Task on Postural Control"

OSP # 504s0498-021

The protocol for the project referenced above has been reviewed by the Institutional Review Board Secretary in the Office of Sponsored Programs and it has been determined that it meets the criteria for approval under the Multiple Assurance Agreement for the UNLV Human Subjects Institutional Review Board. This protocol is approved for a period of one year from the date of this notification and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond a year from the date of this notification, it will be necessary to request an extension.

If you have any questions regarding this approval, please contact Marsha Green in the Office of Sponsored Programs at 895-1357.

cc: M. Hoffman (KIN-3034)
OSP File

Office of Sponsored Programs
4505 Maryland Parkway • Box 451037 • Las Vegas, Nevada 89154-1037
(702) 895-1357 • FAX (702) 895-4242
APPENDIX II

INFORMED CONSENT FORM
Welcome to the Motor Control Lab. You are invited to participate in a study of human balance. The study involves testing static balance, that is standing as still as possible on two feet. If you decide to participate, you will be asked to stand on two feet in heel-to-toe stance (toes of one foot lined up with heel of the other foot). You will also be asked to perform simple arithmetic math tasks. There will always be at least one assistant standing near you should you lose your balance at any time. Each experimental session will last a total of 30 minutes. There are no known risks involved in your participation. This information is based on a large body of experience with similar tasks.

Any information obtained in connection with this study that can be identified with you will remain confidential. The results of the research may be published in aggregate form with no identification given.

Your decision whether or not to participate will not prejudice your future relations with the University of Nevada, Las Vegas. You may withdraw from participation in this experiment at any time, but please inform the experimenter prior to withdrawal. If you have any questions please ask the experimenter. Telephone numbers to call if there are any questions are (702) 895-1241 or (702) 895-3419. For questions regarding rights of Human subjects, you may call the UNLV Office of Sponsored Programs at (702) 895-1357. Thank you for participating in this project.

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNATURE BELOW INDICATES YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INSTRUCTIONS AND INFORMED CONSENT.

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>Participant's Signature &amp; 3 Initials</th>
<th>Part. #</th>
<th>Researcher's Signature / date</th>
</tr>
</thead>
</table>

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QUESTIONNAIRE

Participant Initials (first, middle, last) _________
Participant Number (leave blank) _________

Please answer each of the following questions to the best of your knowledge:

SECTION 1: General Information

1. Name:

2. Age:

3. Occupation:

4. What is the highest level of formal education you have completed (check one):
   
   ___ High School
   ___ University (undergraduate degree)
   ___ Professional degree
   ___ Other
   ___ Junior College
   ___ Master’s
   ___ Ph.D.

5. What is the highest level of math class you have completed?
   ____________________________
   Date completed ______________

SECTION 2: Medical History

1. Have you ever been diagnosed with any of the following (check all that apply):
   
   ___ heart attack
   ___ stroke or transient ischemic attack (TIA)
   ___ epilepsy
   ___ learning disability (if yes, please explain)
   ___ neurological disorder (if yes, please explain)
   ___ bone or joint (musculoskeletal) problems (if yes, please explain)
Medical History continued...

___ visual impairments not correctable with lenses (if yes, please explain)

___ persistent symptoms of vertigo (dizziness) (if yes, please explain)

2. Are you currently taking any medication? (If yes, please list)

3. Have you ever suffered a head injury that resulted in a loss of consciousness for longer than five minutes?

4. Do you experience loss of balance? How often? In what situations?

5. Do you wear eye glasses or contact lenses?
   Is your vision corrected to at least 20/40?

6. Do you have normal hearing?
REFERENCES


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