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Effects of Head Motion on Balance in Middle-Aged and Young Adults with Chronic Motion Sensitivity

Ammar E. Hafiz

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LOMA LINDA UNIVERSITY
School of Allied Health Professions
in conjunction with the
Faculty of Graduate Studies

Effects of Head Motion on Balance in Middle-Aged and Young Adults with Chronic Motion Sensitivity

by

Ammar E. Hafiz

A Dissertation submitted in partial satisfaction of
the requirements for the degree
Doctor of Science in Physical Therapy

June 2019

Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Science.

, Chairperson

Eric Johnson, Professor of Physical Therapy

Noha Daher

Noha Daher, Professor of Epidemiology and Biostatistics

Shilpa Gaikwad, Assistant Professor of Physical Therapy

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ABBREVIATIONS

CMS	Chronic Motion Sensitivity
MSSQ-SF	Motion Sensitivity Susceptibility-Short Form
(IPAQ-S7S)	International Physical Activity Questionnaire short form for the past 7
CDP	Computerized Dynamic Posturography
VOR	Vestibulo-Ocular Reflex
VSR	Vestibulo-Spinal Reflex
COR	Cervico-Ocular Reflex
ES	Equilibrium Score
Hz	Hertz
SD	Standard Deviation
BMI	Body Mass Index
taMAX	theta maximum
taMIN	theta minimum
ICCs	Intra-class correlation coefficients

ABSTRACT OF THE DISSERTATION

Effects of Head Motion on Balance in Middle-Aged and Young Adults with Chronic Motion Sensitivity

by

Ammar E. Hafiz

Doctor of Science, Graduate Program in Physical Therapy
Loma Linda University, June 2019
Dr. Eric Johnson, Chairperson

Chronic motion sensitivity (CMS) often leads to a variety of symptoms including postural instability. There is limited research describing the effects of active head motion on standing postural stability in adults with motion sensitivity. Previous research has described the negative effects of chronic motion sensitivity on postural stability during active head motion. The purpose of this study was to compare the effects of slow and fast head motions, in multiple planes, on postural stability in healthy middle-aged adults with and without CMS. Secondary objective was to compare the effects of head motion on postural stability between young and middle-aged adults, and between groups with and without CMS.

Forty healthy middle-aged adults from 45 to 64 years were recruited. Twenty participants had a history of CMS and 20 participants did not. Prior to data collection, all participants were trained on specific parameters of active cervical rotation, flexion, and extension during horizontal and vertical directions at slow and fast velocities. Secondary, participants aged 20 to 40 years, with and without CMS, were recruited for this second study objective. Participants were assigned to one of two groups (CMS or non-CMS) using the Motion Sickness Susceptibility Questionnaire-Short Form. Postural stability was measured during static and dynamic head motions using the Bertec $^{\text{TM}}$ Balance Computerized Dynamic Posturography with Immersion Virtual Reality.

Mean postural stability was significantly different between participants with versus without CMS in all conditions of head motion (slow horizontal, slow vertical, fast horizontal, and fast vertical). During slow head motion velocity, mean postural stability was significantly different by direction (vertical versus horizontal), however, there was no significant group by direction effect. During fast head motion velocity, mean postural stability did not differ significantly by direction and group by direction. Additionally, Mean ± standard error postural stability of participants with CMS was significantly worse than those without CMS in both vertical (89.7±0.6 versus 91.9±0.6, p=0.01, partial η^2 =0.10), and horizontal head motion conditions (90.3±0.5 versus 92.5±0.6, p=0.01, partial η^2 =0.10). However, mean postural stability in both vertical and horizontal conditions did not significantly differ by age group.

In conclusion, the results suggest that healthy middle-aged adults without CMS have better postural stability during head motion compared to those with CMS. Also, adults with CMS have less postural stability during head motion in both planes compared to adults without CMS.

CHAPTER ONE

INTRODUCTION AND REVIEW OF THE LITERATURE

Motion Sensitivity

Chronic motion sensitivity (CMS), or “motion sickness”, is a common occurrence resulting in a physiological response to actual or virtual motion (Gaikwad et al., 2018; J. R. Lackner, 2014; Oman, 1990; Reason, 1978; Schmal, 2013; Sharma & Aparna, 1997; Zhang et al., 2016). Motion sensitivity typically induces postural instability as well as autonomic nervous systems including nausea, vomiting, dizziness, pallor, sweating, hypersalivation, headache, gastrointestinal dysfunction, chronic fatigue, and lethargy (Akiduki et al., 2003; Alharbi et al., 2017; Bertolini & Straumann, 2016; Gaikwad et al., 2018; Henriques, Douglas de Oliveira, Oliveira-Ferreira, & Andrade, 2014; J. R. Lackner, 2014; Takahashi et al., 1991; Zhang et al., 2016). Nearly 30% of the population experience motion sensitivity during various types of passive transportation (Alharbi et al., 2017; J. F. Golding, 2006; Koslucher, Haaland, Malsch, Webeler, & Stoffregen, 2015; Murdin, Golding, & Bronstein, 2011; Sharma & Aparna, 1997; Mark Turner, 1999; M. Turner & Griffin, 1999). Previous studies reported that motion sensitivity occurs in 70% of young children and 55% in adolescence and adulthood with a higher incidence in females (Bertolini & Straumann, 2016; J. F. Golding, Kadzere, & Gresty, 2005; Henriques et al., 2014; Koslucher et al., 2015; Paillard et al., 2013; Sharma & Aparna, 1997). The neural mechanism of motion sensitivity remains unclear; however, the sensory conflict theory is the most widely accepted explanation (Bertolini & Straumann, 2016; J. F. Golding & Gresty, 2015). Motion sensitivity, according to the sensory conflict theory, results from faulty central nervous system (CNS) processing of visual, vestibular, or somatosensory inputs (Oman, 1990; Reason, 1978). The CNS processes sensory system inputs and drives motor system outputs to maintain postural and visual stability (Herdman & Clendaniel, 2014; Horak & Macpherson, 1996). During sensory system mismatch, particularly with improper vestibular function, postural and visual instability can result (Massion, 1998; Nashner, Black, & Wall, 1982; Ricci et al., 2010). Micro-synaptic changes in the vestibular nerve function occur after the age of forty; whereas vestibular receptor organs become more susceptible to degeneration after age 50. By the age of 60, the electrical conductivity velocity of the vestibular nerve begins to decline (Ricci et al., 2010). In addition, Agrawal et al. (Agrawal et al., 2012) reported that there is general regression of the vestibular apparatus function throughout aging with more significant deficiency of the semicircular canals than otoliths. Abrahamova and Hlavacka (Abrahamova & Hlavacka, 2008) reported that variances in postural stability between young adults (20-40 years) and middle-aged adults (40-60 years) were not as defined as the difference between young and older adults (60-82 years). Similarly, Cohen et al. (Cohen, Heaton, Congdon, & Jenkins, 1996) reported that postural stability continues to decrease thru young adulthood (18-44 years), middle-aged adulthood (45-69 years), and older adulthood (70-89 years). Additional research has determined that postural stability decreases with aging (Sheldon, 1963; Thyssen, Brynskov, Jansen, & Munster-Swendsen, 1982).

Body Balance is Controlled by 3 Sensory Systems:
Vestibular, Visual, and Somatosensory

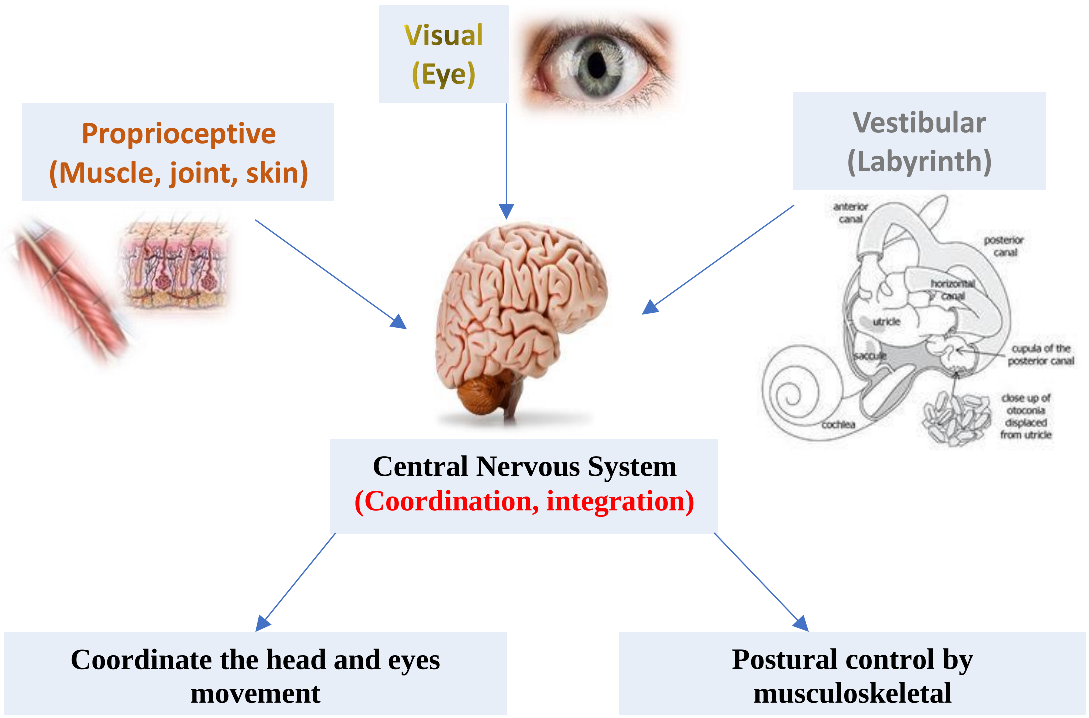

Fig. 1. Sensory Inputs

Motion Sensitivity Assessment

Motion sensitivity assessment tool was used in both studies will be talk about latter in the book. The Motion Sensitivity Susceptibility-Short Form (MSSQ-SF). The MSSQ-SF has two sections of questions A that was about the Childhood period and B was about the last ten years of participances' life. All participants completed the (MSSQ-SF). Participants were assigned to one of the two groups, CMS or non-CMS. The Motion Sickness Susceptibility-Short Form (MSSQ-SF). Golding et al. (J. F. Golding, 1998; J. F. J. P. Golding & differences, 2006) reported that the MSSQ-SF has a high correlation with the MSSQ–Long Form (r = 0.93); in addition, the MSSQ-SF demonstrates high internal consistency (Cronbach's alpha = 0.87); high test–retest reliability (r = 0.9); and there is a significant correlation between Section A (Childhood) and Section B (Adulthood) results (r = 0.68) (J. F. Golding, 1998; J. F. J. P. Golding & differences, 2006).Based on the MSSQ-SFs scores, participants were assigned into two groups. Group 1 included participants with CMS and MSSQ-SF scores ≥ 30th percentile, while the second group included those without CMS with MSSQ-SF scores < 25th percentile. Individuals with MSSQ-SF scores between 25 and 29 percentiles were excluded from the study.

Postural Stability

Postural stability is required for static conditions and dynamic conditions in response to applied or volitional perturbations (Prieto & Myklebust, 1993). Postural stability and the integrity of the various systems contributing to it, is commonly measured using computerized dynamic posturography (CDP) (Chaudhry et al., 2004; Prieto & Myklebust, 1993). Postural stability during common activities such as walking and running are automated by mechanisms integrating vision, vestibular, and proprioceptive inputs (Takahashi, Ogata, & Miura, 1997). These multisensory inputs are incorporated into cooperative actions, so that head turning produces vestibular-ocular reflex and optokinetic reflex for stabilizing gaze in space and vestibulospinal reflex for stabilizing body posture (Schubert, 2019; Takahashi et al., 1997). Walking induces linear and angular head perturbations (Hirasaki, Moore, Raphan, & Cohen, 1999). Walking at alternating velocities places different demands on the control visual and postural stability including contributions of angular and linear vestibulo-ocular, vestibulocollic, vestibulospinal reflexes (Hirasaki et al., 1999). During head-turning motion, multisensory inputs systems are incorporated into cooperative actions resulting in the maintenance of postural stability (Schubert, 2019; Takahashi et al., 1997). Hirasaki et al. reported that walking produces linear and angular head perturbations (Hirasaki et al., 1999).

Head Motion

Head motion “pitch and yaw” in various planes can affect postural stability as head motions may cause nausea and disorientation (Guedry & Benson, 1978). Lackner and Graybiel (James R Lackner & Graybiel, 1985) investigated the effects of head motion on people with motion sensitivity and determined that all head motions aggravated motion sensitivity. Paloski et al. (Paloski et al., 2006) found that postural stability was worse during different head motion frequencies in healthy individuals. Additionally, during postural instability, individuals often report vertigo or dizziness associated with head motion (Akin & Davenport, 2003). Hirasaki et al. (Hirasaki et al.,

1999) postulated that the angular vestibulocollic reflex induces compensatory head pitch on the trunk to maintain a stable head angle position in space at slow walking velocities. Furthermore, vertigo or dizziness is often elicited in patients with vestibular disorders during head motion (Norre & Beckers, 1989). Guedry et al. (Guedry & Benson, 1978) reported that head motion in different planes can affect postural stability as head motions may cause nausea and disorientation. Additionally, Lackner and Graybiel (James R Lackner & Graybiel, 1985) reported that all head motions aggravate symptoms in people with motion sensitivity. Also, Paloski et al. (Paloski et al., 2006) reported that postural stability was worse during increased head motion frequencies. Furthermore, head motion has also been associated with dizziness and postural instability (Akin & Davenport, 2003; Norre & Beckers, 1989). Hirasaki et al. (Hirasaki et al., 1999) reported that the angular vestibulocollic reflex induces compensatory head pitch on the trunk to maintain a stable head angle position in space at slow walking velocities. The coordination of head, trunk, and body movement is most coherent at walking velocities of 1.2–1.8 m/s and least consistent at walking speeds outside that range (Hirasaki et al., 1999). The compensatory mechanisms of the head pitch during slow, moderate, and fast walking are different (Hirasaki et al., 1999). Hirasaki et al suggest that during locomotion, altered reflex mechanisms are responsible for head-trunk coordination dependent on walking speed (Hirasaki et al., 1999). Through the increased variation of walking speed in addition to the amplitude and frequency of vertical head translation increase, it is likely that the linear vestibulocollic reflex is initiated to stimulate the compensatory head pitch in space (Hirasaki et al., 1999). Cooperatively, these reflexes maintain head orientation and stability of gaze over a plethora of walking velocities. Significant frequency of head translation and rotation was limited to a narrow range of 1.4 Hz at 0.6 m/s to 2.5 Hz at 2.2 m/s (Hirasaki et al., 1999).

Computerized Dynamic Posturography

Computerized dynamic posturography (CDP) used to measure postural stability and the integrity of the various sensory inputs (Woollacott & Shumway-Cook, 2002). CDP equilibrium scores are closer to 100 when a person's visual, vestibular, and somatosensory afferent inputs are quickly and accurately integrated in the central nervous system (Chaudhry et al., 2004; Prieto & Myklebust, 1993). Postural stability during CDP testing is typically described as having less sway while postural instability is described as having more sway (Woollacott & Shumway-Cook, 2002). The CDP-IVR measured postural stability by generating an equilibrium score (Bertec, 2019). The CDP-IVR has high validity as compared to the gold-standard NeuroCom® Equitest ($r=.81$, $N=50$, $p<.001$) (Bentley, 2017). Computerized dynamic posturography sensory organization has been shown to have excellent test-retest reliability with an intra class correlation coefficient (ICC) of 0.84 (Hebert & Manago, 2017). Signals from the subjects' effort to maintain balance were sampled and analyzed at 1000 Hertz, and a sway path was computed. Testing protocol calculated the sway path with equilibrium scores quantifying how well the subjects' sway stayed within the expected angular limits of stability during each measurement condition. The following formula was used to calculate the equilibrium score: Equilibrium Score (ES)= ([12.5 degrees-(the taMAX–the taMIN)]/12.5degrees) *100. The ES uses 12.5° as the normal limit of the anterior-posterior sway angle range, taMAX is theta maximum and taMIN is theta minimum.

Sway angle was calculated as follows: Sway Angle =arcsin (COGy/(.55*h)) where y=anterior-posterior sway axis and h=the subject's height in [cm or inches]. The inverse Sin of the center of gravity was divided by 55% of the subject's height. Participants exhibiting little sway achieve equilibrium scores near 100, while participants exhibiting more sway achieve equilibrium scores further away from 100 (Bentley, 2017; Bertec, 2019).

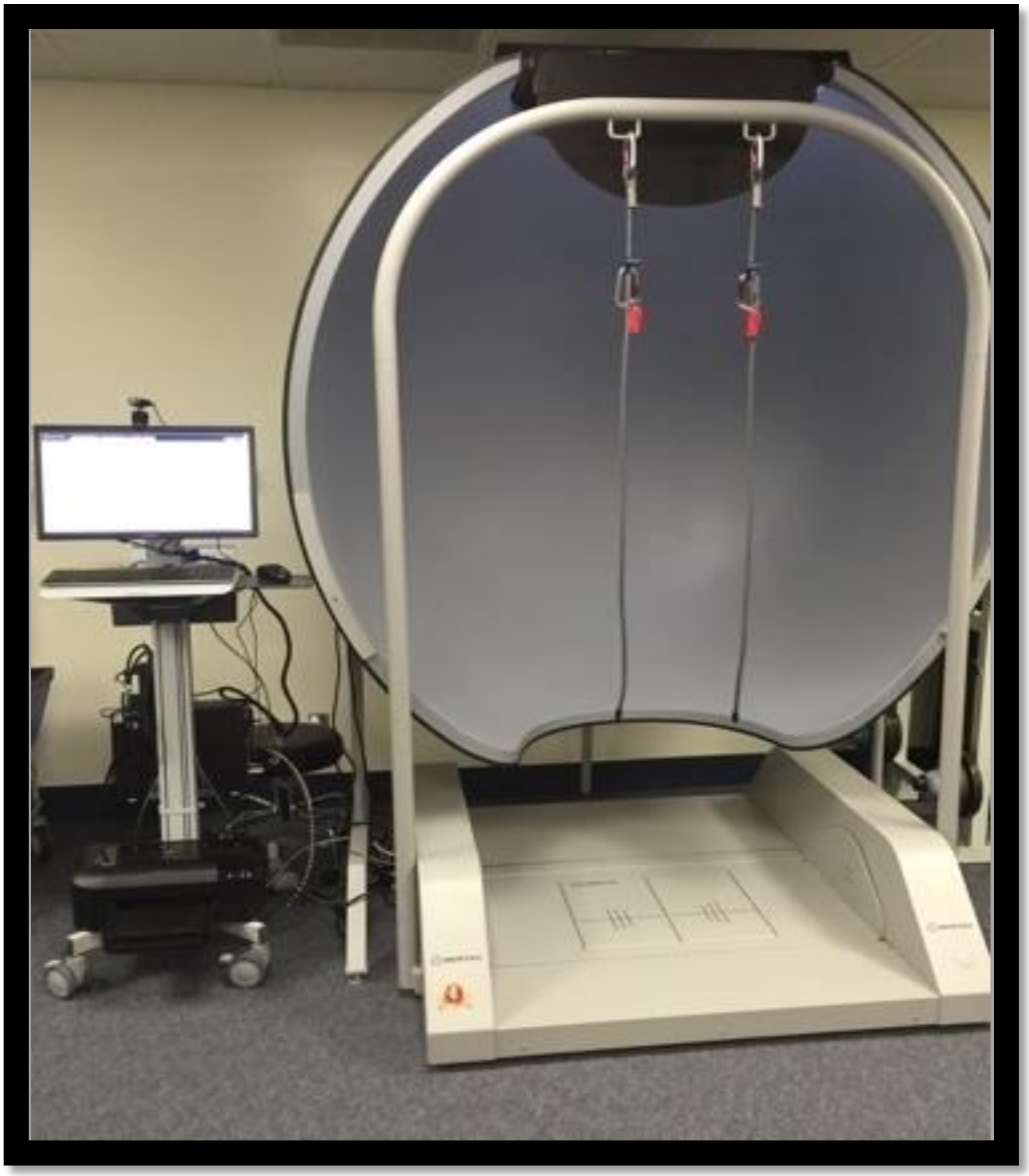

Fig. 2. Bertec™ Balance Computerized Dynamic Posturography with Immersion Virtual Reality (CDP-IVR).

Summary

Chronic Motion sensitivity, according to the sensory conflict theory, results from faulty central nervous system (CNS) processing of visual, vestibular, or somatosensory inputs (Oman, 1990; Reason, 1978). The CNS processes sensory system inputs and drives motor system outputs to maintain postural and visual stability (Herdman & Clendaniel, 2014; Horak & Macpherson, 1996). During sensory system mismatch, particularly with improper vestibular function, postural and visual instability can result (Massion, 1998; Nashner et al., 1982; Ricci et al., 2010). Micro-synaptic changes in the vestibular nerve function occur after the age of forty; whereas vestibular receptor organs become more susceptible to degeneration after age 50. By the age of 60, the electrical conductivity velocity of the vestibular nerve begins to decline (Ricci et al., 2010). Postural stability is required for static conditions and dynamic conditions in response to applied or volitional perturbations (Prieto & Myklebust, 1993). Postural stability and the integrity of the various systems contributing to it, is commonly measured using computerized dynamic posturography (CDP) (Chaudhry et al., 2004; Prieto & Myklebust, 1993). Walking at alternating velocities places different demands on the control visual and postural stability including contributions of angular and linear vestibulo-ocular, vestibulocollic, vestibulospinal reflexes (Hirasaki et al., 1999). During head-turning motion, multisensory inputs systems are incorporated into cooperative actions resulting in the maintenance of postural stability (Schubert, 2019; Takahashi et al., 1997). Hirasaki et al. reported that walking produces linear and angular head perturbations (Hirasaki et al., 1999). Paloski et al. (Paloski et al., 2006) found that postural stability was worse during different head motion frequencies in healthy individuals. The coordination of head, trunk, and body movement is most coherent at walking velocities of 1.2–1.8 m/s and least consistent at walking speeds outside that range (Hirasaki et al., 1999). The compensatory mechanisms of the head pitch during slow, moderate, and fast walking are different (Hirasaki et al., 1999). Cooperatively, these reflexes maintain head orientation and stability of gaze over a plethora of walking velocities. Significant frequency of head translation and rotation was limited to a narrow range of 1.4 Hz at 0.6 m/s to 2.5 Hz at 2.2 m/s (Hirasaki et al., 1999).

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CHAPTER TWO

Effects of Head Motion on Postural Stability in Middle-Aged Adults with Chronic Motion Sensitivity

Hafiz AE[1+], Johnson EG[1*], Alshehri FA[1+], Hudlikar M[2], Sheth I[2], Daher NS[2]

[*]Corresponding Author: Eric G. Johnson, Department of Physical Therapy, Loma Linda University, 24951 North Circle Drive, Nichol Hall A-712, Loma Linda, California 92350 Phone (909) 558-4632 ext. 47471, Fax (909) 558-0459, E-mail ejohnson@llu.edu

[+]Doctor of Science in Physical Therapy Candidate at Loma Linda University, Loma Linda, California, USA.

[1]Department of Physical Therapy, Loma Linda University, Loma Linda, California, USA.

[2]Department of Allied Health Studies, Loma Linda University, Loma Linda, California, USA.

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Abstract

Background/Purpose: Chronic motion sensitivity (CMS) often leads to a variety of symptoms including postural instability. There is limited research describing the effects of active head motion on standing postural stability in adults with motion sensitivity. The purpose of this study was to compare the effects of slow and fast head motions, in multiple planes, on postural stability in healthy middle-aged adults with and without CMS.

Methods: Forty healthy middle-aged adults from 45 to 64 years were recruited. Twenty participants had a history of CMS and 20 participants did not. Prior to data collection, all participants were trained on specific parameters of active cervical rotation, flexion, and extension during horizontal and vertical directions at slow and fast velocities. Postural stability was measured during static and dynamic head motions using the Bertec^{TM} Balance Computerized Dynamic Posturography with Immersion Virtual Reality.

Results: Mean postural stability was significantly different between participants with versus without CMS in all conditions of head motion (slow horizontal, slow vertical, fast horizontal, and fast vertical). During slow head motion velocity, mean postural stability was significantly different by direction (vertical versus horizontal), however, there was no significant group by direction effect. During fast head motion velocity, mean postural stability did not differ significantly by direction and group by direction.

Conclusion: The results suggest that healthy middle-aged adults without CMS have better postural stability during head motion compared to those with CMS.

Keywords
Motion sensitivity; motion sickness, postural stability

Introduction

Chronic motion sensitivity (CMS), or “motion sickness”, is a common occurrence resulting in a physiological response to actual or virtual motion [1-7]. Previous studies reported that 28.4% of the population has motion sensitivity and is more common in females than in males [8-11]. Motion sensitivity, according to the sensory conflict theory, results from faulty central nervous system processing of visual, vestibular, or somatosensory inputs [1, 6]. Symptoms associated with motion sensitivity include autonomic nervous system reactions such as nausea, vomiting, pallor, diaphoresis, hypersalivation, gastrointestinal dysfunction, chronic fatigue, lethargy, and postural instability [3, 7, 12].

Postural stability is required for static conditions and dynamic conditions in response to applied or volitional perturbations [13]. Postural stability and the integrity of the various systems contributing to it, is commonly measured using computerized dynamic posturography (CDP) [13, 14]. CDP equilibrium scores are closer to 100 when a person’s visual, vestibular, and somatosensory afferent inputs are quickly and accurately integrated in the central nervous system [13, 14]. Postural stability during CDP testing is typically described as having less sway while postural instability is described as having more sway [15]. Postural stability during common activities such as walking and running are automated by mechanisms integrating vision, vestibular, and proprioceptive inputs [16]. These multisensory inputs are incorporated into cooperative actions, so that head turning produces vestibular-ocular reflex and optokinetic reflex for stabilizing gaze in space and vestibulospinal reflex for stabilizing body posture [16, 17]. Walking induces linear and angular head perturbations [18]. Walking at alternating velocities places different demands on the control visual and postural stability including contributions of angular and linear vestibulo-ocular, vestibulocollic, vestibulospinal reflexes [18].

Additionally, head motion in various planes can effect postural stability as head motions may cause nausea and disorientation [19]. Lackner and Graybiel [20] investigated the effects of head motion on people with motion sensitivity and determined that all head motions aggravated motion sensitivity. Paloski et al. [21] found that postural stability was worse during different head motion frequencies in healthy individuals. Additionally, during postural instability, individuals often report vertigo or dizziness associated with head motion [22]. Hirasaki et al. [18] postulated that the angular vestibulocollic reflex induces compensatory head pitch on the trunk to maintain a stable head angle position in space at slow walking velocities. Furthermore, vertigo or dizziness is often elicited in patients with vestibular disorders during head motion [23]. The coordination of head, trunk, and body movement is most coherent at walking velocities of 1.2–1.8 m/s and least consistent at walking speeds outside that range [18]. The compensatory mechanisms of the head pitch during slow, moderate, and fast walking are different [18]. Hirasaki et al suggest that during locomotion, altered reflex mechanisms are responsible for head-trunk coordination dependent on walking speed [18]. Through the increased variation of walking speed in addition to the amplitude and frequency of vertical head translation increase, it is likely that the linear vestibulocollic reflex is initiated to stimulate the compensatory head pitch in space [18]. Cooperatively, these reflexes maintain head orientation and stability of gaze over a plethora of walking velocities. Significant frequency of head translation and rotation was limited to a narrow range of 1.4 Hz at 0.6 m/s to 2.5 Hz at 2.2 m/s [18].

Therefore, the primary purpose of this study was to measure the effect of slow and fast head motion velocities in multiple planes on postural stability in middle-aged adults with and without chronic motion sensitivity (CMS). The hypothesis was that postural stability during all conditions of head motions would be worse in participants with CMS. Additional hypotheses were that fast head velocity would negatively impact postural stability greater than slow head velocity, and that postural stability during vertical head motion would be worse than horizontal head motion.

Methods

Participants

This study was an observational cross-sectional design. The effects of head motion on postural stability in healthy middle-aged adults with and without CMS were investigated. Forty healthy middle-aged adults participated in the study. Participant age range was 45 to 64 years and included males and females. Twenty participants had a history of CMS and 20 participants did not. All participants read and signed an informed consent approved by the Loma Linda University Institutional Review Board. All data was collected between 1:00pm and 6:00pm to minimize potential variations in daily fatigue level.

Participants with a history of vestibular disorders, neurological pathology, peripheral diabetic neuropathy, head or cervical trauma, currently taking any medications that might affect balance, recent surgery, or pain affecting their balance were excluded from the study.

Group Assignment

All participants completed the Motion Sickness Susceptibility-Short Form (MSSQ-SF). Golding et al. [24, 25] reported that the MSSQ-SF has a high correlation with the MSSQ–Long Form (r = 0.93); in addition, the MSSQ-SF demonstrates high internal consistency (Cronbach's alpha = 0.87); high test–retest reliability (r = 0.9); and there is a significant correlation between Section A (Childhood) and Section B (Adulthood) results (r = 0.68) [24, 25].Based on the MSSQ-SFs scores, participants were assigned into two groups. Group 1 comprised participants with CMS and MSSQ-SF scores ≥ 30th percentile, while the second group included those without CMS with MSSQ-SF scores < 25th percentile. Individuals with MSSQ-SF scores between 25 and 29 percentiles were excluded from the study.

International Physical Activity Questionnaire

All participants completed the International Physical Activity Questionnaire short form for the past 7 days (IPAQ-S7S) [26]. The (IPAQ-S7S) demonstrated excellent test–retest reliability over 7 days (r=0.75), The criterion validity of the self-report IPAQ short and long form data versus CSA accelerometers has low to moderate agreement between the two measures, the long forms versus the CSA (pooled p = 0.33, 95% CI 0.26–0.39), and for the short form versus CSA (p = 0.30, 95% CI 0.23–0.36); and pooled correlation between the short and long forms was moderate (p= 0.67; 95% CI 0.64 to 0.70; and p = 0.58, 0.51, 0.64, respectively) [27-29].

Bertec ^{TM} Balance Computerized Dynamic Posturography with Head Movement Horizontal and Vertical Planes

Participants' weight and height were taken. Afterward, participants' postural stability was measured during five different conditions using the Bertec^{TM} Balance Computerized Dynamic Posturography (CDP-IVR). Condition 1 was static baseline (see figure 3), Condition 2 was slow horizontal head motion (SH), Condition 3 was slow vertical head motion (SV), Condition 4 was fast horizontal head motion (FH), and Condition 5 was fast vertical head motion (FV) (see figure 4). Each condition included three twenty second trials, and an average was calculated. Based on the Hirasaki et al findings, the present study used a head motion velocity of 2.5Hz for fast speed head motion and 1.5Hz for slow speed head motion in both horizontal and vertical planes [18].

Procedures

Participants actively moved their heads following the auditory cue of a metronome using (Pro Metronome application designed by EUMLab for IOS operation system) to control velocity [30]. A head-mounted laser designed by (SenMoCOR LED/Laser, Orthopedic Physical Therapy Products, USA) (see figure 1. A), and a grid designed by the investigators (see figure 1. B) was used to guide active range of motion amplitude of 11 degrees in horizontal and 8 degrees in vertical amplitude direction. A training session was provided for all participants before collecting data. Previous studies involving head motion during computerized postural stability testing had participants perform head motion with their eyes closed, and they were holding their hands to each side of their face to control the head rotation range of motion within 15 degrees during sensory organization testing [31-33].

The CDP-IVR measured postural stability by generating an equilibrium score [34]. The CDP-IVR has high validity as compared to the gold-standard NeuroCom® Equitest ($r=.81$, $N=50$, $p<.001$) [35]. Computerized dynamic posturography sensory organization has been shown to have excellent test-retest reliability with an intra class correlation coefficient (ICC) of 0.84 [36]. Signals from the subjects' effort to maintain balance were sampled and analyzed at 1000 Hertz, and a sway path was computed. Testing protocol calculated the sway path with equilibrium scores quantifying how well the subjects' sway stayed within the expected angular limits of stability during each measurement condition. The following formula was used to calculate the equilibrium score: Equilibrium Score (ES)= ([12.5 degrees-(the taMAX–the taMIN)]/12.5degrees) *100. The ES uses 12.5° as the normal limit of the anterior-posterior sway angle range, taMAX is theta maximum and taMIN is theta minimum. Sway angle was calculated as follows: Sway Angle =arcsin (COGy/(.55*h)) where y=anterior-posterior sway axis and h=the subject's height in [cm or inches]. The inverse Sin of the center of gravity was divided by 55% of the subject's height. Participants exhibiting little sway achieve equilibrium scores near 100, while participants exhibiting more sway achieve equilibrium scores further away from 100 [34, 35].

Data Analysis

Data analysis was performed using SPSS statistics Software version 24.0 (IBM Corp, Armonk, NY) [37]. A sample size of 40 subjects was estimated using an effect size ($d=0.8$), a power of 0.80 and level of significance set at 0.05. Mean + SD was computed for continuous variables and frequencies (%) for categorical variables. Normality of quantitative variables was assessed using Shapiro-Wilk test and boxplots.

Statistical Analyses

Mean age (years) and body mass index (BMI) (kg/m^2) were compared at baseline between the two groups using independent t-test. The distribution of qualitative variables (gender, physical activity, ethnicity, dominant hand) by group type was examined using Chi Square test of independence. Mean postural stability by study group (with versus without CMS) was compared during the following conditions: Condition 1 “static”, Condition 2 SH head motion, Condition 3 SV head motion, Condition 4 FH head motion, and Condition 5 FV head motion using independent sample *t*-test.

During slow and fast velocity head motion conditions, changes in mean postural stability by direction (horizontal versus vertical) and group type were examined using 2x2 mixed factorial analysis of variance (ANOVA). Also, in the vertical and horizontal directions, changes in mean stability by velocity (slow versus fast) was assessed using mixed factorial ANOVA. The level of significance was set at $p \leq 0.05$.

Results

Forty participants (20 with CMS and 20 without CMS) with mean age of 53.7±5.3 years and BMI of 29.4±6.1 kg/m2 completed the study. The majority of the participants were right hand dominant (n=38, 95.0%), Caucasian (n = 29, 72.5%), and highly active (n=28, 70%). There was no significant difference between the two groups in basic characteristics at baseline (p>0.05, Table 1).

Based on the findings from the independent t-test, there was no significant difference in mean postural stability by study group for condition1 (p=0.22, Table2).

However, mean postural stability was significantly different between participants with versus without CMS in all the other conditions (SH (Condition 2), SV (Condition 3), FH (Condition 4), and FV (Condition 5); (p values ranged from 0.045 to 0.009 and effect size ranged from 0.5 to 0.9, Table 2).

During slow head motion velocity, results of the 2x2 mixed factorial ANOVA showed that mean postural stability was significantly different by direction (vertical versus horizontal) (89.8±0.5 versus 90.6±0.4, F1,38=10.3, p=0.003, partial η2 =0.21), however, there was no significant group by direction effect (F1,38=0.8, p=0.77, partial η2= 0.00; Table 3). During fast head motion velocity, mean postural stability was not significantly different by direction and group by direction (p>0.05, Table 3).

During horizontal and vertical directions, results showed that mean postural stability did not differ significantly by velocity (slow versus fast) and group by velocity (p>0.05, Table 4).

Discussion

Head Motion on Postural Stability

The present study investigated the effect of head motion in the horizontal and vertical directions on postural stability in middle-aged adults with and without CMS. Results demonstrated that postural stability decreased during head motion in both directions in participants with CMS. Similar to the present study results, Paloski et al.[21] reported that during static head tilts with eyes closed, healthy individuals were able to maintain upright stance; while during dynamic head tilts with eyes closed, postural stability decreased with higher frequency of head tilt.

Head Motion Direction between CMS and non-CMS

Mitsutake et al. [38] reported that postural instability significantly increased during head active yaw “horizontal” head motion in stroke patients compared to healthy individuals during open and closed eyes conditions. Similarly, Lackner et al. [20] reported that all head motion direction including pitch “vertical” direction trigger motion sensitivity. In other words, head pitch motion can lead to more postural sway, which can lead to postural instability. In line with the present study results, there was decreased postural stability during both directions of head motion (horizontal and vertical); and the vertical direction negatively impacted the postural stability more than horizontal direction in CMS and non-CMS groups.

Head Motion Velocities between CMS and non-CMS

A secondary study objective was investigating the effects of slow and fast velocity of head motion on postural stability in middle-aged adults with versus without CMS. The results showed that postural stability did not differ significantly during slow and fast head motion in the horizontal and vertical directions in both study groups.

Paloski et al. [21] reported that postural stability was worse during different head motions with varying frequencies in healthy individuals. In the present study, head movement frequencies were 1.5 Hz for slow head motion velocity and 2.5 Hz for fast head motion velocity. These frequencies were based on Hirasaki et al. [18] who reported that frequency of head translation and rotation was limited to a narrow range of 1.4 Hz head motion at 0.6 m/s walking speed and to 2.5 Hz head motion at 2.2 m/s faster walking speed. Fast head motion velocity might induce more stress on postural stability than slow head motion velocity in middle-aged adults with CMS; contrary to Paloski et al. [21] the present study results revealed that there was no significant difference of postural stability between study groups by velocity (slow versus fast).

The present study results found that postural stability was worse during vertical head motion compared to horizontal head motion directions in participants with CMS compared to those without CMS. In general, horizontal and vertical head motions have functional implications on postural stability as they are used functionally in various daily activities during standing, such as looking in kitchen cabinets, searching for objects on supermarket shelves, checking traffic when crossing a street, and showering.

Effect of Physical Activity Level Head Motion in CMS

Lokucijewski [39] reported that physical exercises can improve CMS symptoms by 50%. Caillet et al. [40] reported that individuals with high consistency of physical and sport activities can reduce visual dependency and improve CMS through a sensory rearrangement process. In the present study, participants in the CMS group had higher physical activity levels, which may have enhanced their postural stability scores. The investigators speculate that if the physical activity levels were similar between groups, the differences in mean postural stability would have been larger between groups.

Study Limitations

Limitations of this study include the narrow age range of participants (45-64 years of age); thus, the findings may not be generalizable to younger or older adults. Also, physical activity levels based on the IPAQ-S7S varied between groups. Future studies should include older adults and control for homogenous physical activity levels between groups.

Conclusion

In conclusion, healthy middle-aged adults with CMS have decreased postural stability during head motion in vertical and horizontal planes compared to those without CMS. Moreover, during slow velocity head motion in the horizontal plane, there was significantly decreased postural stability in individuals with CMS.

Conflict of interest

None

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Table 1. Mean ± SD of general baseline characteristics of the study participants (N= 40)

	With CMS (n_1=20)	Without CMS (n_2=20)	p-value
Male; n (%)	10 (50)	10 (50)	1.0
Age (years)	53.4 ± 4.8	54.0 ± 5.9	0.70
BMI (kg/m^2)	28.2 ± 6.6	31.5 ± 5.5	0.23
Physical Activity; n (%)			
Low	2 (10)	3 (15)	0.08
Medium	1 (5)	6 (30)	
High	17 (85)	11 (55)	
Ethnicity; n (%)			
White	15 (75)	14 (70)	0.70
African American	1 (5)	0 (0)	
American Indian	2 (10)	3 (15)	
Asian	2 (10)	3 (15)	
Dominant Hand; n (%)			
Right	18 (90)	20 (100)	0.48

Abbreviations: SD, Standard deviation, CMS = Chronic motion sensitivity, BMI = body mass index

Table 2. Mean (SD) equilibrium score for various conditions by study group after controlling for Body Max Index (N=40)

	With CMS Group (n_1=20)	Without CMS Group (n_2=20)	*p-value* [*] *(effect size)*[a]
Condition 1 (Static)	93.9±1.5	94.3±1.8	0.224 (0.24)
Condition 2 (SH)	89.8±3.2	91.4±2.4	0.038 (0.57)
Condition 3 (SV)	88.9±3.7	90.6±2.4	0.045 (0.55)
Condition 4 (FH)	88.9±3.4	91.5±2.3	0.009 (0.90)
Condition 5 (FV)	89.6±3.4	91.2±2.7	0.045 (0.52)

Abbreviations: SD, Standard deviation; CMS, Chronic motion sensitivity; [*] Independent t-test

[a] Effect size = $\frac{\text{Mean of the difference}}{\text{SD of difference}}$

Table 3. Mean ± (SE) equilibrium score during slow and fast velocity by study group and direction (N=40)

	With CMS (n_1=20)		Without CMS (n_2=20)		Group x Direction p^* (partial η^2)	Direction p^* (partial η^2)[a]
	Horizontal	Vertical	Horizontal	Vertical		
Slow	89.8±0.6	88.9±0.7	91.4±0.6	90.6±0.7	0.772 (0.00)	0.003 (0.21)
Fast	88.9±0.7	89.6±0.7	91.5±0.7	91.2±0.7	0.279 (0.03)	0.636 (0.01)

Abbreviations: SE, Standard error; CMS, Chronic motion sensitivity; * Mixed factorial analysis of variance; [a] partial $\eta^2 = \frac{\text{Group Sum of square}}{\mathit{Total\ Sum\ of\ square}}$

Table 4. Mean ± (SE) equilibrium score during horizontal and vertical direction by study group and velocity (N=40)

	With CMS (n1=20)		Without CMS (n2=20)		Group x Velocity p* (partial η2)	Velocity p* (partial η2)a
	Slow	*Fast*	*Slow*	*Fast*		
Horizontal	89.8±0.6	88.9±0.7	91.4±0.6	90.6±0.7	0.192 (0.04)	0.315 (0.03)
Vertical	88.9±0.7	89.6±0.7	91.5±0.7	91.2±0.7	0.961 (0.00)	0.069 (0.09)

Abbreviations: SE, Standard error; CMS, Chronic motion sensitivity;[*] Mixed factorial analysis of variance; [a] partial

$\eta^2 = \frac{\text{Group Sum of square}}{Total\ Sum\ of\ square}$

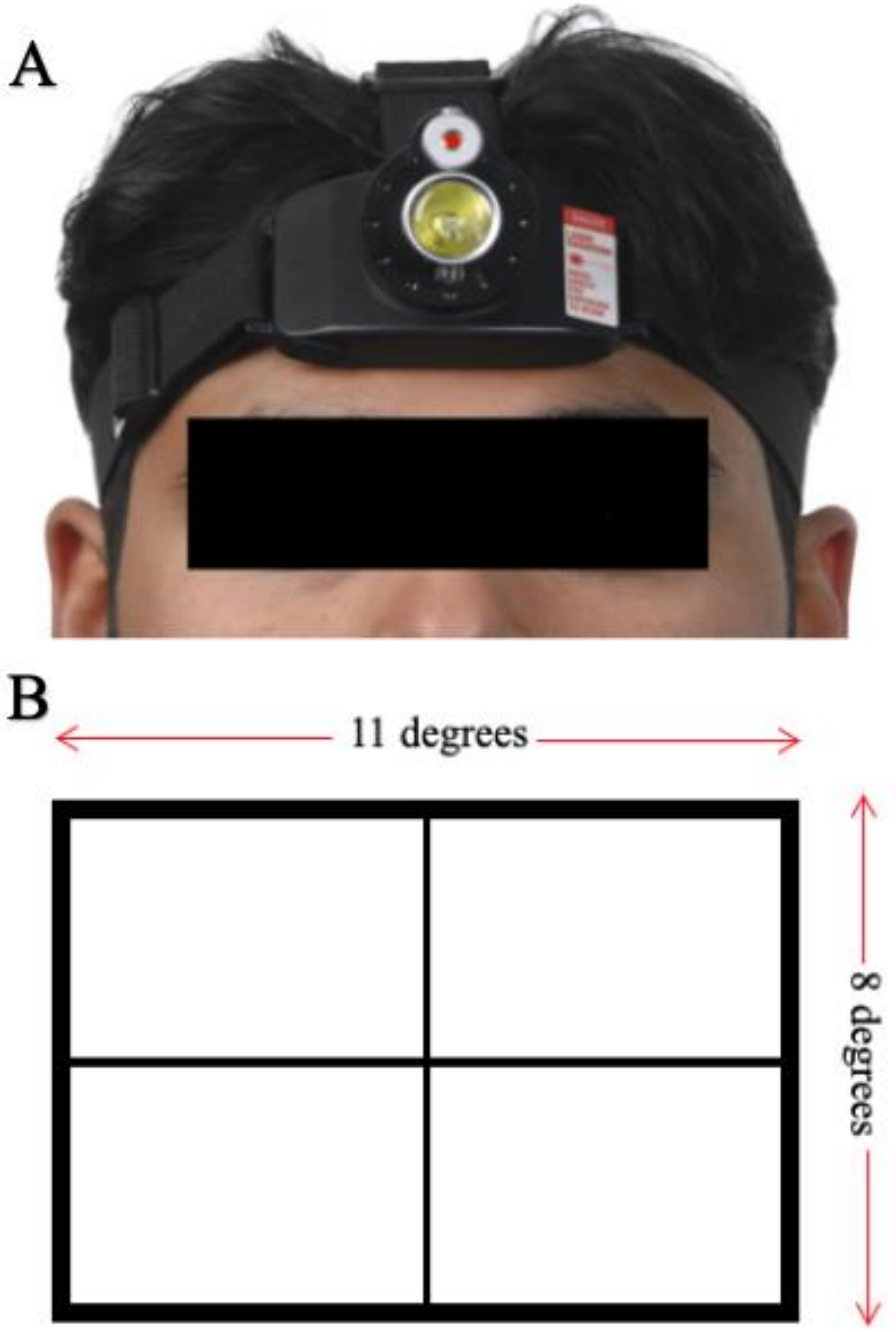
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Fig. 1A. Participants performed horizontal and vertical head motions using a head-mounted laser pointer to control amplitude. ***Fig. 1B.*** This tool was developed to guide horizontal and vertical head motions.

Fig. 2. CDP-IVR static baseline condition 1.

Fig. 3. CDP-IVR dynamic conditions 1-5 Participants performed horizontal and vertical head motions using the showing head-mounted laser pointer and amplitude grid (grid magnified for easier reader viewing).

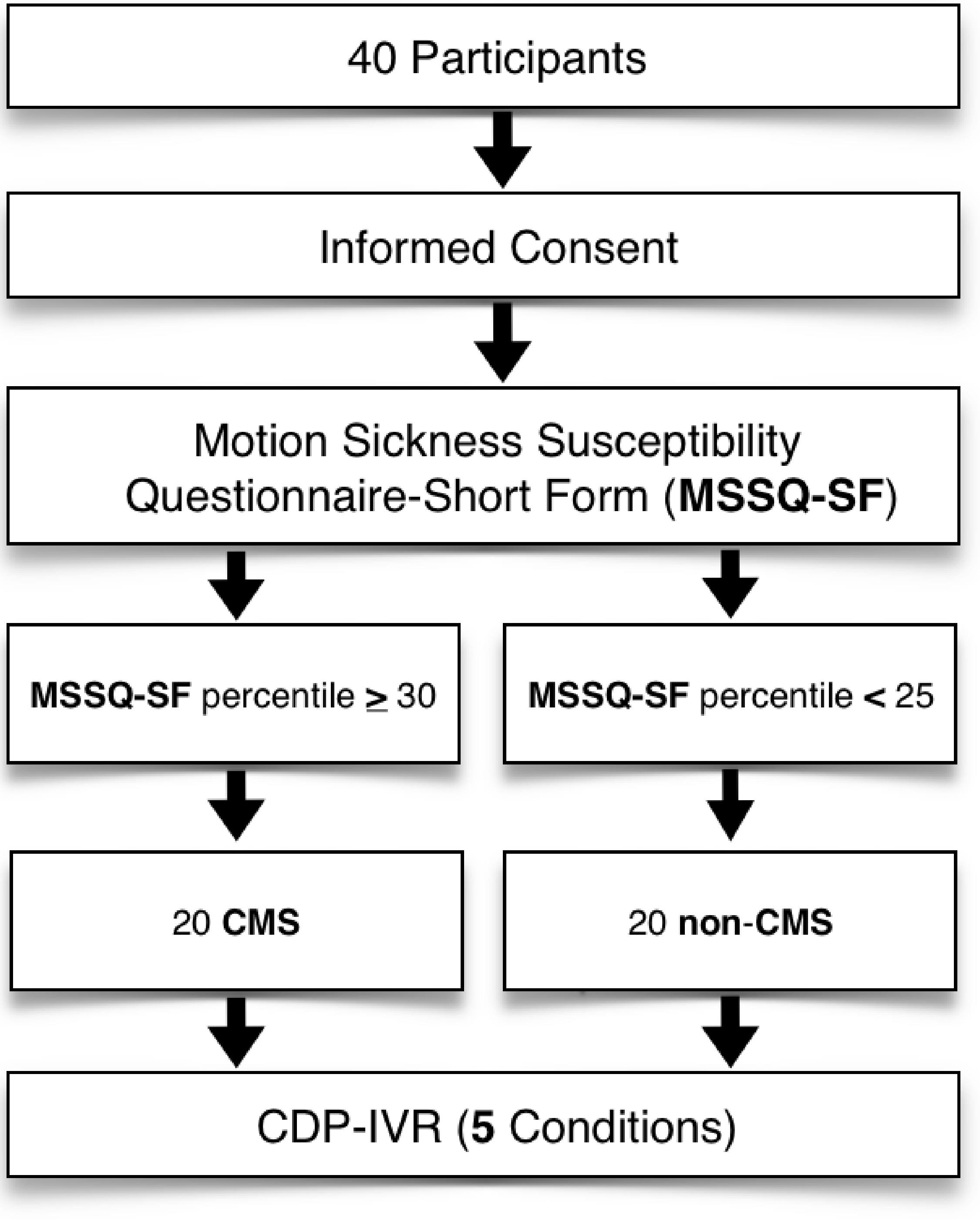

Fig. 4. Diagram illustrating flow of participants and study procedure.

CHAPTER THREE

Effect of Head Movement on Postural Stability in Healthy Adults with Chronic Motion Sensitivity

Hafiz AE[1], Johnson EG[1*], Alshehri FA[1], Hudlikar M[2], Sheth I[2], Daher NS[2]

[*]Corresponding Author: Eric G. Johnson, Department of Physical Therapy, Loma Linda University, 24951 North Circle Drive, Nichol Hall A-712, Loma Linda, California 92350 Phone (909) 558-4632 ext. 47471, Fax (909) 558-0459, E-mail ejohnson@llu.edu

[1]Department of Physical Therapy, Loma Linda University, Loma Linda, California, USA.

[2]Department of Allied Health Studies, Loma Linda University, Loma Linda, California, USA.

Abstract

BACKGROUND: Previous research has described the negative effects of chronic motion sensitivity on postural stability during active head motion.

OBJECTIVE: To compare the effects of head motion on postural stability between young and middle-aged adults, and between groups with and without CMS.

METHODS: Eighty participants aged 20 to 64 years, with and without CMS, were recruited for this study. Participants were assigned to one of two groups (CMS or non-CMS) using the Motion Sickness Susceptibility Questionnaire-Short Form. Postural stability was measured for all participants using the Bertec™ Balance Computerized Dynamic Posturography.

RESULTS: Mean ± standard error postural stability of participants with CMS was significantly worse than those without CMS in both vertical (89.7±0.6 versus 91.9±0.6, $p=0.01$, partial $\eta^2 =0.10$), and horizontal head motion conditions (90.3±0.5 versus 92.5±0.6, $p=0.01$, partial $\eta^2 =0.10$). However, mean postural stability in both vertical and horizontal conditions did not significantly differ by age group.

CONCLUSION: Adults with CMS have less postural stability during head motion in both planes compared to adults without CMS.

Keywords

Motion sensitivity, Postural stability, Head motion

Introduction

Motion sensitivity, also called motion sickness, is an uncomfortable feeling resulting from a physiological response to physical motion or immersion virtual reality (Bertolini & Straumann, 2016; Gaikwad et al., 2018; J. R. Lackner, 2014; Oman, 1990; Reason, 1978; Schmal, 2013; Sharma & Aparna, 1997; Zhang et al., 2016). Motion sensitivity typically induces postural instability as well as autonomic nervous systems including nausea, vomiting, dizziness, pallor, sweating, hypersalivation, headache, gastrointestinal dysfunction, chronic fatigue, and lethargy (Akiduki et al., 2003; Alharbi et al., 2017; Bertolini & Straumann, 2016; Gaikwad et al., 2018; Henriques, Douglas de Oliveira, Oliveira-Ferreira, & Andrade, 2014; J. R. Lackner, 2014; Takahashi et al., 1991; Zhang et al., 2016). Nearly 30% of the population experience motion sensitivity during various types of passive transportation (Alharbi et al., 2017; Murdin, Golding, & Bronstein, 2011; Sharma & Aparna, 1997; Turner, 1999). Previous studies reported that motion sensitivity occurs in 70% of young children and 55% in adolescence and adulthood with a higher incidence in females (Bertolini & Straumann, 2016; Golding, Kadzere, & Gresty, 2005; Henriques et al., 2014; Koslucher, Haaland, Malsch, Webeler, & Stoffregen, 2015; Paillard et al., 2013; Sharma & Aparna, 1997). The neural mechanism of motion sensitivity remains unclear; however, the sensory conflict theory is the most widely accepted explanation (Bertolini & Straumann, 2016; Golding & Gresty, 2015). According to the sensory conflict theory, faulty central nervous system (CNS) processing of visual, vestibular, or somatosensory sensory inputs causes motion sensitivity (Oman, 1990; Reason, 1978).

The CNS processes sensory system inputs and drives motor system outputs to maintain postural and visual stability (Herdman & Clendaniel, 2014; Horak & Macpherson, 1996). During sensory system mismatch, particularly with improper vestibular function, postural and visual instability can result (Massion, 1998; Nashner, Black, & Wall, 1982; Ricci et al., 2010). Micro-synaptic changes in the vestibular nerve function occur after the age of forty; whereas vestibular receptor organs become more susceptible to degeneration after age 50. By the age of 60, the electrical conductivity velocity of the vestibular nerve begins to decline (Ricci et al., 2010). In addition, Agrawal et al. (Agrawal et al., 2012) reported that there is general regression of the vestibular apparatus function throughout aging with more significant deficiency of the semicircular canals than otoliths. Abrahamova and Hlavacka (Abrahamova & Hlavacka, 2008) reported that variances in postural stability between young adults (20-40 years) and middle-aged adults (40-60 years) were not as defined as the difference between young and older adults (60-82 years). Similarly, Cohen et al. (Cohen, Heaton, Congdon, & Jenkins, 1996) reported that postural stability continues to decrease thru young adulthood (18-44 years), middle-aged adulthood (45-69 years), and older adulthood (70-89 years). Additional research has determined that postural stability decreases with aging (Sheldon, 1963; Thyssen, Brynskov, Jansen, & Munster-Swendsen, 1982).

Postural stability is required during various activities of daily living and is managed automatically by central mechanisms that integrate vision, vestibular, and proprioceptive inputs. (Takahashi, Ogata, & Miura, 1997). Computerized dynamic posturography (CDP) can be used to measure postural stability and the integrity of the various sensory inputs (Woollacott & Shumway-Cook, 2002). During head-turning motion, multisensory inputs systems are incorporated into cooperative actions resulting in the maintenance of postural stability (Schubert, 2019; Takahashi et al., 1997). Hirasaki et al. reported that walking produces linear and angular head perturbations (Hirasaki, Moore, Raphan, & Cohen, 1999).

Guedry et al. (Guedry & Benson, 1978) reported that head motion in different planes can affect postural stability as head motions may cause nausea and disorientation. Additionally, Lackner and Graybiel (James R Lackner & Graybiel, 1985) reported that all head motions aggravate symptoms in people with motion sensitivity. Also, Paloski et al. (Paloski et al., 2006) reported that postural stability was worse during increased head motion frequencies. Furthermore, head motion has also been associated with dizziness and postural instability (Akin & Davenport, 2003; Norre & Beckers, 1989). Hirasaki et al. (Hirasaki et al., 1999) reported that the angular vestibulocollic reflex induces compensatory head pitch on the trunk to maintain a stable head angle position in space at slow walking velocities.

Therefore, the objectives of this study were to determine if postural instability during head motion (vertical and horizontal) differs by age (young versus middle-aged adults) in people with and without chronic motion sensitivity (CMS). Investigators hypothesized that postural stability during different head motion conditions in middle-aged adults would be worse than that of young adults. In addition, postural stability during different head motion conditions in participants with CMS would be worse than that of those without CMS.

Methods

Participants

A total of eighty participants, 40 young adults age (20-40 years) and 40 middle-aged adults age (45-64 years), with and without CMS were recruited for this study from the local community. Participants with a history of neurological disorders, vestibular impairments, diabetic peripheral neuropathy, or were taking medications causing dizziness were excluded. All participants read and signed a Loma Linda University's Institutional Review Board approved informed consent form prior participation.

Group assignment

All participants completed the Motion Sensitivity Susceptibility-Short Form (MSSQ-SF). Participants were assigned to one of the two groups, CMS or non-CMS. In this study, 40 participants were allocated to the CMS group and 40 participants into the non-CMS group. The MSSQ-SF evaluates participant differences in CMS that provoked by a variety of stimuli (John F Golding, 2006). The MSSQ-SF demonstrated a strong internal consistency (Cronbach $\alpha = 0.87$); test-retest reliability ($r = 0.9$, $p<0.001$); significant correlation between Section A (child before age of 12 years) and Section B (adult over last 10 years) ($r = 0.68$, $p<0.001$); and predictive validity for motion susceptibility ($r = 0.51$) (Golding, 1998; John F Golding, 2006). A percentile score from 0 to 100 was calculated by summing up the score of Section A (child) and Section B (adult), where 0 indicates no susceptibility to motion sensitivity and 100 indicates maximum susceptibility to motion sensitivity (John F Golding, 2006). Participants who scored $\geq$ 30th percentile on the MSSQ-SF were assigned to the CMS group, while participants who scored < 25th percentile were assigned to the non-CMS group. Furthermore, participants who scored from 25 to 29 percentile were excluded in order to create a “gap” between the two groups.

Computerized Dynamic Posturography (CDP)

The BertecTM Balance Computerized Dynamic Posturography with Immersion Virtual Reality CDP-IVR has high validity as compared to the gold-standard NeuroCom® Equitest (r=.81, N=50, p<.001) (Bentley, 2017). Another research study revealed that computerized dynamic posturography sensory organization test in multiple sclerosis population shown an excellent test-retest reliability (ICC) = 0.84) (Hebert & Manago, 2017). The CDP-IVR calculates postural stability and generates an equilibrium score in the following manner: Signals from the subjects’ effort to maintain balance are sampled and analyzed at 1000 Hertz, and the sway path is computed. The testing protocol calculates the sway path with equilibrium scores quantified by how well the subject's sway remains within the expected angular limits of stability during each testing condition. The following formula was used to calculate the equilibrium score: Equilibrium Score (ES)= ([12.5 degrees-(the taMAX–the taMIN)]/12.5degrees) *100. The ES uses 12.5° as the normal limit of the anterior-posterior sway angle range, taMAX is theta maximum, and taMIN is theta minimum. Sway angle was calculated as follows: Sway Angle =arcsin (COGy/(.55*h)) where y=anterior-posterior sway axis and h=the subject’s height in [cm or inches]. The inverse Sin of the center of gravity was divided by 55% of the subject’s height. Participants exhibiting little sway achieve equilibrium scores near 100, while participants were exhibiting more sway achieve equilibrium scores further away from 100 (Corporation, 2019, March 09).

Head Movement Horizontal & Vertical Planes Procedures

Previous investigators had participants perform head motion with eyes closed while holding their hands to each side of their heads to control head rotation amplitude during sensory organization testing (Honaker, Converse, & Shepard, 2009; Mishra, Davis, Speers, & Shepard, 2009; Moussa & Kholi, 2008). In the present study, a metronome was used to guide participants' head motion velocity and a head-mounted laser pointer (SenMoCOR LED/Laser, Orthopedic Physical Therapy Products, USA) (see Fig.1.A) and grid (see Fig.1.B) were used to guide head motion amplitude (8 degrees vertical and 11 degrees horizontal) amplitude in both horizontal and vertical directions. Additionally, head motion frequency velocity of 1.5 Hz was similar to that which occurs during normal walking (Hirasaki et al., 1999). A training session was provided before collecting data. Afterward, investigators measured participants' postural stability during three different conditions using the Bertec^{TM} Balance Computerized Dynamic Posturography (CDP-IVR) as follow. Condition 1 (see Fig.2) was static baseline, Condition 2 was horizontal head motion (HHM) (see Fig.3), and Condition 3 was vertical head motion (VHM) (see Fig.3) Participants moved their head to the auditory cue of a metronome set at 1.5 Hz [32]. The order of dynamic conditions 2 and 3 were randomized between subjects. Each condition included three twenty-second trials and an average was calculated.

Statistical Analysis

Data analysis was performed using SPSS Statistics Software version 24.0 (IBM Corp, Armonk, NY). Mean + standard deviation (SD) was computed for continuous variables and frequencies (%) for categorical variables. Normality of quantitative variables was assessed using the Shapiro-Wilk test and boxplots. In the current study mean body mass index (kg/m^2) (BMI) was compared by age group (young versus middle aged) and between participants with versus without CMS group using 2x2 Factorial Analysis of Variance (ANOVA). Frequency distribution of gender by study group and age group was examined using Chi Square test. To compare the effect of the of age on postural stability during horizontal and vertical directions by study group, a 2x2 factorial analysis of variance (ANOVA) was conducted. The primary analysis included a comparison between the two age groups using the group x age interaction effect. If the interaction was statistically significant, mean postural stability was compared between those with and without CMS in each age group using independent t-test. Since mean BMI was significantly different by age group, we repeated the same analysis while controlling for BMI. The level of significance was set at $p \leq 0.05$.

Results

The study sample included 80 participants (40 young and 40 middle-aged; 40 with CMS and 40 without CMS) with mean age of 40.2±14.3 years and mean BMI of 27.4±5.4 kg/m^2. There was a significant difference in mean BMI by age group ($p = 0.001$, partial $\eta^2 = 0.15$), however, there was no significant group differences in mean BMI (kg/m^2) by study group (with versus without CMS) ($p = 0.46$, partial $\eta^2 = 0.01$). Furthermore, there were no significant difference in gender distribution by study and age groups. ($p > 0.05$, Table 1).

Based on the findings of the factorial ANOVA, for mean postural stability in Condition1, there was no significant interaction between age and study groups ($F_{1,76} = 1.2$, $p = 0.27$, partial $\eta^2 = 0.02$), no significant age group effect ($F_{1,76} = 0.1$, $p = 0.003$, partial η^2

=0.001), and no significant study group effect ($F_{1,76}$=3.0, p=0.09, partial η^2 =0.04, Table 2). For mean postural stability in Condition 2, there was no significant interaction between age and study groups ($F_{1,76}$=1.2, p=0.28, partial η^2 =0.02). However, there was a significant age group effect ($F_{1,76}$=4.2, p=0.04, partial η^2 =0.06), and a significant study group effect ($F_{1,76}$=7.0, p=0.01, partial η^2 =0.09, Table 2). Similarly, for mean postural stability in Condition 3, there was no significant interaction between age and study groups ($F_{1,76}$=1.2, p=0.28, partial η^2 =0.02). However, there was a significant age group effect ($F_{1,76}$=6.3, p=0.01, partial η^2 =0.08), and a significant study group effect ($F_{1,76}$=6.3, p=0.01, partial η^2 =0.08, Table 2).

For mean postural stability in Condition1, there was no significant interaction between age and study groups ($F_{1,76}$=1.0, p=0.33, partial η^2 =0.01), no significant age group effect ($F_{1,76}$=0.0, p=0.96, partial η^2 =0.00), and no significant study group effect ($F_{1,76}$=3.2, p=0.08, partial η^2 =0.04, Table 3). For mean postural stability in Condition 2, there was no significant interaction between age and study groups ($F_{1,76}$=0.8, p=0.37, partial η^2 =0.01), and no significant age group effect ($F_{1,76}$=1.5, p=0.22, partial η^2 =0.02). However, there was a significant study group effect ($F_{1,76}$=8.0, p=0.01, partial η^2 =0.10, Table 3). Similarly, for mean postural stability in Condition 3, there was no significant interaction between age and study groups ($F_{1,76}$=0.6, p=0.43, partial η^2 =0.01), and no significant age group effect ($F_{1,76}$=1.7, p=0.20, partial η^2 =0.02). However, there was a significant study group effect ($F_{1,76}$=8.4, p=0.01, partial η^2 =0.10, Table 3).

Discussion

In the present study, the effect of head motion on postural stability in young and middle-aged adults with and without CMS was examined. The results demonstrated that there was a significant difference in mean postural stability between participants with CMS compared to those without CMS and by age group during vertical and horizontal head motions when the effect of BMI was not controlled. After controlling for BMI, there was no significant interaction between study group and age group and no significant difference in mean postural stability by age group. However, mean postural stability of participants with CMS was significantly worse than those without in both vertical and horizontal head motion conditions.

Head Motion Directions on Postural Stability between CMS and non-CMS group

This present study investigated the effect of head motion in the horizontal and vertical planes on postural stability in adults with and without CMS. Results demonstrated that postural stability decreased during head motion in both planes in participants with CMS. These results supported by Paloski et al.(Paloski et al., 2006) who revealed a direct correlation between postural instability and frequency of head tilts. In addition, Mitsutake et al. (Mitsutake et al., 2014) reported that postural instability was significantly increased during head active yaw “horizontal” head motion in stroke patients compared to healthy individuals while open and closed eyes conditions. Similarly, Lackner et al. (James R Lackner & Graybiel, 1985) revealed that head motion during pitch “vertical” direction cause motion sensitivity; and that head pitch could induce postural instability. In line with the present study results that showed there was a significant decline in postural stability during pitch head motion for both study groups.

Effect of Head Motion on Postural Stability and Ageing

Turner and M. Griffin (Turner, 1999) reported that CMS susceptibly increases thru aging. However, Paillard et al. (Paillard et al., 2013) reported that in both healthy individuals and vestibular patients, CMS susceptibility declines with aging. Likewise, Golding et al. (J. F. Golding, 2006; Golding & Gresty, 2015) reported that across adolescence, adulthood, and older age, CMS susceptibility gradually declines. Agrawal et al (Agrawal et al., 2012) reported a general decline in semicircular canal and otolith function with aging.

Additionally, Paillard et al. (Paillard et al., 2013) reported that patients with vestibular dysfunction have greater CMS than healthy subjects, whereas individuals with vestibular loss have lower CMS compared to healthy subjects. The present study results determined that there was a significant difference in postural stability during head motion in both planes by age group (young and middle-aged adults) and by study group (with and without CMS) before BMI was controlled; however, there was no difference in mean postural stability between age groups after controlling for BMI. It is possible that CMS susceptibility declines through habituation as a person age.

Conclusion

Adults with CMS have less postural stability during head motion in both planes compared to adults without CMS. Additionally, vertical head motion has more effect on postural stability than horizontal head motion on those with CMS.

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Table 1. Mean ± SD of General Characteristics by Age and CMS Groups (N=80)

	Young (n1=40)		Middle-Aged (n2=40)		p-value* (age X group) (partial η2)	p-value* (age) (partial η2)	p-value* (group) (partial η2)
	With CMS (N1=20)	Without CMS (N2=20)	With CMS (N1=20)	Without CMS (N2=20)			
BMI (Kg/m2)	25.5±4.3	25.2±3.2	28.4±6.5	30.4±5.6	0.31 (0.01)	0.001 (0.15)	0.46 (0.01)
Female; (n, %)	11(47.8)	12(52.2)	9(45.0)	11(55.0)		P>0.05	

Abbreviations: SD, Standard Deviation; CMS, Chronic Motion Sensitivity; BMI, Body Mass Index.

* Factorial Analysis of Variance; partial $\eta^2 = \frac{\text{Group Sum of square}}{Total\ Sum\ of\ square}$

Table 2. Mean ± SE of Equilibrium Score for Various Conditions by Age and CMS Groups

	Young (n1=40)		Middle-Aged (n2=40)		p-value* (age x group) (partial η2)	p-value* (age) (partial η2)	p-value* (group) (partial η2)
	With CMS (N1=20)	Without CMS (N2=20)	With CMS (N1=20)	Without CMS (N2=20)			
Baseline	93.7±0.4	94.9±0.4	94.0±0.4	94.3±0.4	0.27 (0.02)	0.74 (0.00)	0.09 (0.04)
Vertical	90.3±0.8	93.3±0.8	89.2±0.8	90.3±0.8	0.28 (0.02)	0.01 (0.08)	0.01 (0.08)
Horizontal	90.7±0.8	93.6±0.8	90.0±0.8	91.2±0.8	0.28 (0.02)	0.04 (0.06)	0.01 (0.09)

Abbreviations: SE, Standard Error; CMS, Chronic Motion Sensitivity.

* Factorial Analysis of Variance; partial $\eta^2 = \frac{\text{Group Sum of square}}{Total\ Sum\ of\ square}$

Table 3. Mean ± SE Equilibrium Score for Various Conditions by Age and CMS Groups after Controlling for BMI

	Young (n1=40)		Middle-Aged (n2=40)		p-value* (age x group) (partial η2)	p-value* (age) (partial η2)	p-value* (group) (partial η2)
	With CMS (N1=20)	Without CMS (N2=20)	With CMS (N1=20)	Without CMS (N2=20)			
Baseline	93.6±0.4	94.8±0.4	94.0±0.4	94.4±0.5	0.33 (0.01)	0.96 (0.00)	0.08 (0.04)
Vertical	89.9±0.8	92.8±0.8	89.4±0.8	91.1±0.8	0.43 (0.01)	0.20 (0.02)	0.01 (0.10)
Horizontal	90.5±0.8	93.3±0.8	90.2±0.8	91.6±0.8	0.37 (0.01)	0.22 (0.02)	0.01 (0.10)

Abbreviations: SE, Standard Error; CMS, Chronic Motion Sensitivity; BMI, Body Mass Index (Kg/m2).

* Factorial Analysis of Variance; partial $\eta^2 = \frac{\text{Group Sum of square}}{Total\ Sum\ of\ square}$

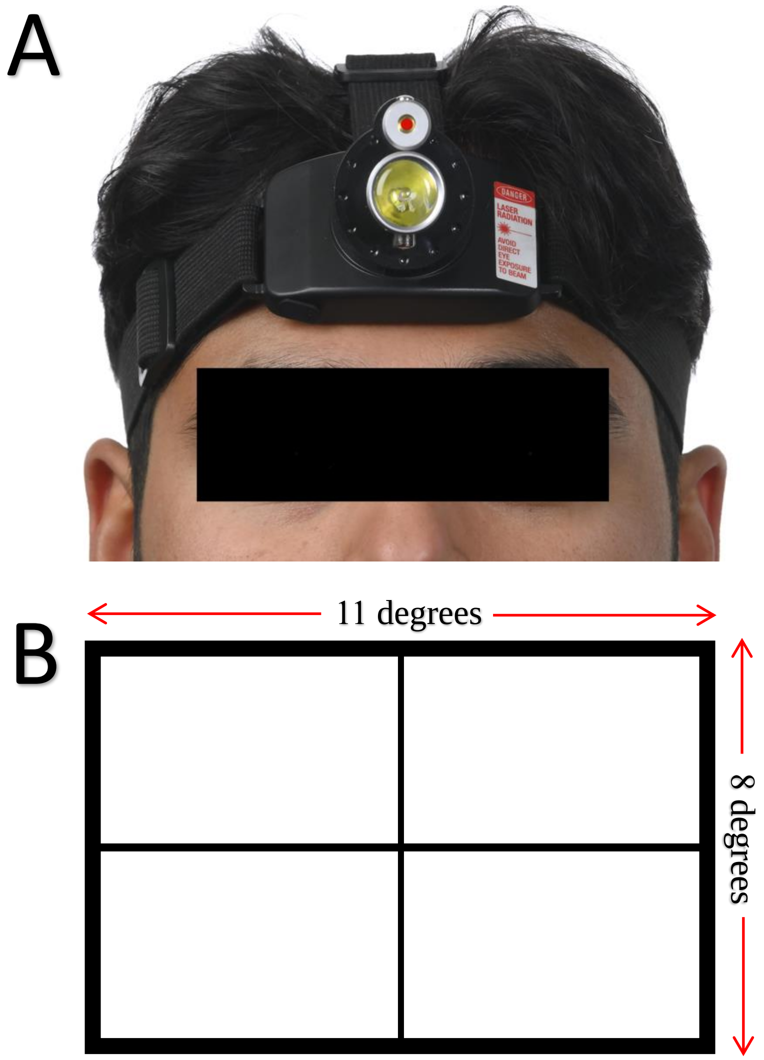
[redacted]

Fig. 1A. Participants performed horizontal and vertical head motions using a head-mounted laser pointer to control amplitude. ***Fig. 1B.*** This tool was developed to guide horizontal and vertical head motions.

Fig. 2. CDP-IVR static baseline condition 1.

Fig. 3. CDP-IVR, laser pointer over subject head, the grid pic.is magnified to be easy to see, This demonstration for head motion conditions 2, and 3.

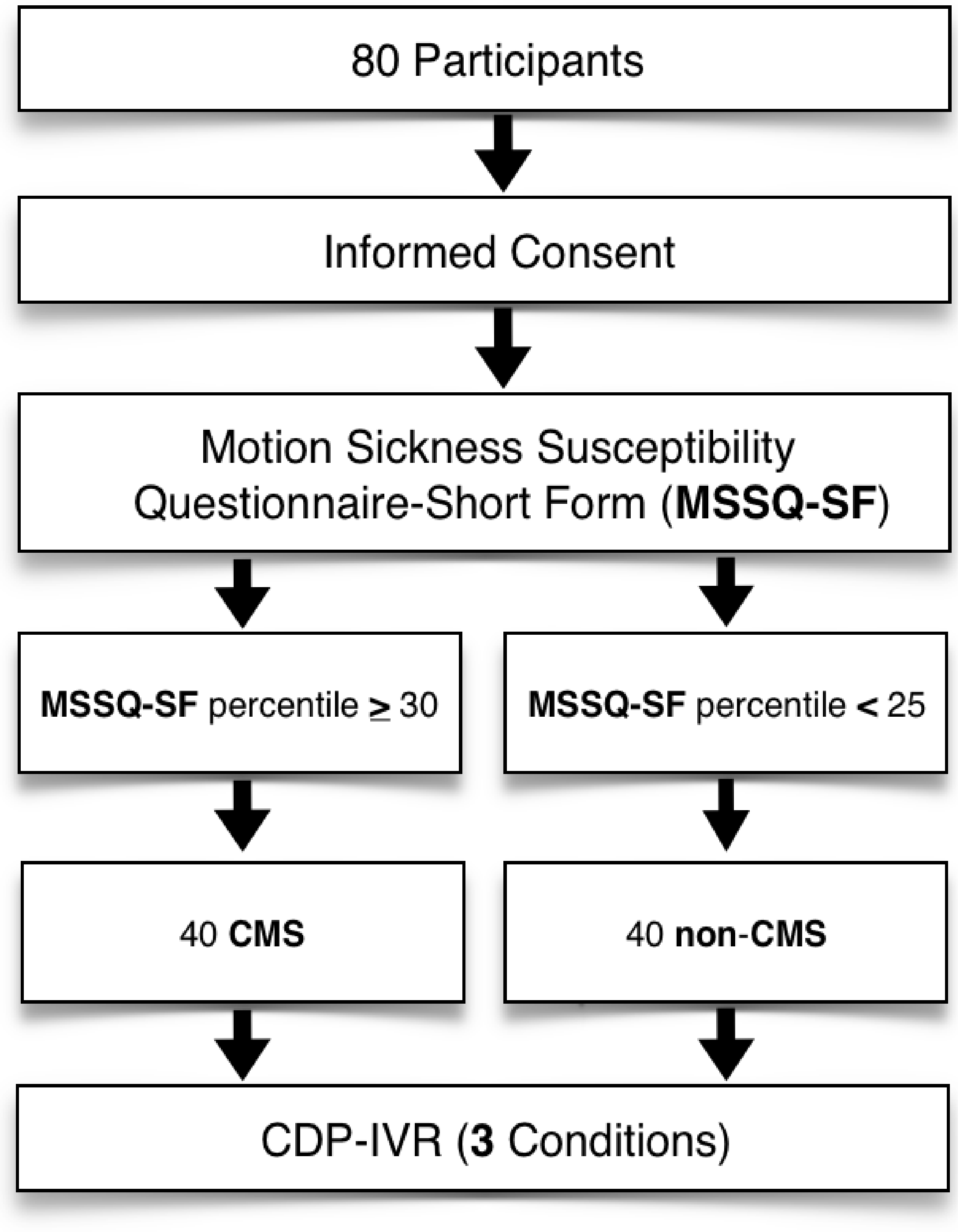

Fig. 4. Diagram illustrating flow of participants and study procedure

Chapter Four

Discussion I

Head Motion Directions on Postural Stability between CMS and non-CMS group

The first study investigated the effect of head motion in the horizontal and vertical directions on postural stability in middle-aged adults with and without CMS. Results demonstrated that postural stability decreased during head motion in both directions in participants with CMS. Similar to the present study results, Paloski et al.(Paloski et al., 2006) reported that during static head tilts with eyes closed, healthy individuals were able to maintain upright stance; while during dynamic head tilts with eyes closed, postural stability decreased with higher frequency of head tilt. Mitsutake et al. (Mitsutake et al., 2014) reported that postural instability significantly increased during head active yaw "horizontal" head motion in stroke patients compared to healthy individuals during open and closed eyes conditions. Similarly, Lackner et al. (Lackner & Graybiel, 1985) reported that all head motion direction including pitch "vertical" direction trigger motion sensitivity. In other words, head pitch motion can lead to more postural sway, which can lead to postural instability. In line with the present study results, there was decreased postural stability during both directions of head motion (horizontal and vertical); and the vertical direction negatively impacted the postural stability more than horizontal direction in CMS and non-CMS groups.

Head Motion Velocities between CMS and non-CMS

A secondary study objective was investigating the effects of slow and fast velocity of head motion on postural stability in middle-aged adults with versus without

CMS. The results showed that postural stability did not differ significantly during slow and fast head motion in the horizontal and vertical directions in both study groups.

Paloski et al. (Paloski et al., 2006) reported that postural stability was worse during different head motions with varying frequencies in healthy individuals. In the present study, head movement frequencies were 1.5 Hz for slow head motion velocity and 2.5 Hz for fast head motion velocity. These frequencies were based on Hirasaki et al.(Hirasaki, Moore, Raphan, & Cohen, 1999) who reported that frequency of head translation and rotation was limited to a narrow range of 1.4 Hz head motion at 0.6 m/s walking speed and to 2.5 Hz head motion at 2.2 m/s faster walking speed. Fast head motion velocity might induce more stress on postural stability than slow head motion velocity in middle-aged adults with CMS; contrary to Paloski et al. (Paloski et al., 2006) the present study results revealed that there was no significant difference of postural stability between study groups by velocity (slow versus fast).

The present study results found that postural stability was worse during vertical head motion compared to horizontal head motion directions in participants with CMS compared to those without CMS. In general, horizontal and vertical head motions have functional implications on postural stability as they are used functionally in various daily activities during standing, such as looking in kitchen cabinets, searching for objects on supermarket shelves, checking traffic when crossing a street, and showering.

Effect of Physical Activity Level Head Motion in CMS

Lokucijewski (Łokucijewski & Researches, 2014) reported that physical exercises can improve CMS symptoms by 50%. Caillet et al. (Caillet et al., 2006) reported that individuals with high consistency of physical and sport activities can reduce visual dependency and improve CMS through a sensory rearrangement process. In the present study, participants in the CMS group had higher physical activity levels, which may have enhanced their postural stability scores. The investigators speculate that if the physical activity levels were similar between groups, the differences in mean postural stability would have been larger between groups.

Discussion II

Head Motion Directions on Postural Stability between CMS and non-CMS group

In the second study, the effect of head motion on postural stability in young and middle-aged adults with and without CMS was examined. The results demonstrated that there was a significant difference in mean postural stability between participants with CMS compared to those without CMS and by age group during vertical and horizontal head motions when the effect of BMI was not controlled. After controlling for BMI, there was no significant interaction between study group and age group and no significant difference in mean postural stability by age group. However, mean postural stability of participants with CMS was significantly worse than those without in both vertical and horizontal head motion conditions. This present study investigated the effect of head motion in the horizontal and vertical planes on postural stability in adults with and without CMS. Results demonstrated that postural stability decreased during head motion in both planes in participants with CMS. These results supported by Paloski et al.(Paloski et al., 2006) who revealed a direct correlation between postural instability and frequency of head tilts. In addition, Mitsutake et al. (Mitsutake et al., 2014) reported that postural instability was significantly increased during head active yaw “horizontal” head motion in stroke patients compared to healthy individuals while open and closed eyes conditions. Similarly, Lackner et al. (Lackner & Graybiel, 1985) revealed that head motion during pitch “vertical” direction cause motion sensitivity; and that head pitch could induce postural instability. In line with the present study results that showed there was a significant decline in postural stability during pitch head motion for both study groups.

Effect of Head Motion on Postural Stability and Ageing

Turner and M. Griffin (Turner, 1999) reported that CMS susceptibly increases thru aging. However, Paillard et al. (Paillard et al., 2013) reported that in both healthy individuals and vestibular patients, CMS susceptibility declines with aging. Likewise, Golding et al. (Golding, 2006; Golding & Gresty, 2015) reported that across adolescence, adulthood, and older age, CMS susceptibility gradually declines. Agrawal et al (Agrawal et al., 2012) reported a general decline in semicircular canal and otolith function with aging.

Additionally, Paillard et al. (Paillard et al., 2013) reported that patients with vestibular dysfunction have greater CMS than healthy subjects, whereas individuals with vestibular loss have lower CMS compared to healthy subjects. The present study results determined that there was a significant difference in postural stability during head motion in both planes by age group (young and middle-aged adults) and by study group (with and without CMS) before BMI was controlled; however, there was no difference in mean postural stability between age groups after controlling for BMI. It is possible that CMS susceptibility declines through habituation as a person age.

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APPENDIX A

HEALTH HISTORY SCREENING FORM

LOMA LINDA
UNIVERSITY

School of Allied
Health Professions

Effects of Visual Inputs on Postural Stability in Middle-Aged Adults with and without Chronic Motion Sensitivity

Health History Screening Form

Date: ________________
Subject's ID Code: ________________
Subject's Age: ________________

Please indicate if you have any of the following:

▪ Past or current cervical spinal orthopedic impairments	No	Yes
▪ Current lower extremity injuries	No	Yes
▪ Past or current vestibular impairments	No	Yes
▪ Past or current neurological pathology	No	Yes
▪ Current medications causing dizziness or imbalance	No	Yes

APPENDIX B

INFORMED CONSENT

LOMA LINDA
UNIVERSITY

School of Allied
Health Professions

TITLE: **EFFECTS OF MOTION SENSITIVITY ON BALANCE, STRENGTH, AND STRESS IN MIDDLE-AGED ADULTS**

SPONSOR: **Department of Allied Health Studies, Loma Linda University**

PRINCIPAL INVESTIGATOR: Eric Glenn Johnson, DSc, PT, MS-HPEd, NCS
Professor, Physical Therapy Department
Loma Linda University, Loma Linda CA
School of Allied Health Professions
Nichol Hall Room #A-712
Phone: (909) 558-4632 Extension 47471
Fax: *(909) 558-0459*
Email Address: ejohnson@llu.edu

STUDENT CO-INVESTIGATORS: Fahad Alshehri, Doctor of Science in Physical Therapy Candidate
Ammar Hafiz, Doctor of Science in Physical Therapy Candidate

1. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to study the effects of motion sensitivity on several aspects of physical performance and stress. Specifically, we aim to examine whether adults between the ages of 45-64 years, with or without motion sensitivity, have differences in various aspects of balance, lower limb and neck strength, and stress. To our knowledge, this information has not been previously reported in the literature. You are invited to participate in this research study because you are a healthy adult between 45-64 years of age with or without motion sensitivity.

2. HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?

Approximately 100 subjects will be recruited to participate in this study.

3. HOW LONG WILL THE STUDY GO ON?

The study requires one session. The session will be approximately 90 minutes in the research lab.

4. HOW WILL I BE INVOLVED?

You will be asked several questions to determine your eligibility to participate in this study. If you are eligible and willing to participate, you will be responsible for your own travel to and from the research lab. Your date of birth, height and weight will be recorded followed by these activities:

- You will complete two motion sensitivity questionnaires.
- You will complete an anxiety questionnaire.
- You will complete a physical activity questionnaire.
- You will complete dizziness questionnaire.
- Your blood pressure and heart rate will be measured.
- Your standing balance will be measured in several conditions.
- Your lower limb strength will be measured.

5. WHAT ARE THE REASONABLY FORESEEABLE RISKS OR DISCOMFORTS I MIGHT HAVE?

There is risk of falling and/or mild dizziness during the standing balance testing. To minimize the risk of falling, you will be wearing a safety harness and two researchers will be standing beside you at all times during testing. There is also a minimal risk of breach of confidentiality.

6. WILL THERE BE ANY BENEFIT TO ME OR OTHERS?

There is no expected benefit to you but the expected benefit to humanity is to improve our understanding concerning the effects of chronic motion sensitivity on the balance systems, lower limb and neck strength, and stress response. This knowledge may lead to future research aimed at reducing symptoms associated with chronic motion sensitivity.

7. WHAT ARE MY RIGHTS AS A SUBJECT?

Participation in this study is voluntary. Your decision whether or not to participate or terminate at any time will not affect your present or future relationship with the Loma Linda University Department of Physical Therapy. You do not give up any legal rights by participating in this study.

8. WHAT HAPPENS IF I WANT TO STOP TAKING PART IN THIS STUDY?

You are free to withdraw from this study at any time. If you decide to withdraw from this study you should notify the research team immediately. The research team may also end your participation in this study if you do not follow instructions or if your safety and welfare are at greater than minimal risk.

9. HOW WILL INFORMATION ABOUT ME BE KEPT CONFIDENTIAL?

Efforts will be made to keep your personal information confidential, but we cannot guarantee absolute confidentiality. We will use a pseudonym throughout the study for all recorded data so your actual name will not be used. You will not be identified by name in any publications describing the results of this study. Data in hard copy will be kept in a locked file cabinet in a locked office and electronic data will be password protected.

10. WHAT COSTS ARE INVOLVED?

There is no cost to you for participating in this study beyond the time involved to participate.

11. WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

You will receive a $50 gift card on the day of data collection if you complete the session.

12. WHO DO I CALL IF I HAVE QUESTIONS?

If you feel you have been injured by taking part in this study, consult with a physician or call 911 if the situation is a medical emergency. No funds have been set aside nor any plans made to compensate you for time lost for work, disability, pain or other discomforts resulting from your participation in this research.

If you wish to contact an impartial third party not associated with this study regarding any question or complaint you may have about the study, you may contact the Office of Patient Relations, Loma Linda University Medical Center, Loma Linda, CA 92354, phone (909) 558-4674, e-mail patientrelations@llu.edu for information and assistance.

13. SUBJECT’S STATEMENT OF CONSENT

I have read the contents of the consent form and have listened to the verbal explanation given by the investigators. My questions concerning this study have been answered to my satisfaction. I hereby give voluntary consent to participate in this study. I have been given a copy of this consent form. Signing this consent document does not waive my rights nor does it release the investigators, institution, or sponsors from their responsibilities. I may call and leave a voice message for Eric Johnson, DSc during routine office hours at this number (909) 558-4632 ext. 47471 or e-mail him at ejohnson@llu.edu, if I have additional questions and concerns.

I understand I will be given a copy of this consent form after signing it.

Signature of Subject	Printed Name of Subject

Date

14. INVESTIGATOR'S STATEMENT

I have reviewed the contents of this consent form with the person signing above. I have explained potential risks and benefits of the study.

Signature of Investigator	Printed Name of Investigator

Date

APPENDIX C

AUTHORIZATION FOR USE OF PROTECTED HEALTH INFORMATION

INSTITUTIONAL REVIEW BOARD
Authorization for Use of
Protected Health Information (PHI)

Per 45 CFR §164.508(b)

RESEARCH PROTECTION PROGRAMS
LOMA LINDA UNIVERSITY | Office of the Vice President of Research Affairs
24887 Taylor Street, Suite 202 Loma Linda, CA 92350
(909) 558-4531 (voice) / (909) 558-0131 (fax)/e-mail: irb@llu.edu

LOMA LINDA UNIVERSITY
School of Allied Health Professions

TITLE OF STUDY:	Effects of Chronic Motion Sensitivity on Vestibular Function, Balance, Strength, and Stress in Middle-Aged Adults
PRINCIPAL INVESTIGATOR:	Eric G. Johnson, DSc, PT, MS-HPEd, NCS
Others who will use, collect, or share PHI:	Authorized Research Personnel

The student research study named above may be performed only by using personal information relating to your health. National and international data protection regulations give you the right to control the use of your medical information. Therefore, by signing this form, you specifically authorize your medical information to be used or shared as described below.

The following personal information, considered “Protected Health Information” (PHI) is needed to conduct this study and may include, but is not limited to name, birth date, phone number, e-mail, and a health questionnaire.

The individual(s) listed above will use or share this PHI in the course of this study with the Institutional Review Board (IRB) and the Office of Research Affairs of Loma Linda University.

The main reason for sharing this information is to be able to conduct the study as described earlier in the consent form. In addition, it is shared to ensure that the study meets legal, institutional, and accreditation standards. Information may also be shared to report adverse events or situations that may help prevent placing other individuals at risk.

All reasonable efforts will be used to protect the confidentiality of your PHI, which may be shared with others to support this study, to carry out their responsibilities, to conduct public health reporting and to comply with the law as applicable. Those who receive the PHI may share with others if they are required by law, and they may share it with others who may not be required to follow national and international "protected health information" (PHI) regulations such as the federal privacy rule.

Subject to any legal limitations, you have the right to access any protected health information created during this study. You may request this information from the Principal Investigator named above but it will only become available after the study analyses are complete.

This authorization does <u>not</u> expire and will continue indefinitely unless you notify the researchers that you wish to revoke it.

You may change your mind about this authorization at any time. If this happens, you must withdraw your permission in writing. Beginning on the date you withdraw your permission; no new personal health information will be used for this study. However, study personnel may continue to use the health information that was provided before you withdrew your permission. If you sign this form and enter the study, but later change your mind and withdraw your permission, you will be removed from the study at that time. To withdraw your permission, please contact the Principal Investigator or study personnel at 909-583-4966.

You may refuse to sign this authorization. Refusing to sign will not affect the present or future care you receive at this institution and will not cause any penalty or loss of benefits to which you are entitled. However, if you do not sign this authorization form, you will not be able to take part in the study for which you are being considered. You will receive a copy of this signed and dated authorization prior to your participation in this study.

I agree that my personal health information may be used for the study purposes described in this form.

Signature of Patient *or* Patient's Legal Representative	Date
Printed Name of Legal Representative (if any)	Representative's Authority to Act for Patient
Signature of Investigator Obtaining Authorization	Date

APPENDIX D

Flyer for Recruiting Participants

LOMA LINDA
UNIVERSITY
School of Allied
Health Professions

Research Opportunity

Effects of Chronic Motion Sensitivity on Vestibular Function, Balance, Strength, and Stress in Middle-Aged Adults

The Physical Therapy Department in the School of Allied Health Profession at Loma Linda University is conducting a Doctoral Student research project examining the effects of motion sensitivity on balance, lower limb and neck strength, and stress response in middle-aged adults.

PARTICIPANTS ARE NEEDED

You may qualify to participate in this study if:

- You are a healthy adult **with** or **without** history of motion sensitivity.
- Your age is between 45-64

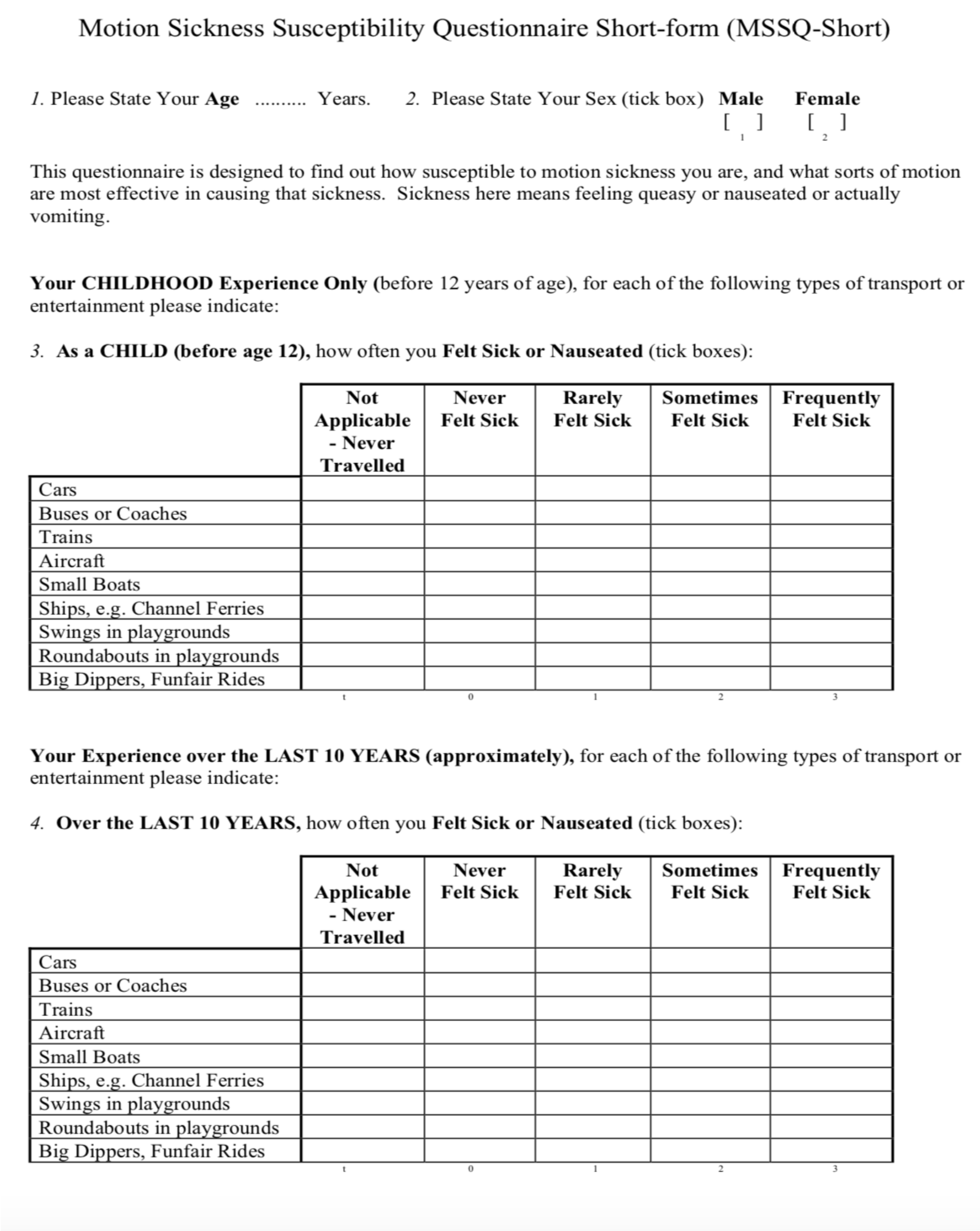
You're eligible to participate if you don't have past or current neck problems, current vestibular disorders, neurological disease or pathology, diabetic peripheral neuropathy, or current medications causing dizziness or imbalance. Your balance, strength, and stress levels will be measured using a combination of non-invasive computerized machines, manual examination, and questionnaires.

Neither you nor your health insurance provider will be charged for the cost of any evaluation or treatment provided for the purposes of this study. After completing the assessment, you will receive a gift card as an expression of our thanks for your participation.

If you are interested in participating or would like to know more about the study, please contact **Eric Johnson** at **909-658-5223** or **909-558-4632 ext. 47471**/email at **ejohnson@llu.edu**

APPENDIX E

Motion Sickness Susceptibility Questionnaire-Short Form



Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** .... Years.

2. Please State Your Sex (tick box) **Male** [ ]₁ **Female** [ ]₂

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Scoring the MSSQ- Short

Section A (Child) (Question 3)

Score the number of types of transportation not experienced (i.e., total the number of ticks in the 't' column, maximum is 9).

Total the sickness scores for each mode of transportation, i.e. the nine types from 'cars' to 'big dippers' (use the 0-3 number score key at bottom, those scores in the 't' column count as zeroes).

MSA = (total sickness score child) x (9) / (9 - number of types not experienced as a child)

Note 1. Where a subject has not experienced any forms of transport a division by zero error occurs. It is not possible to estimate this subject's motion sickness susceptibility in the absence of any relevant motion exposure.
Note 2. The Section A (Child) score can be used as a pre-morbid indicator of motion sickness susceptibility in patients with vestibular disease.

Section B (Adult) (Question 4)

Repeat as for section A but using the data from section B.

MSB = (total sickness score adult) x (9) / (9 - number of types not experienced as an adult)

Raw Score MSSQ-Short

Total the section A (Child) MSA score and the section B (Adult) MSB score to give the MSSQ-Short raw score (possible range from minimum 0 to maximum 54, the maximum being unlikely)

MSSQ raw score = MSA + MSB

Percentile Score MSSQ-Short

The raw to percentile conversions are given below in the Table of Statistics & Figure, use interpolation where necessary.

Alternatively a close approximation is given by the fitted polynomial where y is percentile; x is raw score

$y = a.x + b.x^2 + c.x^3 + d.x^4$

a = 5.1160923	b = -0.055169904
c = -0.00067784495	d = 1.0714752e-005

Table of Means and Percentile Conversion Statistics for the MSSQ-Short (n=257)

Percentiles Conversion	Raw Scores MSSQ-Short		
	Child Section A	Adult Section B	Total A+B
0	0	0	0
10	.0	.0	.8
20	2.0	1.0	3.0
30	4.0	1.3	7.0
40	5.6	2.6	9.0
50	7.0	3.7	11.3
60	9.0	6.0	14.1
70	11.0	7.0	17.9
80	13.0	9.0	21.6
90	16.0	12.0	25.9
95	20.0	15.0	30.4
100	23.6	21.0	44.6
Mean	7.75	5.11	12.90
Std. Deviation	5.94	4.84	9.90

Table note: numbers are rounded

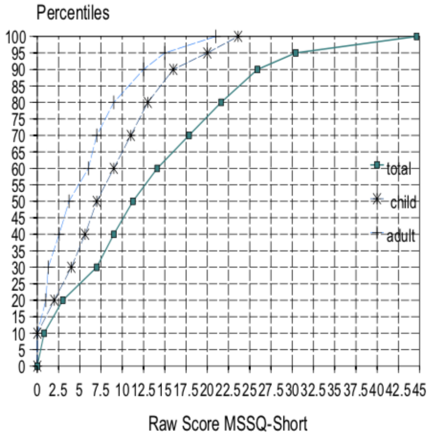


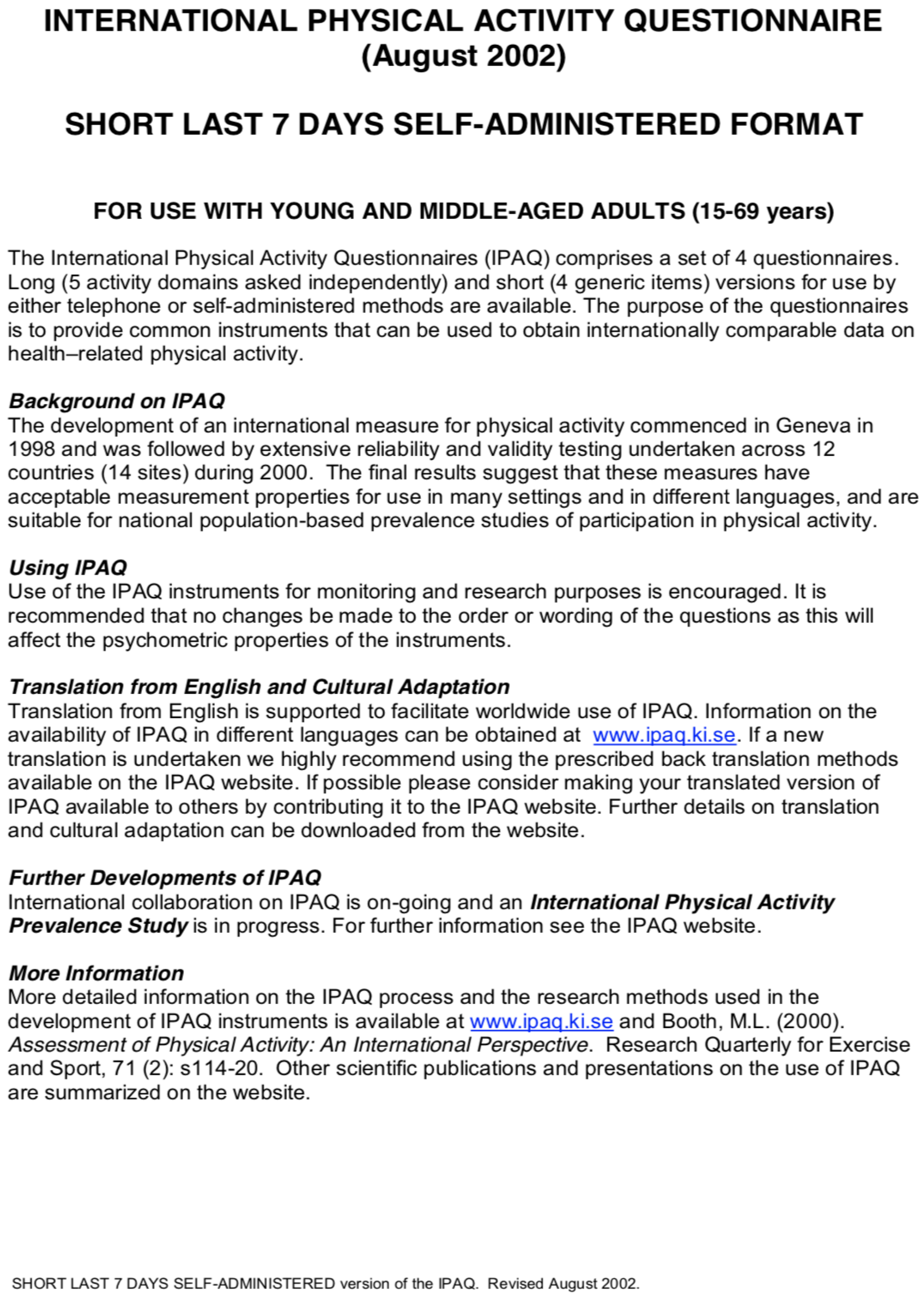
Figure: Cumulative distribution Percentiles of the Raw Scores of the MSSQ-Short (n=257 subjects).

Reference Note

For more background information and references to the original Reason & Brand MSSQ and to its revised version the 'MSSQ-Long', see:
Golding JF. Motion sickness susceptibility questionnaire revised and its relationship to other forms of sickness. **Brain Research Bulletin**, 1998; 47: 507-516.
Golding JF. (2006) Predicting Individual Differences in Motion Sickness Susceptibility by Questionnaire. **Personality and Individual differences, 41:** 237-248.

APPENDIX F

International Physical Activity Questionnaire-Short Form



INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE
(August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ
The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ
Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation
Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ
International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information
More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____ **days per week**

☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

SHORT LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised August 2002.