

TOWARD UNDERSTANDING FACTORS AFFECTING FALLS AMONG INDIVIDUALS WHO ARE OBESE

XUEFANG WU

Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State
University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Industrial & System Engineering

Michael L. Madigan(Chair)
Maury A. Nussbaum (Co-Chair)
Michael J. Agnew
Zhenyu (James) Kong
Gareth A. Thomson

March 27th, 2015
Blacksburg, VA

Keywords: Obesity, Falls, Plantar sensitivity, Executive function, Gait, BMI

Toward understanding factors affecting falls among individuals who are obese

Xuefang Wu

ABSTRACT

The prevalence of obesity is high in the United States. One of the many concerns with the high prevalence of obesity is its association with an increased risk of falls and subsequent injury. Thus, it is important to understand factors affecting falls among individuals who are obese, to help develop effective intervention solutions to mitigate falls in this population. Obese individuals have been hypothesized to have an impaired plantar sensitivity, and this may influence their balance control, thus lead to more falls. Executive function deficits in individuals who are obese may affect their ability to allocate attentional resources to dual tasks (walking while performing other tasks), and may put them at higher risks of falls. Gait alterations and muscle strength deficits in individuals who are obese may also increase their fall risks. Therefore, three studies were carried out to provide better understanding into the factors affecting falls in individuals who are obese.

The first study investigated the effects of obesity on plantar sensitivity, and explored the relationship between plantar sensitivity and postural sway during quiet standing. Plantar sensitivity was measured as the force threshold at which an increasing force applied to the plantar surface of the foot was first perceived, and the force threshold at which a decreasing force was last perceived. Measurements were obtained while standing, and at two locations on the plantar surface of the dominant foot. Postural sway during quiet standing was then measured under three different sensory conditions. Results indicated less sensitive plantar sensitivity and increased postural sway among individuals who are obese, and statistically significant correlations between plantar sensitivity and postural sway that were characterized as weak to moderate in strength. As such, impaired plantar sensitivity among individuals who are obese may be a mechanism by which obesity degrades standing balance among these individuals.

The second study investigated the influence of obesity on executive function, and determined whether there is a relationship between executive function and fall risk (as estimated from selected gait parameters). Four major components of executive function were assessed, including selective attention, divided attention, semantic memory and working memory. Both single- and dual-task walking (walking-while-talking) were completed to evaluate fall risk during gait. Less effective selective attention, semantic memory, and working memory were found among young obese adults. Participants exhibited higher fall risks during dual-task walking, and executive function scores were associated with gait during dual-task walking. In conclusion, obese individuals exhibited less effective executive function, which may be associated with their increased fall risk.

The third study explored differences in gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size between fallers and non-fallers, and the strength of the association between the same factors and slip severity. Participants' gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size measures were obtained. An unexpected slip was introduced in a laboratory setting to

obtain slip severity related measures and slip outcome. Results indicated obese fallers exhibited better executive function (selective attention), stronger lower extremity muscle strength, lower BMI and smaller waist circumference. Results also indicated increased slip severity was associated with faster walking speed, longer step length, higher RCOF, worse executive function (working memory), and lower BMI. Slower reactive recovery response was also associated with lower BMI. As such, better selective attention and stronger muscle strength exhibited limited benefit in slip recovery among individuals who are obese. Altered gait pattern, and working memory may be factors by which obesity increased slip severity, and lower BMI among individuals who are obese may increase slip-induced fall risks.

In conclusion, reduced plantar sensitivity, impairments in executive function, altered gait pattern were associated with deficits in standing and walking balance control, and increased slip severity among individuals who are obese. Therefore, appropriate fall prevention/intervention program targeting at some or all of these factors may be considered as solutions to decrease fall risks for obese individuals.

Acknowledgements

First, I would like to thank my advisor, Dr. Michael Madigan, for your guidance throughout this research. I am extremely grateful to you for sharing your knowledge and experience with me. And I really appreciate your understanding, patience and encouragement for me in the past couple years. You are not only my advisor, but also my mentor and friend. I would also like to thank my co-advisor Dr. Maury Nussbaum, my committee members, Dr. Michael Agnew, Dr. Gareth Thomson, and Dr. Zhenyu Kong, for your comments, suggestions, and different perspectives.

Many thanks to my lab friends, Leigh Allin, Hoda Koushyar, John Scanlon, and Tina Garman for your help to my work. I would also like to thank Mr. Darrell Link for your technical support during my experiments.

I owe thanks to my parents, Jieren Wu and Jianjun Song, and my parents-in-law Chan Chew Yeoh and Sew Kee Chia for your unconditional care and support throughout this journey. Without you I wouldn't have accomplished the journey and become who I am today. I can't thank you enough.

Last but not least, I would like to thank my husband, my love, Dr. Han Teik Yeoh. Thank you for your love, your trust, your support and your confidence in me. There are no appropriate words that could express how much you mean to me. We are simply part of each other. I love you!

Table of Contents

Specific Aims	1
Chapter 1 Background and Literature Review	2
1.1 Significance of obesity and its related fall risks	2
1.2 Factors which may influence falls in individuals who are obese	3
1.3 Existing literature gap.....	5
1.4 Summary.....	8
Reference	9
Chapter 2 Impaired Plantar Sensitivity among the Obese is Associated with Increased Postural Sway	17
2.1 Introduction	18
2.2 Materials and Methods	19
2.3 Results	25
2.4 Discussion.....	29
Reference	33
Chapter 3 Executive Function and Measures of Fall Risk among Individuals who are Obese	38
3.1 Introduction	39
3.2 Methods	41
3.3 Results	45
3.4 Discussion.....	48
References	52
Chapter 4 Differences between Obese Fallers and Non-fallers after a Laboratory-Induced Slip.....	60
4.1 Introduction	61
4.2 Methods	63
4.3 Results	69
4.4 Discussion.....	73
Reference	78
Chapter 5 Conclusion and Future Implications	85
5.1 Overall conclusion.....	86
5.2 Future studies.....	87
5.3 Plan for publications.....	87
5.4 Intervention implications.....	87
Reference	89
Appendix A.....	93
Appendix B.....	97
Appendix C.....	106

List of Figures

Figure 1-1 Fall event model	4
Figure 2-1 Custom-designed platform to assess plantar sensitivity while standing	21
Figure 2-2 Digital force gauge setup was mounted on lab jack under the platform. The investigators adjusted the vertical position of the probe by manipulating the lab jack, and read off the force threshold from the digital readout when indicated by the participants.	22
Figure 2-3 Force threshold measurements separated by group, location, and force direction.	26
Figure 2-4 Group by location by force direction interaction plot illustrating differences between groups	27
Figure 2-5 Scatter plots of correlation between plantar sensitivity and postural sway measures.	28
Figure 3-1 Group \times gender interaction effects on stance time and stance time IQR.	47
Figure 4-1 Differences in body size measures between fallers and non-fallers with <i>p</i> -value.....	70
Figure 4-2 Scatter plots of correlations between slip severity (slip distance and peak slip speed) and gait measures (walking speed, step length, and RCOF), Digit Span test score, and BMI.....	72
Figure 4-3 Scatter plots of correlation between BMI and non-slipping foot reaction time.....	73

List of Tables

Table 2-1 Summary of participants' estimated body fat percentage, presented as means ...	20
Table 2-2 Median(IQR) of postural sway measures by condition.....	27
Table 2-3 Median(IQR) of postural sway measures by group	28
Table 3-1 Group differences in tests of executive function, with summary results presented as means (standard deviation) and <i>p</i> -values for the main effects of group. The symbol * indicates a significant difference between groups.....	46
Table 3-2 Task differences in gait parameters, with summary results presented as means (standard deviation), and <i>p</i> -values for the main effect of task. The symbol * indicates a significant difference between tasks.....	47
Table 4-1 Mean (standard deviation), and <i>p</i> -values of gait characteristics, executive function, body size and slip severity related measures for fallers and non-fallers, with * indicates $p \leq 0.05$	70
Table 4-2 Median (interquartile range), and <i>p</i> -values of plantar sensitivity and lower extremity muscle strength for fallers and non-fallers, with * indicates $p \leq 0.05$	71

Specific Aims

The prevalence of obesity is high in the United States. Costs attributed to obesity in the U.S. rose from \$99.2 billion in 1995 to \$147 billion in 2008. One of the many concerns with the high prevalence of obesity is its association with an increased risk of falls and subsequent injury. In the occupational domain, obese workers slip and fall more frequently, and file more workers' compensation claims due to slip and fall accidents than their normal weight counterparts. Thus, it is important to understand factors affecting falls among individuals who are obese, to help develop effective intervention programs to mitigate falls in the obese population.

In general, the ability to walk safely and preserve balance is dependent upon intact sensory and musculoskeletal systems as well as appropriate internal models and gait characteristics. Obesity can affect the functions of these systems and may place these individuals at a higher risk for fall accidents. For example, obese individuals have been hypothesized to have an impaired plantar sensitivity, and this may influence their balance control, and thus lead to more falls. Executive function deficits in individuals who are obese may affect their ability to allocate attentional resources to dual tasks (walking while performing other tasks), and may put them at higher risks of falls. Gait alterations and muscle strength deficits in individuals who are obese may also increase their fall risks. However, to date, no study has investigated whether these factors influence the increased fall risks in individuals who are obese.

The primary objective of the proposed work was to investigate how gait, plantar sensitivity, executive function, and muscle strength contribute to the increased fall risks in the obese. Three studies were designed for the proposed work and addressed the following specific aims.

Specific Aim 1: Investigate the effects of obesity on plantar sensitivity, and the relationship between plantar sensitivity and postural sway during quiet standing. Plantar sensitivity was measured at two locations on the plantar surface of the dominant foot for obese and non-obese individuals. It was hypothesized that 1) obesity would impair plantar sensitivity; and 2) impaired plantar sensitivity would be associated with increased postural sway.

Specific Aim 2: Evaluate the effects of obesity on executive function and the relationship between executive function and fall risk among obese individuals. Executive function was assessed by the Stroop test, Verbal Fluency test, Trail Making Tests and Digit Span tests. Fall risk was assessed by participants' gait characteristics under single- and dual-task walking. Four hypotheses were tested: 1) executive function would be lower among individuals who are obese versus normal weight; 2) adding a dual-task to walking would increase fall risk; 3) this increase in fall risk would be more substantial among individuals who are obese; and 4) executive function would have an inverse association with fall risk, especially under the more challenging dual-task condition.

Specific Aim 3: Explore the differences in biomechanical and physiological factors such as, gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size between fallers and non-fallers, and investigate the strength of association between these same factors and measurements related to slip severity. Slip-induced fall risk was assessed using slip severity and slip outcome measures. It was hypothesized that 1) fallers would exhibit altered gait, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size compared to non-fallers; and 2) altered gait, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size would be associated with increased slip severity.

Chapter 1 Background and Literature Review

1.1 Significance of obesity and its related fall risks

The global burden of obesity is rising at an alarming rate (Anandacoomarasamy et al., 2008). The World Health Organization estimates that in 2008, worldwide, more than 1.4 billion people were overweight or obese, 500 million were obese, and the number of obese individuals had doubled since 1980 (WHO, 2013). Over the past four decades, the prevalence of obesity in the United States among adults aged 20-74 has more than doubled from 15% to 35.7% (Flegal et al., 1998; Kuczmarski et al., 1994; Flegal et al. 2002; Flegal et al., 2010), while overweight prevalence among children and adolescents aged 2-19 has more than tripled from about 5% to 17.1% (CDC, 2014). This high prevalence is problematic because obesity is associated with numerous health problems including heart disease, diabetes, cancer, and breathing problems as well as increased mortality (US Department of Health and Human Services). Obesity is also associated with anatomical and functional impairments (Hills et al., 2002). A few of these include low back pain, osteoporosis, fibromyalgia, gait disturbance, and osteoarthritis (Anandacoomarasamy et al., 2008; Sturmer et al., 2000). Due to the high prevalence of obesity and its associated debilitating conditions, obesity poses a major threat to the health care system in the US (Colditz 1999; Flegal et al., 2010). Costs attributed to obesity in the United States rose from \$99.2 billion in 1995 to \$147 billion in 2008 (Colditz 1999; Flegal et al., 2010).

Another concern with the high prevalence of obesity is its association with an increased risk of falls and subsequent injury. Individuals who are obese fall almost twice as often (27% vs. 15%) compared to non-obese individuals (Fjeldstad et al. 2008), and falls

have been identified as the most common (~36%) cause of injuries in individuals who are obese (Matter et al. 2007). In the occupational domain, according to study carried out by researchers from the Duke University, obese workers slipped and fell more frequently, and filed more workers' compensation claims than their normal weight counterparts due to slips and fall accidents (Ostbye et al., 2007). Thus, it is important to understand the factors affecting falls in individuals who are obese to help develop effective intervention solutions to mitigate falls among these individuals.

1.2 Factors which may influence falls in individuals who are obese

A fall event model during walking can be divided into five distinct stages (Initiation, Detection, Perception, Action Selection and Action Execution) (Figure 1-1). Initiation is the triggering event that may lead to a fall accident. A fall can be initiated by a slip, trip or other postural perturbation. Gait and postural alterations may increase fall initiation risks (Wu et al., 2012). Detection is the initial process that information of a fall initiation event from the environment gain access to the brain (Wickens and Hollands, 2000). During the detection phase of a fall event, if a potential fall is imminent, proprioceptive, visual, and vestibular sensory inputs must be detected and sent into the central nerve system (CNS). As such, at the detection stage, any sensory deteriorations may increase the likelihood of falls. Perception is the interpretation process that decodes the raw sensory information (Wickens and Hollands, 2000). Action selection is the translation process that transfers the perceived information about the environment into action (Wickens and Hollands, 2000). Both perception and action selection phases are dependent largely upon cognitive process. During a potential fall event, an inappropriate control scheme (Horak, 1996) (using the internal model) may alter the motor command generation (perception and action selection

phases), leading to inappropriate recovery response to a perturbation, and increase the risk of falls. Adequate attentional resources are also required to generate appropriate motor command. Executive function deficits may contribute to inappropriate attentional resources allocation during complex situations (i.e. slip or trip), leading to improper perception and action selection, and resulting in greater chances of falls. Action execution is the muscle coordination process for motion generations. Thus, muscular weakness can make it difficult to properly adjust (action execution) the whole body center-of-mass to prevent falls (Lockhart et al., 2005), leading to increased fall propensity.

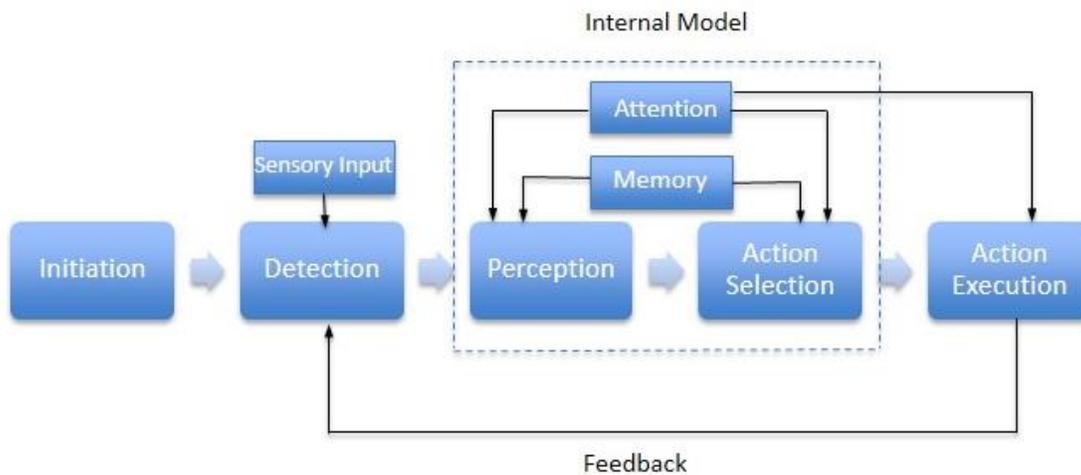


Figure 1-1 Fall event model (Adapted from Wickens and Hollands, 2000)

Obesity can contribute to falls by influencing several components of the model (Figure 1-1). Gait and postural changes in individuals who are obese may elevate their fall initiation risks (DeVita and Hortobagyi 2003; Fabris de Souza et al. 2006; Lai et al. 2008; Spyropoulos et al. 1991; Wu et al., 2012). Plantar sensitivity and proprioception deteriorations in individuals who are obese may increase their detection time and elevate their fall risks (Dowling and Steel 2001; Wang et al., 2008). Executive function alterations in individuals who are obese may also affect the attentional resources allocation during perception and action selection processes, leading to higher fall propensity (Mingardot et

al., 2010). Muscular weakness in individuals who are obese may influence their action execution and ability to recover from a fall initiation event, resulting in increased fall risks (Anandacoomarasamy et al., 2008). Therefore, it can be hypothesized that obese individuals have an increased tendency to a fall initiation event (i.e. slip), and an impaired ability to recover their balance after the onset of a perturbation. Although numerous studies have been conducted on normal weight individuals, the knowledge regarding factors affecting falls in individuals who are obese is limited, which may make it difficult to design and implement effective fall prevention programs for this cohort. Studies are therefore warranted to provide better understanding of factors affecting falls in individuals who are obese.

1.3 Existing literature gap

Gait

Generally, gait changes influence fall initiation risks (Lockhart et al., 2003). For example, it is believed that slip-induced falls occur when the available coefficient of friction (ACOF) is less than the required coefficient of friction (RCOF) at the foot during the heel contact phase of the gait cycle (Hanson et al., 1999, and Lockhart et al., 2003). The increased number of slips and falls is directly associated with the greater differences between ACOF and RCOF (Hanson et al., 1999). Slowed walking velocity, longer step length and decreased cadence are also associated with increased slip-induced falls as they may influence the required ratio between horizontal and vertical forces (RCOF) (Espy et al., 2010; Moyer et al., 2006). Obesity alters several gait characteristics (Browning and Kram 2007; Corbeil et al. 2001; DeVita and Hortobagyi 2003; Hue et al. 2008; Lai et al. 2008) that may influence slip initiation risks. Obese individuals exhibit significantly lower

preferred walking speed and increased RCOF, shorter step length and slower cadence compared to non-obese individuals (DeVita and Hortobagyi 2003; Fabris de Souza et al. 2006; Kejonen et al., 2003; Lai et al. 2008; Spyropoulos et al. 1991). However, the exact mechanism by which obesity alters gait and influences their fall risks remains unclear. Therefore, studies are needed to directly assess the effects of gait adaptations due to the obesity on fall risks.

Sensory function

Sensory function degradation may influence the fall detection risks. Evidence suggests that obesity may influence their foot sensitivity. The high incidence of foot pain (Riddle et al., 2003) and impaired foot structure and function found in individuals who are obese (Hills et al., 2002; Prichasuk 1994) are possible contributors to impaired plantar sensitivity. In particular, plantar heel pain is five times more likely to develop in individuals who are obese than their lean counterparts (Riddle et al. 2003), possibly relating to their significantly higher contact area and greater plantar pressure (Dowling and Steel 2001; Fabris et al. 2006; Hennig et al., 1993; Nass et al., 1999; Riddiford-Harland et al. 2000). A greater pressure and contact area may lead to continuous stimulation over the footpad and resulting in reduced sensitivity of the foot mechanoreceptors and, consequently, impaired balance (Kavounoudias et al. 2001; Meyer et al. 2004). However, no study has directly investigated the effect of obesity on plantar sensitivity and its subsequent effects on their balance control.

Cognition

Cognition alteration may influence the fall perception and action selection risks. The ability to control gait and balance requires complex sensory-motor and cognitive processes (i.e. executive function) (Brown et al., 2002). Executive function is defined as “a product of the coordinated operation of various processes to accomplish a particular goal in a flexible manner” (Funahashi, 2001). Neuropsychological studies suggested that executive function is critically dependent on frontal lobe functions (Luria, 2002; Stuss and Benson, 1984). Emerging evidences also suggested that executive processes are also mediated by prefrontal, posterior cortical and, subcortical regions of the brain (Chafee and Goldman-Rakic, 1998; Mesulam, 1998). The cerebellum (subcortical region) is conventionally believed to serve motor control (Leiner et al., 1989; Thach, 1998). Recently, there is increasing recognition that the cerebellum contributes to cognitive processing (Ito, 1993; Keele and Ivry, 1990; Schmahmann 1991), emotion (Schmahmann and Caplan, 2006), memory (Andersen et al., 1999), speech (Ackermann et al., 2007), affect (Cutting, 1976) and attention (Limperopoulos et al., 2007). The cerebral cortex (posterior cortical region) plays a key role in memory, attention, perceptual awareness, thought, language, and consciousness (Kandel et al., 2000). Obesity is associated with compromised cerebellar development in the children (Miller et al., 2009) and cerebral atrophy in adults (Gustafson et al., 2004), both of which may influence their executive functions (Elliott, 2003). In fact, a study conducted by Mingardot et al., (2010) found that obese (young, middle age and old) individuals allocated more attentional resources to control postural stability than non-obese participants, which may implicate their compromised executive functions (Mingardot et al., 2010). An altered executive function in individuals who are obese may contribute to their increased fall risks during challenging situations (Springer et al., 2006). However, the effect

of obesity on executive function and subsequent influence on their fall risks is not clear. Therefore, studies evaluating the effect of executive functions in individuals who are obese on fall risks are also warranted.

Musculoskeletal function

Muscular weakness may influence the action execution risks during a fall. Obesity is highly associated with impaired musculoskeletal function, particularly in the lower limbs (Anandacoomarasamy et al., 2008). Obese adults are able to generate higher absolute strength and power with the lower extremity compared to non-obese adults. However, strength and power are lower in obese adults when normalized to their body weight (Handrigan et al. 2010; Hulens et al. 2001; Lafortuna et al., 2005; Maffiuletti et al. 2007). Impaired muscle strength along with increased body size may be associated with an increased risk of falls (Close et al. 2005). In particular, the recovery from a fall depends largely on the strength of the lower extremity and proximal muscles (Diener et al., 1988; Takazawa et al. 2003; Tang and Woollacott, 1998; Whipple et al. 1987). The inability to generate the greater joint torques during recovery, either in magnitude or in the rate of development, to control the body's center-of-mass can result in falls (Lockhart et al., 2005).

1.4 Summary

In general, the ability to walk safely and not fall is dependent upon intact gait, sensory function, cognition and musculoskeletal function (Figure 1-1). Obesity affects the functions of these systems and may place these individuals at a higher risk for fall accidents (Anandacoomarasamy et al., 2008). The goal of the proposed study was to investigate the

contribution of gait alterations, plantar sensitivity, executive function, and lower extremity muscle strength on risk of falls among individuals who are obese.

Reference

Ackermann, H., Mathiak, K., Recker, A., 2007. The contribution of the cerebellum to speech production and speech perception: clinical and functional imaging data. *The Cerebellum*, 6: 202-213.

Anandacoomarasamy, A., Caterson, I., Sambrook, P., Fransen, M., March L., 2008. The impact of obesity on the musculoskeletal system. *International Journal of Obesity*, 32: 211-222.

Andersen, N.C., O'Leary, D.S., Paradiso, S., Cizadlo, T., Arndt, S., Watkins, G.L., Boles Ponto, L.L., Hichwa, R.D., 1999. The cerebellum plays a role in conscious episodic memory retrieval. *Human Brain Mapping*, 8: 226-234.

Brown, L.A., Sleik, R.J., Winder, T.R., 2002. Attentional demands for static postural control after stroke. *Archives of Physical and Medical Rehabilitation*, 83: 1732-1735.

Browning, R. C., Kram, R., 2007. Effects of obesity on the biomechanics of walking at different speeds. *Medical Science and Sports Exercise*, 39(9): 1632-1641.

Center of Disease Control, 2014. Overweight and obesity facts.

<http://www.cdc.gov/obesity/data/facts.html>. Last assessed on May 19th, 2014, Blacksburg, VA.

Chafee, M.V., Goldman-Rakic, P.S., 1998. Matching patterns of activity in primate prefrontal area 8a and parietal area 7ip neurons during a spatial working memory task. *Journal of Neurophysiology*, 79: 2919-2940.

Close, J. C., Lord, S.L., Menz, H.B., Sherrington, C., 2005. What is the role of falls? *Best Practice Research Clinical Rheumatology*, 19(6): 913-935.

Colditz, G.A., 1999. Economic costs of obesity and inactivity. *Medical Science and Sports Exercise*, 31: S663-S667.

Corbeil, P., Simoueau, M., Rancourt, M., Tremblay, A., Teasdale, N., 2001. Increased risk for falling associated with obesity: mathematical modeling of postural control. *IEEE Transaction on Neural Systems and Rehabilitation Engineering*, 9: 126-136.

Cutting, J.C., 1976. Chronic mania in childhood: case report of a possible association with a radiological picture of cerebellar disease. *Psychology Medicine*, 6: 635-642.

DeVita, P., Hortobagyi, T., 2003. Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics* 36(9), 1355-1362.

Diener, H.C., Horak, F.B., Nashner, L.M., 1988. Influence of stimulus parameters on human postural responses. *Journal of neurophysiology*, 59(6): 1888-1905.

Dowling, A. M., Steel, J., 2001. What are the effects of gender and obesity on foot structure in children? *Fifth Symposium on Footwear Biomechanics*, Zurich, Switzerland.

Elliott, R., 2003. Executive functions and their disorders. *British Medical Bulletin*, 65(1): 49-59.

Espy, D.D., Yang, F., Bhatt, T., Pai, Y.C., 2010. Independent influence of gait speed and step length on stability and fall risk. *Gait Posture* 32(3), 378-382.

Fabris, S. M., Valezi, A.C., Fabris de Souza, S.A., Faintuch, J., Ceconello, I., Junior, M.P., 2006. Computerized baropodometry in obese patients. *Obesity Surgery*, 16(12): 1574-1578.

Fjeldstad, C., Fjeldstad, A.S., Acree, L.S., Nickel, K.J., Gardner, A.W., 2008. The influence of obesity on falls and quality of life. *Dynamic Medicine*, 7 (4): 27 February.

Flegal, K.M., Carroll, M.D., Ogden, C.L., Curtin, L.R., 2010. Prevalence and trends in obesity among US adults, 1999-2008. *The Journal of American Medical Association*, 303(3): 235-241.

Flegal, K.M., Carroll, M.D., Ogden, C.L., Johnson, C.L., 2002. Prevalence and trends in obesity among US adults, 1999-2000. *The Journal of American Medical Association*, 288(14): 1723-1727.

Flegal, K.M., Carroll, M.D., Kuczmarski, R.J., Johnson, C.L., 1998. Overweight and obesity in the United States: prevalence and trends, 1960-1994. *International journal of Obesity related Metabolism Disorders*, 22(1): 39-47.

Funahashi, S., 2001. Neuronal mechanisms of executive control by the prefrontal cortex. *Neuroscience Research*, 39: 147-165.

Gustafson, D., Lissener, L., Bengtsson, C., Bjorkelund, C., Skoog, I., 2004. A 24-year follow-up of body mass index and cerebral atrophy. *Neurology*, 63(10): 1878-1881.

Handrigan, G., Hue, O., Simoneau, M., Corbeil, P., Marceau, P., Marceau, S., Tremblay A., Teasdale N., 2010. Weight loss and muscular strength affect static balance control. *International Journal of Obesity*, 34(5): 936-942.

Hanson, J.P., Redfern, M.S., Mazumdar, M., 1999. Predicting slips and falls considering required and available friction. *Ergonomics*, 42: 1619-1633.

Hennig, E. M., Milani, T.L., 1993. The tripod support of the foot. An analysis of pressure distribution under static and dynamic loading. *Zurich Orthopedic Ihre Grenzgeb*, 131(3): 279-284.

Hills, A.P., Henning, E.M., Byrne, N.M., Steele, J.R., 2002. The biomechanics of adiposity—structural and functional limitations of obesity and implications for movement. *Obesity review*, 3: 35-43.

Hulens, M., Vansant, G., Lysens, R., Claessens, A.L., Muls, E., Brumagne, S., 2001. Study of differences in peripheral muscle strength of lean versus obese women: an allometric approach. *International Journal of Obesity Related Metabolic Disorders*, 25(5): 676-681.

Horak, F.B., 1996. Adaptation of automatic postural responses. In: Bloedel J., Ebner TJ, Wise SP, eds. *Acquisition of motor behavior in vertebrates*, Cambridge, Mass: The MIT Press, 57-85.

Hue, O., Berrigan, F., Simoneau, M., Marcotte, J., Marceau, P., Marceau, S., Tremblay, A., Teasdale, N., 2008. Muscle force and force control after weight loss in obese and morbidly obese men. *Obese Surgery*, 18: 1112-1118.

Ito, M., 1993. Movement and thought: identical control mechanisms by the cerebellum. *Trends Neurosciences*, 16: 448-450.

Kandel, E.R., Schwartz, J.H., Jessell, T.M., 2000. *Principles of Neural Science* Fourth Edition. USA: McGraw-Hill.

Kavounoudias, A., Roll, R., Roll, J.P., 2001. Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation. *Journal of Physiology*, 532(Pt 3): 869-878.

Keele, S.W., Ivry R., 1990. Does the cerebellar provide output nucleus during cognitive processing. *Science*, 265: 949-951.

Kejonen, P., Kauranen, K., Vanharanta, H., 2003. The relationship between anthropometric factors and body-balancing movements in postural balance. *Archives of physics and medical rehabilitations* 84, 17-22.

Lafortuna, C.L., Maffiuletti, N.A., Agosti, F., Sartorio, A., 2005. Gender variations of body composition, muscle strength and power output in morbid obesity. *International Journal of Obesity*, 29(7): 833-841.

Lai, P.P., Leung, A.K., Li, A.N., Zhang, M., 2008. Three-dimensional gait analysis of obese adults. *Clinical Biomechanics*, 23(Supplment 1): S2–S6.

Leiner, H.C., Leiner, P.L., Dow, R.S., 1989. Reappearing the cerebellum: what does the hindbrain contribute to the forebrain? *Behavioral Neruoscience*, 103: 998-1008.

Limperopoulos, C., Bassan, H., Gauvreau, K., Roberson, R.L. Jr., Sullivan, N.R., Benson, C.B., Avery, L., Stewart, J., Soul, J.S., Ringer, S.A., Volpe, J.J., duPlessis, A.J., 2007. Does cerebellar injury in premature infants contribute to the high prevalence of long-term cognitive, learning, and behavioral disability in survivors? *Pediatrics*, 120: 584-593.

Lockhart, T.E., Woldstad, J.C., Smith, J.L., 2003. Effects of age-related gait changes on the biomechanics of slips and falls. *Ergonomics*, 46(12): 1136-1160.

Lockhart, T.E., Smith, J.L., Woldstad, J.C., 2005. Effects of aging on the biomechanics of slips and falls. *Human factors*, 47(4): 708-729.

Luria, A.R., 2002. Frontal lobe syndromes. In: Pinken, P.J., Bruyn, G.W. (eds) *Handbook of Clinical Neurology*, 2. Amsterdam: North Holland, 725-757.

Maffiuletti, N.A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., Lafortuna, C.L., Sartorio, A., 2007. Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *European Journal of Applied Physiology*, 101(1): 51-59.

Matter, K.C., Sinclair, S.A., Hostetler, S.G., Xiang, H., 2007. A comparison of the characteristics of injuries between obese and non-obese inpatients. *Obesity (Silver Spring)*, 15(10): 2384-2390.

Mesulam, M.M., 1998. From sensation to cognition. *Brain*, 121: 1013-1052.

Meyer, P. F., Oddsson, L.I., De Luca, C.J., 2004. The role of plantar cutaneous sensation in unperturbed stance. *Experimental Brain Research*, 156(4): 505-512.

Mingardot, J., Olivier, I., Promayon, E., Nougier, V., 2010. Obesity impact on the attentional cost for controlling posture. *PLoS One*, 5(12): e14387.

Miller, J.L., Couch, J., Schwenk, K., Long, M., Towler, S., Theriaque, D.W., He, G., Liu, Y., Driscoll, D.J., Leonard, C.M., 2009. Early childhood obesity is associated with compromised cerebellar development. *Development of Neuropsychology*, 34(3): 272-283.

Moyer, B.E., Chambers, A.J., Redfern, M.S., Cham, R., 2007. Gait parameters as predictors of slip severity in younger and older adults. *Ergonomics*, 49(4): 329-343.

Nass, D., Hennig, E., van Treenk, R., 1999. The thickness of the heel pad loaded by body weight in obese and normal weight adults *Proceedings of the Fourth Symposium on Footwear Biomechanics*, Canada: University of Calgary, In: Hennig EM, Stephanyshin DJ (eds). Obsbye, T., Dement, J.M., Krause, K.M., 2007. Obesity and workers' compensation. *Archived International Medicine*, 167: 766-773.

Ostbye, T., Dement, J.M., Krause, K.M., 2007. Obesity and workers' compensation. *Archived International Medicine*, 167: 766-773.

Riddiford-Harland, D.L., Steele, J.R., Storlein, L.H., 2000. Does obesity influence foot structure in prepubescent children? *International Journal of Obesity*, 24: 541-544.

Riddle, D. Pulisic, L.M., Pidcoe, P., Johnson, R.E., 2003. Risk factors for plantar fasciitis: a matched case-control study. *Journal of Bone Joint Surgery, Am* 85-A (5): 872-877.

Schmahmann, J.D., Caplan, D., 2006. Cognition, emotion and the cerebellum. *Brain*, 129: 288-292.

Schmahmann, J.D., 1991. An emerging concept: the cerebellar contribution to higher function. *Archived Neurology*, 48: 1178-1187.

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E.S., Hausdorff, J.M., 2006. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Movement Disorder*, 21: 950-957.

Spyropoulos, P., Pisciotta, J.C., Pavlou, K.N., Cairns, M.A., Simon, S.R., 1991. Biomechanical gait analysis in obese men. *Archives of physics and medical rehabilitations*, 72: 1065-1070.

Sturmer, T., Gunther K.P., Brenner H., 2000. Obesity, overweight and patterns of osteoarthritis: the Ulm Osteoarthritis Study. *Journal of Clinical Epidemiology*, 53: 307-313.

Stuss, D.T., Benson, D.F., 1984. Neuropsychological studies of the frontal lobes. *Psychology Bulletin*, 95: 3-28.

Tang, P., Woollacott, M.H., Chong, R.K.Y., 1998. Control of reactive balance adjustments in perturbed walking: roles of proximal and distal postural muscle activity. *Experimental Brain Research*, 119(2): 141-152.

Takazawa, K., Arisawa, K., Honda, S., Shibata Y., Saito H., 2003. Lower-extremity muscle forces measured by a hand-held dynamometer and the risk of falls among day-care users in Japan: using multinomial logistic regression analysis. *Disability Rehabilitation*, 25(8): 399-404.

Thach, W.T., 1998. What is the role of the cerebellum in motor learning and cognition? *Trends Cognitive Science*, 2: 331-337.

Whipple, R. H., Wolfson L.I., Amerman, P.M., 1987. The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. *Journal of American Geriatric Society*, 35(1): 13-20.

Wickens, C.D., Hollands, J.G., 2000. *Engineering psychology and human performance* 3rd Edition. Upper Saddle River, NJ: Prentice-Hall.

World Health Organization, 2013. Obesity and overweight.

<http://www.who.int/mediacentre/factsheets/fs311/en/> last assessed on April 20th, 2013,

Blacksburg, VA.

Wu, X., Lockhart, T.E., Yeoh, H.T., 2012. Effects of obesity on slip-induced fall risks among young obese males. *Journal of biomechanics*, 45(6): 1042-1047.

Chapter 2 Impaired Plantar Sensitivity among the Obese is Associated with Increased Postural Sway

Abstract

Impaired foot plantar sensitivity has been hypothesized among individuals who are obese, and may contribute to their impaired balance during quiet standing. The objective of this study was to investigate the effects of obesity on plantar sensitivity, and explore the relationship between plantar sensitivity and balance during quiet standing. Thirty-nine young adults from the university population participated in the study including 19 obese and 20 non-obese adults. Plantar sensitivity was measured as the force threshold at which an increasing force applied to the plantar surface of the foot was first perceived, and the force threshold at which a decreasing force was last perceived. Measurements were obtained while standing, and at two locations on the plantar surface of the dominant foot. Postural sway during quiet standing was then measured under three different sensory conditions. Results indicated less sensitive plantar sensitivity and increased postural sway among the obese, and statistically significant correlations between plantar sensitivity and postural sway that were characterized as weak to moderate in strength. As such, impaired plantar sensitivity among individuals who are obese may be a mechanism by which obesity degrades standing balance among these individuals.

Keywords: Obesity, Plantar sensitivity, Postural sway, Postural balance

2.1 Introduction

An estimated 500 million people worldwide were obese in 2008, and the prevalence of obesity has nearly doubled since 1980 (WHO, 2011). One of the concerns with the high prevalence of obesity is its association with an increased risk of falls. Each year, obese adults fall almost twice as frequently (27%) as their non-obese counterparts (15%) (Fjeldstad et al. 2008). This is problematic because falls can be injurious. The biomechanical and/or physiological mechanisms leading to the higher rate of falls among individuals who are obese are unclear. Understanding these mechanisms could lead to more effective fall prevention programs.

One mechanism by which obesity could contribute to falls is by degrading balance due to impaired plantar sensitivity on the bottom of the feet. Human standing balance control relies on feedback from the proprioceptive system (Lee, 1989; Zhang & Li, 2013). This system includes cutaneous mechanoreceptors which detect pressure and deformation in the skin (Winter et al., 1990). Studies have demonstrated that impairments in plantar sensitivity influence balance control among older adults and individuals with chronic ankle instability (Bretan et al., 2010; Magnusson et al., 1990 A & B ; Menz et al., 2005; Powell et al., 2014). Obesity increases postural sway during quiet standing (Teasdale et al., 2013), and may do so, at least in part, due to impaired plantar sensitivity. Higher plantar pressures have been reported among individuals who are obese (Hills et al., 2001), but no studies to our knowledge have investigated the effect of obesity on plantar sensitivity, or the association between plantar sensitivity and balance as a mechanism by which individuals who are obese exhibit impaired balance.

The objective of this study was to investigate the effect of obesity on plantar sensitivity, and explore the relationship between plantar sensitivity and postural sway. Our first hypothesis was that obesity would adversely affect plantar sensitivity. Our second hypothesis was that impaired plantar sensitivity would be associated with increased postural sway. The results from this study will provide insight to the mechanisms by which obesity impairs balance, and potentially guide future efforts aimed at developing interventions to mitigate the deleterious effects of obesity on balance.

2.2 Materials and Methods

Thirty-nine young (age=21.3±2.6 years) adults recruited from the university population participated in the study. Participants included 19 obese (body mass index or BMI = 33.0±2.9kg/m²; 14 females and 5 males) and 20 non-obese (BMI = 22.2±2.2 kg/m²; 14 females and 6 males) adults. Body fat percentage was also measured using skinfold caliper measurements at the front of the upper arm, back of the upper arm, below the scapula, and on the abdomen (1cm to the right of the navel). Obese participants were required to have a body fat percentage above 35% for women and above 25% for men from these caliper measurements (WHO, 1995), as well as a BMI above 30 kg/m². Participants' body fat percentage was summarized in Table 2-1. No difference in height between obese and non-obese groups of participants. All participants were free from any self-reported foot pain or known neurological conditions that might affect their performance in this test.

Table 2-1 Summary of participants' estimated body fat percentage, presented as means (standard deviation), range for obese and gender groups

	Obese		Non-obese	
	Women	Men	Women	Men
Mean (SD) (%)	38.9(2.7)	27.4(1.2)	29.1(4.1)	19.3(9.0)
Range (%)	[34.8, 43.2]	[25.6, 28.8]	[22, 35]	[5.5, 25]

Participants completed one experimental session, during which multiple measurements of plantar sensitivity were obtained while standing. Plantar sensitivity was operationalized as the force threshold at which an increasing force applied to the plantar surface was first perceived, and the force threshold at which a decreasing force was last perceived. Measurements were obtained immediately upon standing, and at two locations on the plantar surface of the dominant foot including the calcaneus and the head of the third metatarsal. Postural sway was then evaluated under three different conditions. Participants wore a T-shirt, tight-fitting pants, no shoes, and no socks during testing. Room temperature was controlled at 74°F.

The setup and methodology was based upon a recent study investigating the effects of added weight on plantar sensitivity while upright standing (Handrigan et al., 2012). Plantar sensitivity was assessed using a custom-designed platform (Figure 2-1) and a digital force gauge (Exttech, Model 475040, Nashua, NH, USA). The aluminum platform (40 × 81 cm) was covered in vinyl floor tile and included a 1.5mm diameter hole so that a small stainless steel probe tip (diameter = 1mm) attached to the force gauge could pass through and come into contact with participants' foot sole while weight bearing. The position of the probe tip was controlled from beneath the platform via a manual lab jack (LJ750, Thorlabs Inc, Newton, New Jersey, USA) (Figure 2-2).

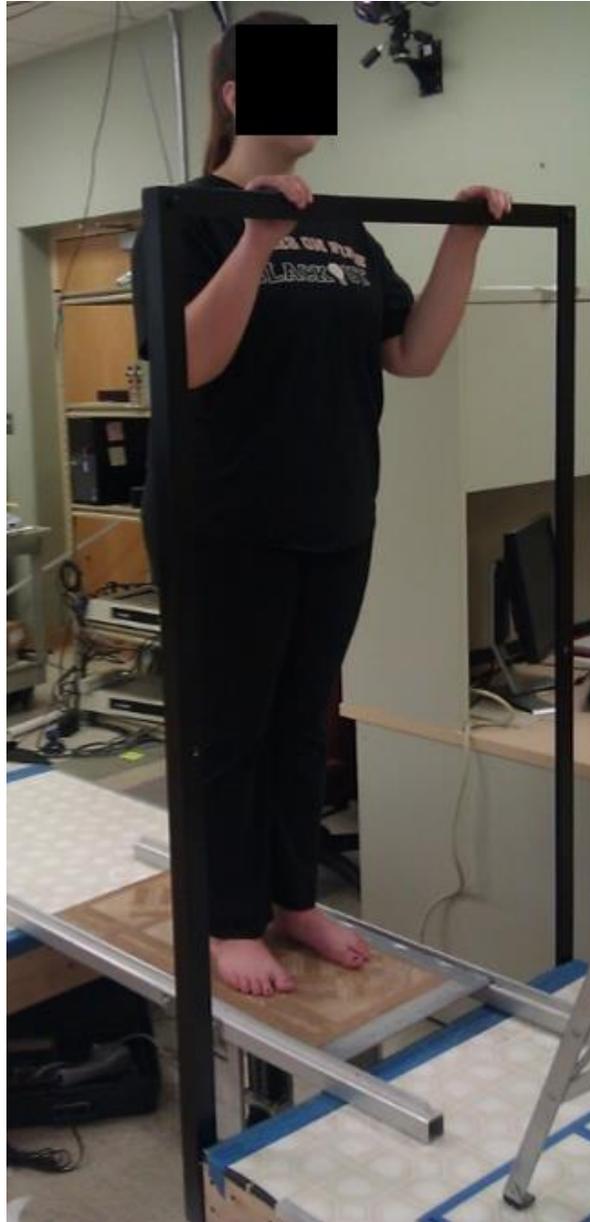


Figure 2-1 Custom-designed platform to assess plantar sensitivity while standing

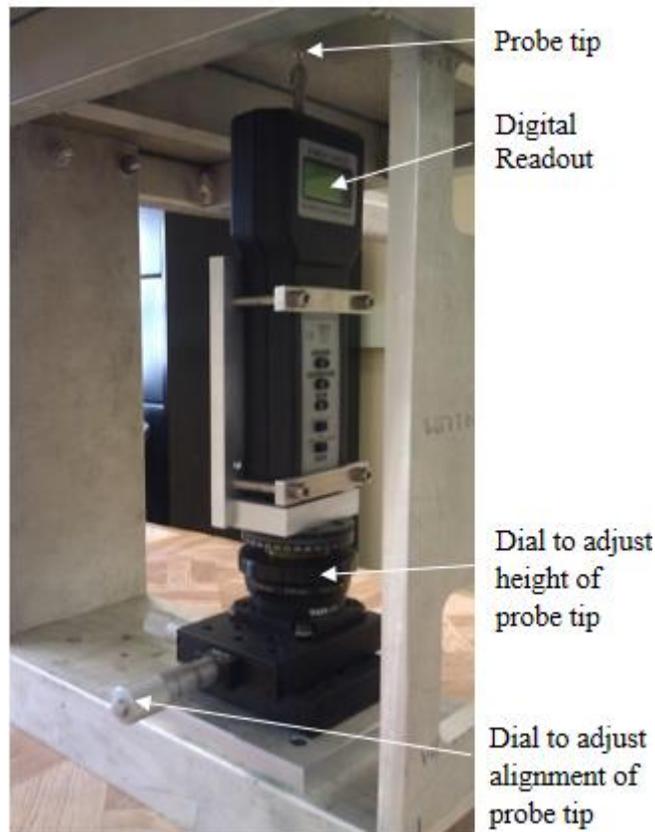


Figure 2-2 Digital force gauge setup was mounted on lab jack under the platform. The investigators adjusted the vertical position of the probe by manipulating the lab jack, and read off the force threshold from the digital readout when indicated by the participants.

Two practice trials were performed on each participant at the beginning of the experiment. Practice trials were performed at a random site on the plantar surface of the foot not including the two testing sites. Participants were then asked to sit for 10 minutes. To start testing, participants were asked to stand on the platform while the investigator positioned their foot so that the testing site was aligned with the hole in the platform. Participants were instructed to stand as still as possible, look straight forward, hold onto the bars in front of them to help standstill, and give verbal indication when they were able to feel the force by saying “Now”. At the start of each trial, the probe tip was initially below the surface of the platform and not in contact with the plantar surface of the foot. After a random delay of up to 10 seconds, the investigator began manually rotating a dial on the lab

jack (Figure 2-2) in increments of approximately 60 degrees every half second until given a verbal indication by the participant. Once the probe tip translated upward far enough to contact the plantar surface of the foot, this rotating pattern increased the force applied to the foot in a step-wise manner at a rate of ~5 grams every half second. After the participant detected the force, this force threshold was recorded, and the investigator continued to raise the probe tip until the force reached 180 grams (a value well above all participants' force threshold). The lab jack was then used to translate the force probe tip downward, resulting in the force applied to the foot decreasing in a step-wise manner at a rate of ~5 grams every half second. Participants were instructed to give verbal indication when they were no longer able to feel the force by saying "Now". A total of four trials were performed at each site, with each trial involving the force increasing and decreasing one time. The order of the two sites was counterbalanced within each group. The experimenter also randomly picked one of the four increasing trials to check whether the participant was giving false verbal indication on their foot sensitivity, or experiencing phantom sensation, by delaying the initiation of the trial for 30 seconds after indicating the start of the trial. None of the participants gave indication before the start of the trial during the experiment.

Postural sway was then evaluated while participants attempted to stand as still as possible with bare feet, arms at sides and feet pointed forward and 7.5cm apart (to mitigate the effect of stance on postural sway, distance between feet was kept constant (Kim et al., 2014)). The trials were collected under three different sensory conditions: eyes-open (baseline), eyes-closed (impaired visual feedback), and eyes-closed with the head tilted backward (impaired visual, and vestibular feedback). Tilting the head backward is thought to render balance-related vestibular information unreliable by placing the otolith organs

outside their normal working range. (Brandt et al., 1998; Mientjes & Frank 1999; Vuillerme et al., 2008). These conditions were imposed because impairing the visual, and vestibular systems makes the balance control system more dependent upon the somatosensory system (e.g. plantar sensitivity), and may strengthen the relationship between plantar sensitivity and balance. Participants were required to tilt their head backwards at least 30°, as measured by investigator observation. Three trials of 75 s were collected under each condition, and two minutes of rest were allowed in between consecutive trials. The order of the trials was randomized within each group.

During standing trials, ground reaction forces were sampled at 1000 Hz using a force platform (Bertec Corporation, Columbus, OH, USA), and low-pass filtered at 7 Hz using a 4th order Butterworth zero-lag filter (Oliveira et al., 2009). Dependent variables during standing included center of pressure (COP) mean velocity, and COP root mean square (RMS) distance from the mean position in the radial direction. Mean velocity was defined as the total COP distance traveled divided by collection time. The RMS distance was defined as the standard deviation about the mean COP position in radial direction (Lin et al., 2008). For each standing trial, the initial and final 5 seconds of the data was removed to avoid initial transients and termination anticipation effects, respectively (Lin et al., 2008).

A four-way mixed-model analysis of variance was performed on force threshold measurements with independent variables including group (obese or non-obese), location (head of the third metatarsal or calcaneus), force direction (increasing or decreasing), and trial. A two-way mixed-model ANOVA was performed on postural sway measures with

independent variables including group (obese or non-obese) and condition (baseline, impaired vision, or impaired visual, and vestibular feedback) (Kunter et al., 2001). Tukey's Honestly Significant Difference procedure was used to perform pair-wise comparisons of interest in the event of significant interactions. A log transform on force threshold measurements and postural sway measures was performed prior to the analyses to achieve a normal distribution of residuals.

Bivariate correlation analysis was performed between plantar sensitivity and postural sway measures, and the strength of the correlation was quantified using the Pearson product-moment correlation coefficient. Mean of the four plantar sensitivity trials under each testing location and force direction was correlated with the mean of the three postural sway trials under each condition. Two data points were identified as influential points as they were associated with larger Cook's distance values (Montgomery et al., 2008), and thus were excluded from the bivariate analyses to avoid a disproportionate influence on the correlation. The strength of correlations was characterized using the correlation coefficient (r) as strong (0.6-0.8), moderate (0.4-0.6), and weak (0.2-0.4) (Kunter et al., 2001). JMP 10 (SAS Institute Inc., Cary, NC, USA) was used to carry out the statistical analyses, and statistical significance was concluded if $p \leq 0.05$.

2.3 Results

Force threshold measurements exhibited a mean value of 29.8 grams and a range of 2 to 156 grams across all groups (Figure 2-3). It exhibited a group by location by force direction interaction ($p = 0.040$; Figure 2-4). Under the third metatarsal, the obese group exhibited a 56% higher force threshold when force was increasing ($p < 0.001$), and a 22%

higher force threshold when force was decreasing ($p = 0.008$). Under the calcaneus, the obese group exhibited a 30% higher force threshold when force was increasing ($p = 0.019$), and a 22% higher force threshold when force was decreasing ($p < 0.001$). The force threshold across both groups was 79% higher at the calcaneus compared to the third metatarsal when force was increasing ($p < 0.001$), but not significantly different between these locations when force was decreasing. Lastly, the force threshold across both groups was 183% higher when force was increasing compared to decreasing under the calcaneus ($p < 0.001$), and 91% higher when force was increasing under the third metatarsal ($p < 0.001$).

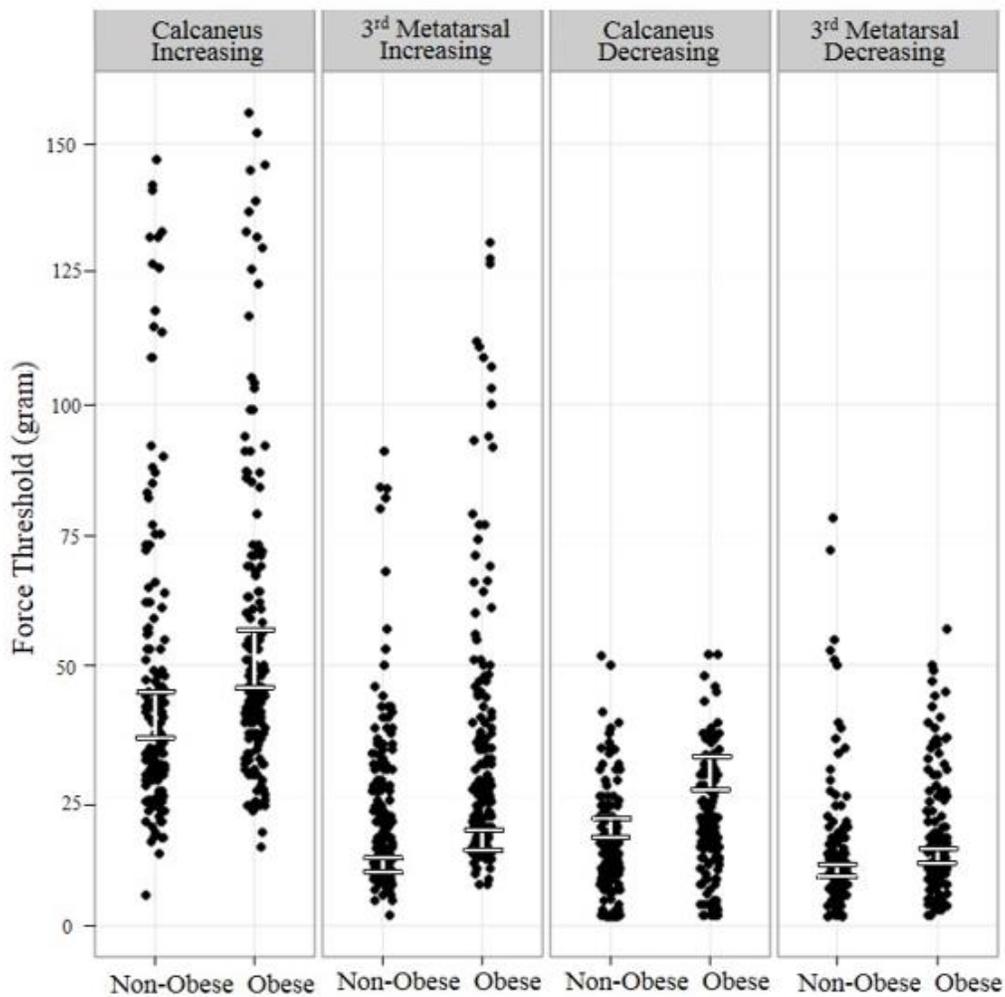


Figure 2-3 Force threshold measurements separated by group, location, and force direction. Dots indicate individual measurements, and brackets indicate 95% confidence intervals of the mean

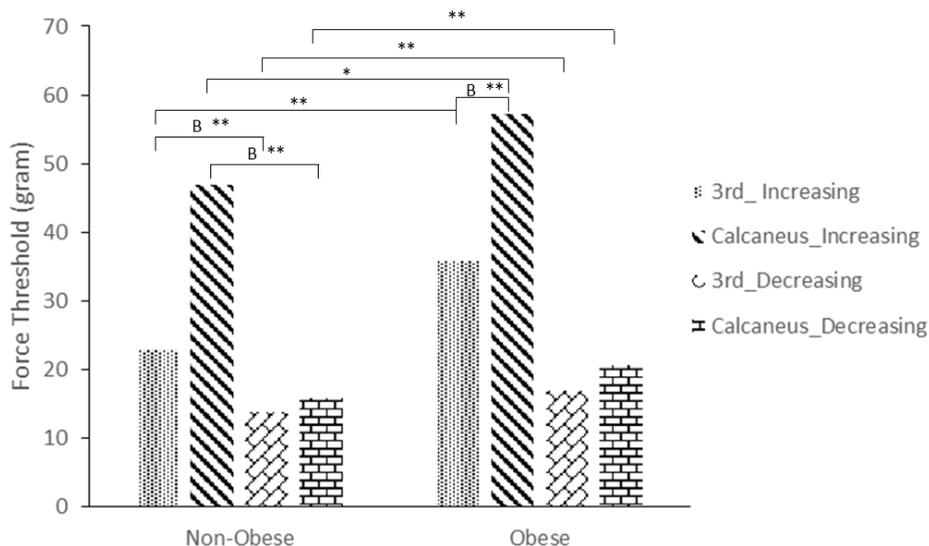


Figure 2-4 Group by location by force direction interaction plot illustrating differences between groups and conditions * indicates $p \leq 0.05$, ** indicates $p \leq 0.01$. B indicates statistical significance when combining across both groups.

Both mean velocity and RMS distance exhibited no group by condition interaction ($p = 0.344$ for mean velocity and $p = 0.179$ for RMS distance), but did exhibit main effects of group ($p = 0.008$ for mean velocity and $p = 0.016$ for RMS distance) and condition ($p < 0.001$ for mean velocity and RMS distance) (Table 2-2 and 2-3). The obese group exhibited 5% higher mean velocity and 7% higher RMS distance compared to the non-obese group.

Table 2-2 Median(IQR) of postural sway measures by condition

	Baseline	Impaired vision	Impaired vision and vestibular
Mean Velocity (cm/s)	1.0(0.4)	0.9(0.4)	1.2(0.8)
RMS distance (cm)	1.3(0.5)	1.0(0.4)	1.5(0.9)

Table 2-3 Median(IQR) of postural sway measures by group		
	Non-obese	Obese
Mean Velocity (cm/s)	1.0(0.5)	1.1(0.5)
RMS distance (cm)	1.2(0.6)	1.4(0.7)

Bivariate analyses revealed positive correlations of weak to moderate strength between two plantar sensitivity measurements (calcaneus/decreasing force, and 3rd metatarsal/increasing force), and both postural sway measurements under the three different conditions (Figure 2-5). No other correlations were significant.

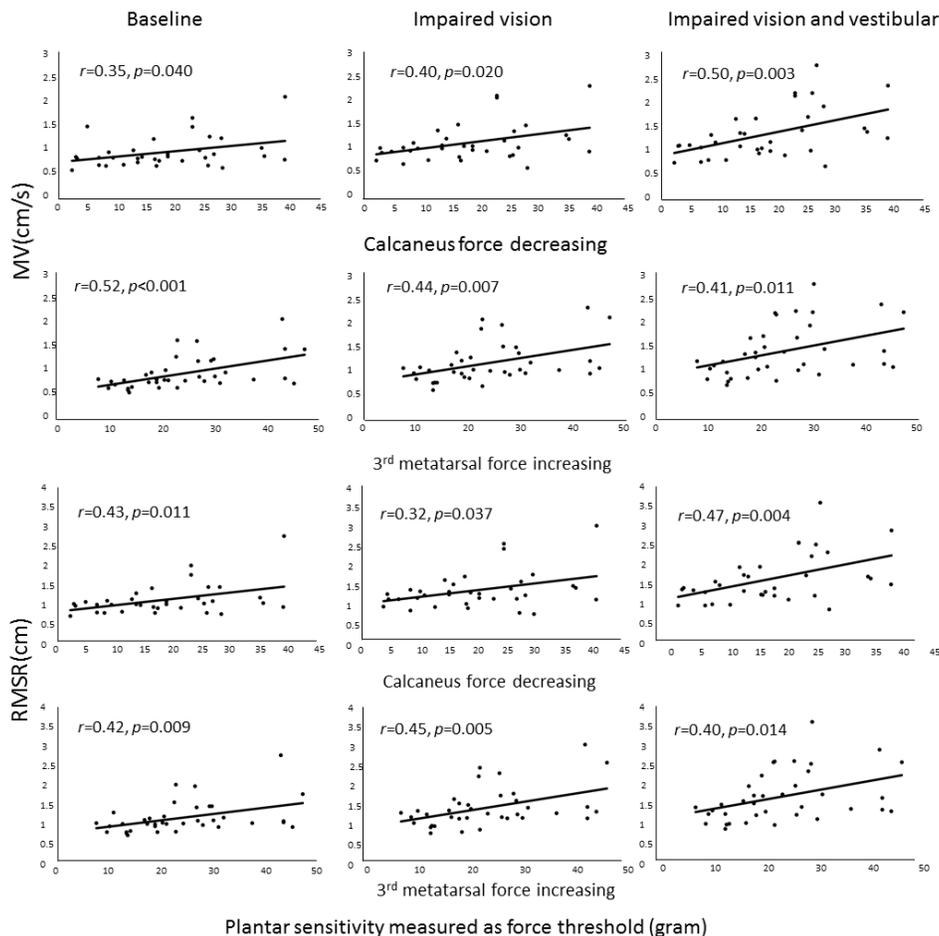


Figure 2-5 Scatter plots of correlation between plantar sensitivity (calcaneus/immediately upon standing/decreasing force and 3rd metatarsal/immediately upon standing/increasing force) and postural sway measures (mean velocity and RMS distance) with r and p values. Each dot represented each participant's mean across four plantar sensitivity trials and three postural sway trials.

2.4 Discussion

The objective of this study was to investigate the effect of obesity on plantar sensitivity, and explore the relationship between plantar sensitivity and postural sway. We hypothesized obesity would adversely affect plantar sensitivity. The threshold to detect force onset and offset were both higher among obese participants at both locations tested. These results indicated obese participants were unable to sense plantar forces as small as non-obese participants while standing. As such, this hypothesis was accepted. We also hypothesized that impaired plantar sensitivity would be associated with increased postural sway. This hypothesis was accepted because weak to moderate correlations were found between the postural sway and plantar sensitivity measures.

The mean force thresholds, and the effects of obesity on force thresholds, measured here are comparable to a prior study that investigated the effects of adding body mass on plantar sensitivity (Handrigan et al., 2012). Handrigan et al. (2012) measured the minimum force threshold while standing, and compared these measurements before and after adding 23 kg of body mass with a weighted vest. This added body mass corresponded to an increase in BMI from 24.7 to 31.9 kg/m². The mean force threshold reported by Handrigan et al. (2012) was 20.0 g before adding weight, which was comparable to the 25.6 g threshold measured among non-obese participants in the current study across all conditions. Handrigan et al. (2012) also reported a 30% increase in force threshold after adding 23 kg of body mass, which was comparable to the 29.3% higher threshold among the obese group in the current study across all conditions. Together, these studies provide evidence for the added body mass associated with obesity eliciting impaired plantar sensitivity.

Two characteristics of mechanoreceptors may help to explain the impaired plantar sensitivity among obese participants found here. First, the relationship between mechanical stimulus intensity and internal mechanoreceptor voltage potential is nonlinear, and suggests less sensitivity at higher intensities (Guyton & Hall, 2006). At lower stimulus intensities, only slight changes in stimulus intensity are needed to markedly increase the mechanoreceptor potential. At higher stimulus intensities, however, an equivalent increase in stimulus intensity only results in a slight increase in mechanoreceptor potential. The higher plantar pressure associated with obesity (Hills et al., 2001) may result in the operating range of the plantar mechanoreceptor to be closer to the range over which changes in stimulus intensity only result in slight changes in mechanoreceptor potential. Second, the Weber-Fechner Principle states that the amount of change in mechanical stimulus intensity necessary for detection is proportional to the stimulus intensity (Boff et al., 1986; Guyton & Hall, 2006; Lanzara, 1994). As such, the higher plantar pressure associated with obesity would require a larger change in plantar mechanical stimulus to be detected, and result in reduced sensitivity on the plantar surface of the foot.

Force thresholds were lower when force was decreasing than increasing. We have two possible explanations for these results. First, Meissner's corpuscles and Pacinian corpuscles are two rapidly adapting mechanoreceptors responsible for detecting the onset and offset of a mechanical stimulus (Fleming & Luo, 2013). Meissner's corpuscles are thought to be more amenable to detecting light touch due to their relatively superficial distribution within the skin, and Pacinian corpuscles are thought to be more amenable to detecting deep pressure due to their deeper distribution within the skin (Fleming & Luo, 2013). Given these differences, detecting the onset of an initially zero force that increased

may be mostly dependent upon Meissner's corpuscles, whereas detecting the offset of an initially high force (that stimulated deeper Pacinian corpuscles) and decreased may have involved both Meissner's and Pacinian corpuscles. Involvement of Pacinian corpuscles may have offered more sensitivity while force was decreasing because Pacinian corpuscles have a lower response threshold than Meissner's corpuscles (Kenndy & Inglis, 2002). Our second possible explanation is related to the mechanical properties of the skin (Pubols, 1982). Skin is viscoelastic, which means its mechanical response to force depends upon time. Measurements as force increased were made shortly (less than 18 seconds, on average) after the force was applied, and measurements as force decreased were made after the force was applied for at least 30 seconds. Therefore, the viscoelastic stress relaxation that would have occurred during testing likely resulted in differences in the mechanical state (i.e. tissue strain) at the testing site that may have contributed to differences in force thresholds.

Our results indicated that plantar sensitivity was weakly to moderately correlated with postural sway. Mechanoreceptors are preferentially distributed in the anterior, lateral border and heel regions of the plantar surface (Kenndy & Inglis, 2002), which could correspond to the critical regions of the foot that support the majority weight of the body under the weight-bearing condition (Perry et al., 2002). Similarly, mechanoreceptors under the anterior and posterior regions of the feet provide feedback that regulates the body to tilt posteriorly and anteriorly (Kavounoudias et al., 2001). The central nervous system may be able to extract a spatial distribution cue according to the plantar pressure which could be transformed into a body position cue indicating the direction and the amplitude of the whole-body inclination (Kavounoudias et al., 2001; Meyer et al., 2004). Therefore, deficits

in plantar sensitivity could have a direct influence on balance control (Bretan et al., 2010; Menz et al., 2005; Powell et al., 2014). However, the mechanism of why only calcaneus/decreasing force and 3rd metatarsal/increasing force were correlated with postural sway measurements under the three different conditions is not clear.

The postural sway condition with eyes closed and head tilted backward was included based upon the expectation that any impairment in plantar sensitivity among obese participants would have a greater effect on postural sway when input from the visual, and vestibular systems were eliminated or altered. Based upon the lack of a group by condition interaction in sway measures, this expectation was not met. This may have been due to not tilting participants head backward sufficiently far, or input from other components of the proprioceptive system (e.g. receptors in skin/tissues of ankles) offsetting the altered input from the plantar surface among the obese participants. Nevertheless, postural sway exhibited weak to moderate correlation with plantar sensitivity despite not adequately impairing vestibular input during sway measurements.

Several limitations are to be noted for this study. First, changes in force were stepwise and in increments of ~5 gram per half second, rather than at a steady rate. This may have limited our force threshold resolution 5 grams, but this amount of force was ostensibly sufficiently small to identify the effects of interest. Second, the results may be dependent upon the nature and duration of activities performed before testing (someone may have been standing for hours while another may have been laying down). However, these data were not obtained. Third, plantar sensitivity was only obtained from the dominant foot, and it is unclear if any left/right asymmetry in plantar sensitivity is common.

Fourth, the amplitude of head tilting was not controlled in the current study, and may have contributed to some inter-subject variability in the vestibular feedback during this condition.

In conclusion, obesity impaired plantar sensitivity among a cohort of young adults. This impairment was associated with increased postural sway during quiet standing, and may be a contributing factor to the increased fall risks among individuals who are obese.

Reference

- Billot, M., Handrigan, G.A., Simoneau, M., Corbeil, P., Teasdale, N., 2013. Short term alteration of balance control after reduction of plantar mechanoreceptor sensation through cooling. *Neuroscience Letters*, 535: 40-44.
- Bretan, O., Pinheiro, R.M., Corrente, J.E., 2010. Balance and plantar cutaneous sensitivity functional assessment in community dwelling elderly. *Brazil Journal of Otorhinolaryngology*, 76(2): 219-224.
- Boff, K.R., Kaufman, L., Thomas, J.P., 1986. *Handbook of Perception and Human Performance*. John Wiley & Sons, Inc.
- Brandt, T., Bartenstein, P., Janek, A., Dieterich, M., 1998. Reciprocal inhibitory visual-vestibular interaction—Visual motion simulation deactivates the parieto-insular vestibular cortex. *Brain*, 121: 1749-1758.
- Fjeldstad, C., Fjeldstad, A.S., Acree, L.S., Nickel, K.J., Gardner, A.W., 2008. The influence of obesity on falls and quality of life. *Dynamic Medicine*, 7 (4): 27 February.
- Fleming, M.S., Luo, W., 2013. The anatomy, function, and development of mammalian A β low-threshold mechanoreceptors. *Front Biology*, 8(4): 408-420.

Guyton, A.C., Hall, J.E., 2006. Textbook of medical physiology, 11th edn. Elsevier Saunders.

Handrigan, G.A., Simoneau, M., Teasdale, N., Corbeil, P., 2012. The effects of added mass on plantar sole sensitivity in upright standing. *Journal of Biomechanics* 45(Supplement 1): S233.

Hills, A.P., Henning, E.M., McDonald, M., Bar-Or, O., 2001. Plantar pressure differences between obese and non-obese adults: a biomechanical analysis. *International Journal of Obesity*, 25: 1674-1679.

Hue, O., Simoneau, M., Marcotte, J., Berrigan, F., Dore, J., Marceau, P., Marceau, S., Tremblay, A., Teasdale, N., 2006. Body weight is a strong predictor of postural stability. *Gait Posture*, 26: 32-38.

Kavounoudias, A., Roll, R. J., 2001. Foot sole and ankle muscle inputs contribute jointly to human erect posture regulation. *Journal of Physiology*, 532: 869-878.

Kennedy, P.M., Inglis, J.T., 2002. Distribution and behavior of glabrous cutaneous receptors in the human foot sole. *Journal of Physiology*, 538(Pt 3): 995-1002.

Kim, J., Kwon, Y., Jeon, H., Bang, M., Jun, J., Eom, G., Lim, D., 2014. Feet distance and static postural balance: implication on the role of natural stance. *Bio-Medical Materials and Engineering*, 24: 2681-2688.

Kunter, M.H., Nachtsheim, C.J., Neter, J., Li, W., 2004. Applied linear statistical Models. Irwin: McGraw-Hill, Columbus.

Lanzara, R.G., 1994. Weber's law modeled by the mathematical description of a beam balance. *Mathematical Biosciences*, 122: 89-94.

Lee, W.A., 1989. A Control Systems Framework for Understanding Normal and Abnormal Posture. *The American Journal of Occupational Therapy*, 43: 291-301.

Lin, D., Seol, H., Nussbaum, M.A., Madigan, M.L., 2008. Reliability of COP-based postural sway measures and age-related differences. *Gait & Posture*, 28(2): 337-342.

Magnusson, M., Enbom, H., Johansson, R., Pyykko, I., 1990A. The Importance of Somatosensory Information from the Feet - Postural Control in Man. *Disorders of Posture & Gait*, 190-193.

Magnusson, M., Enbom, H., Johansson, R., Pyykko, I., 1990B. Significance of Pressor Input from the Human Feet in Anterior-Posterior Postural Control. *Acta Otolaryngol (Stockh)*, 110: 182-188.

Matter, K.C., Sinclair, S.A., Hostetler, S.G., Xiang, H., 2007. A comparison of the characteristics of injuries between obese and non-obese inpatients. *Obesity (Silver Spring)*, 15(10): 2384-2390.

Menz, H.B., Morris, M.E., Lord, S.R., 2005. Foot and ankle characteristics associated with impaired balance and functional ability in older people. *Journal of Gerontology*, 60(12): 1546-1552.

Meyer, P.F., Oddson, L.I., De Luca, C.J., 2004. The role of plantar cutaneous sensation in unperturbed stance. *Experimental Brain Research*, 156: 505-512.

Mientjes, M.I.V., Frank, J.S., 1999. Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. *Clinical Biomechanics*, 14: 710-716.

Montgomery, D.C., Peck, E.A., Vining, G.G., 2012. *Introduction to Linear Regression Analysis*, 5th Edition, Wiley, New York.

Oliveira, L.F., Vieira, T.M., Macedo, A.R., Simpson, D.M., Nadal, J., 2009. Postural sway changes during pregnancy: a descriptive study using stabilometry. *European Journal of Obstetrics and Gynecology and Reproductive Biology*, 147(1): 25-28.

Perry, S.D., Mcllroy, W.E., Maki, B.E., 2002. The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. *Brain Research*, 877(2): 401-406.

Powell, M.R., Powden, C.J., Houston, M.N., Hoch, M.C., 2014. Plantar cutaneous sensitivity and balance in individuals with and without chronic ankle instability. *Clinical Journal of Sports Medicine*, Epub Ahead.

Pubols, B.H., 1982. Factors affecting cutaneous mechanoreceptor response. I. constant-force versus constant-displacement stimulation. *Journal of Neurophysiology*, 47(3): 515-529.

Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Dore, J., Marceau, P., Marceau, S., Tremblay, A., 2007. Reducing weight increases postural stability in obese and morbid obese men. *International Journal of Obesity*, 31: 153-160.

Teasdale, N., Simoneau, M., Corbeil, P., Handrigan, G., Tremblay, A., Hue, O., 2013. Obesity alters balance and movement control. *Current Obesity Reports*, 2: 235-240.

Vuillerme, N., Chenu, O., Pinsault, N., Fleury, A., Demongeot, J., Payan, Y., 2008. Can a plantar pressure-based tongue-placed eletrotactile biofeedback improve postural control under altered vestibular and neck proprioceptive conditions? *Neuroscience*, 155 (1): 291-296.

Winter, D.A., Patla, A.E., Frank, J.S., 1990. Assessment of balance control in humans. *Medical Progress through Technology*, 16: 31-51.

World Health Organization (WHO) Physical status: the use and interpretation of anthropometry: report of a WHO Expert Committee. Published 1995. Geneva, Switzerland: WHO Technical Report Series 854; p378 http://whqlibdoc.who.int/trs/WHO_TRS_854.pdf Accessed March 31st, 2014.

World Health Organization (WHO), Obesity and overweight 2011.

<http://www.who.int/mediacentre/factsheets/fs311/en/>. Last accessed March 20th, 2014,

Blacksburg, Virginia, USA.

Zhang, S., Li, L., 2013. The differential effects of foot sole sensory on plantar pressure distribution between balance and gait. *Gait Posture*, 37(4): 532-535.

Chapter 3 Executive Function and Measures of Fall Risk among Individuals who are Obese

Abstract

Obesity may be associated with deficits in executive function, specifically effective attention allocation to balance maintenance during multi-task conditions, and potentially lead to gait and postural control changes and higher fall risk. The purpose of this study was to investigate the influence of obesity on executive function, and to determine whether there is a relationship between executive function and fall risk (as estimated from selected gait parameters). Thirty-nine young adults participated, including 19 obese and 20 non-obese adults. Four major components of executive function were assessed, including selective attention, divided attention, semantic memory and working memory. Both single- and dual-task walking (walking-while-talking) were completed to evaluate fall risk during gait. Less effective selective attention, semantic memory, and working memory were found among young obese adults. Participants exhibited higher fall risks during dual-task walking (e.g. lower minimum toe clearance, longer stance time, and increased stance time variability), and executive function scores were associated with gait during dual-task walking. In conclusion, obese individuals exhibited less effective executive function, which may be associated with their increased fall risk.

Keywords: Obesity, Executive function, Dual-task walking, Falls

3.1 Introduction

The ability to control gait and balance requires complex sensory-motor and cognitive processes (Brown et al., 2002; Nagamatsu, et al., 2011; Woollacott & Shumway-Cook, 2002). Executive function is an umbrella term for cognitive processes that regulate, control, and manage other cognitive processes (Elliott, 2003), such as planning, memory, attention, problem solving, concentration, strategizing, and task-switching (Monsell, 2003). Growing evidence indicates that even in healthy young adults, balance control requires attentional resources (Brauer et al., 2002; Camicioli et al., 1997; Woollacott & Shumway-Cook, 2002). As such, executive function plays an essential role in the ability to simultaneously walk and perform another task (Adams & Parsons, 2003; Anstery, et al., 2006; Fuster, 1999; Goethals et al., 2004; Lezak et al., 2004; Persad et al., 1995), and to ensure that the appropriate amount of attention is allocated to balance control (Springer et al., 2006).

Both the cerebellum and cerebral cortex play key roles in executive function (Golfman-Rakic, 1998; Mesulam, 1998). Because obesity is associated with compromised cerebellar development among children (Miller et al., 2009) and cerebral atrophy among adults (Gustafson et al., 2004), obesity may affect executive function (Elliott, 2003). In fact, a recent review of 31 previous studies indicated that obesity in children and adolescents is associated with compromised development of executive function (Reinert et al., 2013). Deficits in executive function may impact the ability of an individual who is obese to control balance efficiently and safely during multi-tasking situations (Yogev et al., 2008). This is of particular relevance since fall rates appear to be higher with obesity (Fjeldstad et al., 2008). These higher rates could partly result from a relative inability, related to obesity,

to effectively allocate attention to balance maintenance during multi-task conditions, leading to gait and postural control changes. However, to our knowledge, no study to date has investigated the effect of obesity on executive function among young adults.

Dual-tasking paradigm has been used in several prior studies to assess attentional allocation toward gait and postural control during complex situations. Dual tasking relies upon executive function and the ability to divide attention (Della et al., 1995). According to the capacity theory (Abernethy, 1988; Fraizer & Mitra, 2008; Tombu & Jolicoeur, 2003), and if both balance control and a secondary task are attentionally-demanding, performance of at least one of the tasks deteriorate when they are performed simultaneously (Seidler et al., 2010; Woollacott & Shumway-Cook, 2002). The extent to which performance on either task declines indicates interference between the processes controlling the two tasks, and thus the extent to which the two tasks share attentional resources (Kerr, et al., 1985). The walking-while-talking paradigm has been studied as a realistic test of divided attention to examine cognitive-motor interactions, especially in the context of identifying fall risks (Bootsma-van der Wiel et al., 2003; Caimicioli et al., 1997; De Hoon et al., 2003; Hyndam & Ashburn, 2004; Lundin-Olsson et al., 1997; Sheridan et al., 2003; Verghese et al., 2002). Therefore, this study employed the walking-while-talking paradigm to examine whether executive function is a contributing factor in increased fall risks among individuals who are obese.

The purpose of this study was to investigate the influence of obesity on executive function, and to determine whether there is a relationship between executive function and fall risk (as estimated from selected gait parameters). Four hypotheses were tested: 1)

executive function would be lower among individuals who are obese versus normal weight; 2) adding a dual-task to walking would increase fall risk; 3) this increase in fall risk would be more substantial among individuals who are obese; and 4) executive function would have an inverse association with fall risk, especially under the more challenging dual-task condition. Results from this study were intended to help identify potential factors increasing fall risk among those who are obese, and to contribute to the development of fall intervention/prevention programs for this population.

3.2 Methods

A total of 39 young (age=21.3±2.6 years, education=15.1±1.6 years) adults completed the study, and were recruited from the local university population. Participants included 19 who were obese (body mass index or BMI = 33.0±2.9 kg/m²; 14 females and 5 males) and 20 who were normal weight (BMI = 22.2±2.2 kg/m²; 14 females and 6 males). Body fat percentage was also estimated, using skinfold calipers, at the front of the upper arm, back of the upper arm, below the scapula, and on the abdomen (1cm to the right of the navel). Participants were included in the obese group only if they had a body fat percentage above 35% for women and above 25% for men from these caliper measurements (WHO, 1995), and a BMI ≥ 30 kg/m². All participants were free from any self-reported foot pain or known neurological conditions that might have affected their performance in this study. This study was approved by Virginia Tech Institutional Review Board, and all participants provided written informed consent prior to testing.

Participants completed one experimental session involving three tasks. Initially, the four major components of executive function were assessed as described below.

Subsequently, both single-task walking (so all attentional resources could be dedicated to walking) and dual-task walking (walking while talking to divide attentional resources) were completed.

Four tests of executive function were performed (Lezak et al., 2004), including the Stroop test (for selective attention), Trail Making test (for divided attention, visuomotor tracking, and cognitive flexibility), Verbal Fluency test (for semantic memory) and Digit Span test (for working memory). Measures from these are related to balance control, as reported previously (Yogev, et al., 2008). The Stroop test included the color-word naming subtest. Performance was assessed by the time required to name 100 items, with a shorter time indicating better performance. The Trail Making test consisted of 25 circles on a piece of paper, and the circles included both numbers (1-13) and letters (A-L) (Reitan, 1958). Participants were asked to draw lines to connect the circles in an ascending pattern, with alternating letters between the numbers (i.e. 1-A-2-B-3-C). Performance was assessed by the time required to complete the test, with a shorter time indicating better performance (Three participants (1 obese and 2 non-obese) made mistakes during the task, so they were excluded from further analyses). The Verbal Fluency test involved two subtests, with participants asked to name as many words as possible that start with a given letter (i.e. words starts with letter 'p') and in a given category domain (i.e., fruit), each for 60 seconds (Benton et al., 1976; Rosen, 1980). A higher number of correct words indicated better performance. The Digit Span test involved two subtests, including forward and backward tests (Wechsler, 1981). For both subtests, participants were presented with a series of digits, and they were required to immediately repeat them back. The series of digits were presented verbally to participants at a rate of one per second. For the forward subtest, the

participant's task was to repeat each sequence exactly as it was given. For the backward subtest, the participant was asked to repeat each sequence in reverse order. Both subtests began with three digits and increased by one at a time up to nine. Each subtest was performed twice using different series of digits. The number of successful sequences was considered the score, and ranged from 0 to 14. The difference between the forward and backward subtest scores was used as an indicator of working memory function, with smaller differences indicated better working memory (Wechsler, 1981).

Single-task and dual-task walking were then performed with the order counterbalanced within groups (partially in the case of obese group, given the odd number of participants). All participants wore a T-shirt, tight-fitting shorts, and identical dress shoes (hard PVC soles) to minimize shoe-sole differences. For single-task walking, participants were instructed to walk at a self-selected speed along a 9-m walkway. For dual-task walking, participants were instructed to walk at a self-selected speed along the walkway, but while also reciting every other letter of the alphabet (Verghese et al., 2006). Participants were instructed to "pay equal attention to both walking and talking" and "if the first 13 letters are finished, continue with the second 13 letters, starting with a letter "B" if starting with letter "A" the first time and vice versa, and continue this process until instructed to stop." The initial letter on the reciting task was randomly varied between "A" (A-C-E) and "B" (B-D-F) between participants. To reduce learning effects, participants were given 3 minutes to practice reciting alternate letters of alphabet, and 10 trials to practice the dual-task walking, prior to data collection. Practice walking trials also allowed participants to acclimate to the experimental setup, and allowed for determining the appropriate starting point along the walkway (so that participants naturally and consistently stepped on a force

platform embedded within the walkway). Five walking trials were collected under each task condition.

During walking trials, ground reaction forces were sampled at 1000 Hz using a six degree-of-freedom force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) in the center of the walkway. The position of five reflective markers on the left and right calcaneus, top of the foot, and right upper back were sampled at 100 Hz, using a six-camera motion analysis system (VICON 460, VICON Motion Systems Inc., Lake Forest, CA, USA). Both the force plate and markers data were low-pass filtered (4th order Butterworth, zero-lag filter), using 40 and 6 Hz cutoffs, respectively.

Several dependent variables were calculated from data in each walking trial, and were selected because they are related to balance control and fall risks among the elderly and obese individuals (Montero-Odasso, et al., 2012; Wu, et al., 2012). Minimum toe clearance (MTC) is associated with the likelihood of tripping while walking, and was calculated as the minimum vertical distance between the toe marker and the ground during mid-swing phase of the gait cycle (Khandoker, et al., 2010). The required coefficient of friction (RCOF) is associated with the likelihood of slipping while walking, and was determined as the maximum ratio of resultant shear ground reaction force to the vertical ground reaction force (Wu et al., 2012). Heel contact and toe off were identified from heel and toe kinematics (Mickelborough et al., 2000), and stance time was the period between these two events for a single limb (Uustal and Baerga, 2004). The interquartile range (IQR) of stance time was the difference between upper and lower quartiles (Upton and Cook, 1996), and was computed to represent the variability of gait under each condition.

To address hypothesis 1, two-way analyses of variance (ANOVAs) were performed on completion times from the Stroop and Trail Making tests, the number of words named in the Verbal Fluency tests (both letter and category conditions), and Digit Span test scores. In each of these ANOVAs, independent variables were group (obese or non-obese), gender, and their interaction, and with age and years of education included as covariates.

To address hypotheses 2 and 3, three-way, mixed-factor ANOVAs were performed on gait parameters, with independent variables of group, gender, task (single or dual-task walking), and all interactions. Significant interaction effects were explored using simple effects testing. Normal quantile plots were used to detect outliers (three data points from distinct participants were removed prior to analyses based on visual inspection).

To address hypothesis 4, Pearson bivariate correlation coefficients were used to quantify the associations between each executive function score and each gait parameter; this was done separately for the single- and dual-task data. The strengths of these were characterized as strong (0.6-0.8), moderate (0.4-0.6), or weak (0.2-0.4) (Kunter et al., 2001). JMP 10 (SAS Institute Inc., Cary, NC, USA) was used to carry out statistical analyses, with statistical significance indicated by $p \leq 0.05$.

3.3 Results

None of the executive function tests were affected by an obesity group \times gender interaction ($p > 0.256$), but two were affected by a main effect of obesity group (Table 3-1). Time to complete the Stroop test was 12.7% (10.5 s) longer (i.e. worse) among the obese

group, and performance on the Digit Span test was 35.1% (0.8 points) worse among the obese group. In addition, the number of words named during the Verbal Fluency letter subtest was 17.1% (3 words) lower among the obese group, but this result only approached statistical significance. No effects of gender ($p > 0.169$), age ($p > 0.346$) or years of education ($p > 0.402$) were found for any executive function tests.

Table 3-1 Group differences in tests of executive function, with summary results presented as means (standard deviation) and p -values for the main effects of group. The symbol * indicates a significant difference between groups.

	Obese	Non-obese	p -value for group
Stroop Test (s)	93.2 (17.0)	82.7 (13.8)	0.028*
Trail Making Test (s)	48.8 (12.5)	44.2 (11.6)	0.222
Verbal Fluency (letter)	16.7 (5.0)	20.0 (4.2)	0.098
Verbal Fluency (category)	16.6 (4.2)	15.8 (3.7)	0.940
Digit Span	2.2 (1.3)	1.4 (1.4)	0.043*

None of the gait parameters were affected by a three-way ($p > 0.075$), gender \times task ($p > 0.089$), or obesity group \times task ($p > 0.327$) interactions. Stance time ($p = 0.041$) and stance time IQR ($p = 0.006$) both exhibited an obesity group \times gender interaction (Figure 3-1). In particular, stance time was 15.7% (0.11 s) longer among obese males compared to obese females, and was 12.7% (0.091 s) longer among obese males compared to non-obese males. Moreover, stance time IQR was 49.8% (0.016 s) more variable among obese females compared to non-obese females, and was 40.1% (0.014 s) more variable among non-obese females compared to non-obese males. Several gait parameters also exhibited an effect of task (Table 3-2). During dual-task versus single-task walking, MTC was 33% (0.46 cm) lower, and RCOF was 5% (0.01) smaller. Also during dual-task walking, participants spent 13% (0.08 s) more time during the stance phase, and IQR was 33% (0.01 s) higher. Only RCOF differed between obesity groups across both tasks, with obese participants exhibiting 11.9% (0.03) higher RCOF ($p = 0.011$).

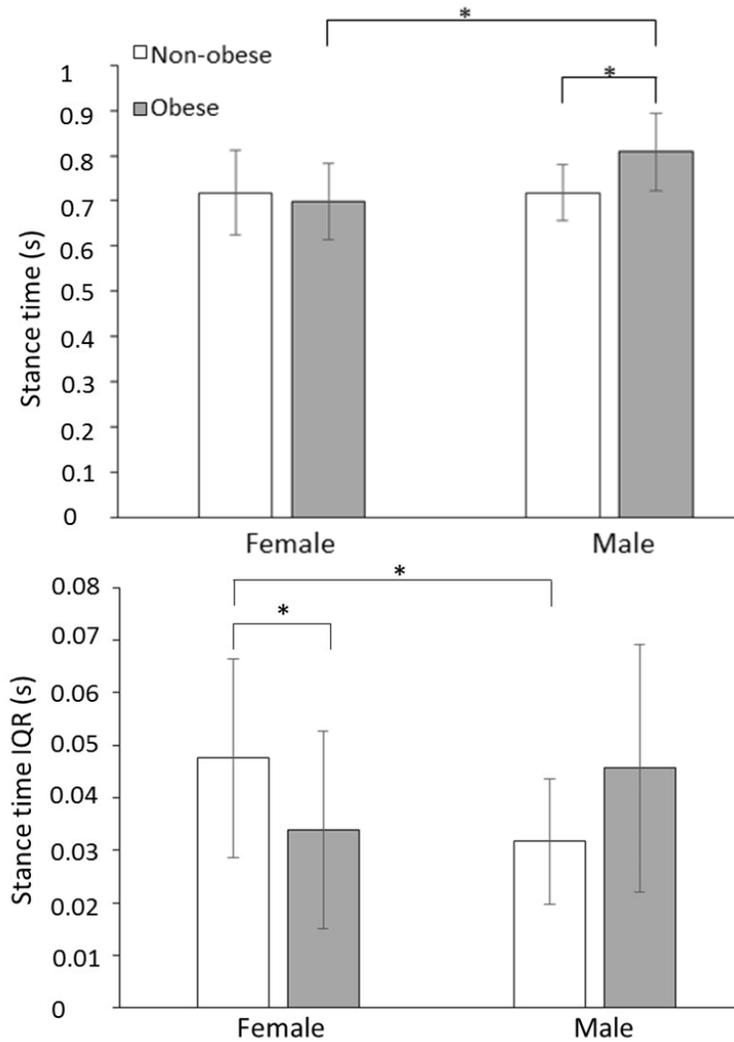


Figure 3-1 Group \times gender interaction effects on stance time (top) and stance time IQR (bottom). Error bars indicate standard deviations, and significant paired differences (from simple-effects tests, $p < 0.05$) are indicated by the symbol *.

Table 3-2 Task differences in gait parameters, with summary results presented as means (standard deviation), and p -values for the main effect of task. The symbol * indicates a significant difference between tasks.

	Single-task	Dual-task	p -value
MTC (cm)	1.42(0.85)	0.94(0.62)	0.003*
RCOF	0.21(0.03)	0.20(0.03)	0.019*
Walking speed (m/s)	1.28(0.14)	1.13(0.16)	<0.001*
Stance time (s)	0.68(0.06)	0.76(0.10)	<0.001*
Stance time IQR (s)	0.04(0.02)	0.05(0.03)	0.045*

During dual-task walking, RCOF was negatively correlated with the number of words named in Verbal Fluency category subtest ($r = -0.32, p = 0.044$), and stance time IQR was positively correlated with Stroop test completion time ($r = 0.38, p = 0.020$). The strength of both correlations was considered weak. No other correlations were significant.

3.4 Discussion

The purpose of this study was to investigate the influence of obesity on executive function, and to determine whether there is a relationship between executive function and fall risk (as estimated from selected gait parameters). Our first hypothesis was that executive function would be lower among obese individuals versus non-obese individuals. This hypothesis was supported because the obese group required a longer time to complete the Stroop test, and scored worse in the Digit Span test. Although not significant, obese individuals also named fewer words during the Verbal Fluency test. Our second hypothesis was that adding a dual-task to walking would increase fall risk as estimated by selected gait parameters. This hypothesis was also supported because dual-task walking exhibited lower MTC, longer stance time, and greater stance time variability compared to single-task walking, all three of which are suggestive of a higher fall risk (Beauchet et al., 2005; Kim and Brunt, 2003; Learmonth et al., 2014; Lindenberger, et al., 2000). Our third hypothesis was that adding a dual-task to walking would affect gait parameters associated with fall risk to a greater extent among individuals who are obese. This hypothesis was not supported because no group \times task interaction effects were found for any of the gait parameters. Our fourth hypothesis was that executive function would have an inverse association with fall risk, especially under the more challenging dual-task condition. This hypothesis was accepted because statistically significant (although weak) correlations were found between

executive function measures and gait parameters during dual-task walking. Considering all results, executive function may increase fall risk among individuals who are obese.

Therefore, improvements in executive function through intervention may have a secondary effect of reducing fall risk.

Scores from executive function tests and gait parameters found here were comparable to other studies. The mean Stroop test completion time of 87.8 s in the current study was similar, yet slightly shorter, than 100.4 s reported by Jensen (1965) across 436 young adults. The mean Trail Making test completion time of 46.5 s in the current study, again similar and slightly shorter than the value of ~55 s reported by Tombaugh (2004) among young adults. The mean Digit Span score of 2 in the current study was slightly larger than the mean score of ~1.5 reported by Foster et al (1998) among a control group of young healthy adults. The mean MTC was 1.4 cm in the current study during single-task walking, and was comparable to a mean of ~1.5 cm reported for young adults (Khandoker, et al., 2010; Mills et al., 2008). The current mean RCOF of 0.21 was similarly comparable to a mean of 0.20 reported by Yamaguchi et al. (2012) among young adults. Finally, the mean stance time during single-task walking of 0.67 s was similar to the mean of 0.70 s reported by Oh-Park et al. (2010).

Introducing a dual task to walking in the current study decreased MTC, and increased gait (stance time) variability, which was similar to earlier reports among healthy young and older adults (Aldridge, 2009; Beauchet et al., 2005; Kim and Brunt, 2003; Learmonth et al., 2014; Lindenberger, et al., 2000). In particular, the current study found MTC to decrease 33% when adding the dual task to walking, whereas Aldridge (2009)

reported it to decrease 4% when adding talking task over the phone to walking. A decrease in MTC is directly associated with an increased likelihood of tripping (Aldridge, 2009). The current study also found stance time variability to increase 33% when adding the dual task to walking, whereas Beauchet et al. (2005) reported it to increase 5.9% when adding backward counting to walking. Increases in stance time variability may also suggest an increase fall risk, because greater gait variability is indicative of impairments in stability (Hausdorff et al., 2001; Hausdorff, 2009; Plotnik et al., 2011), and thus impaired balance control. A longer stance time may suggest a more cautious walking strategy while simultaneously performing the dual tasks. However, a longer stance time is associated with increased fall risk, and is also considered to reflect alterations in sensorimotor function (Maki, 1997; Taylor et al., 2013), and deficits in balance control. Different effect sizes found between the current study and previous studies may have been due to differences between study protocols and/or participant characteristics.

The current study is the first to our knowledge to demonstrate an adverse effect of obesity on executive function among young adults. Young obese adults performed worse in Stroop test, Verbal Fluency, and Digit Span test indicating possible impairments in selective attention, semantic memory and working memory. Memory and attention are two major components of executive function (Elliott, 2003). And, as noted earlier, obesity is associated with compromised cerebellar development among children (Miller et al., 2009) and cerebral atrophy among adults (Gustafson et al., 2004), both of which may influence executive function (Elliott, 2003). In particular, Willette and Kapogiannis (2014) recently reported a positive association between body fat and frontal grey matter atrophy. Smaller grey matter volume was found earlier to be associated with worse semantic memory (Taki

et al., 2011). Therefore, obesity may influence executive function as a consequence of alterations in brain structure, although, the exact mechanism is still unclear.

Executive function plays an essential role in the ability to simultaneously walk and perform another task (Adams & Parsons, 2003; Anstery, et al., 2006; Fuster, 1999; Goethals et al., 2004; Lezak et al., 2004; Persad et al., 1995). Changes in gait due to the simultaneous performance of dual tasks result from a competition for attention resources between the two tasks (Woollacoot and Shumway-Cook, 2002). Similar to the correlations between the executive function tests and gait found here, Holtzer et al. (2006) found executive function (measured by cognitive battery) can explain 15% variance in gait speed during dual-task walking among elderly participants. Springer et al. (2006) reported strong associations (0.61) between executive function (performance on Stroop test) and gait variability during dual-task walking among elderly fallers. As a whole, the current study and prior work indicated that gait is a complex task requiring higher-level control of executive processing, attention, and memory, even among young adults. There is also evidence, albeit not strong, that deficits in executive function may increase their fall risk during dual-task conditions.

Three limitations warrant mentioning. First, we were not able to detect any significant group \times task interaction effects. One reason for this could be that the walking-while-talking task was too challenging, as indicated by almost all participants, and precluded identifying a differential effect of the dual task between the two obesity groups. Future work should consider incorporating different levels of task difficulty in the dual task condition. Second, the manner in which attention is divided between two tasks depends on the priority given to each task. Here, participants were instructed to pay equal attention to

both tasks, to create a condition in which attention was divided (Beauchet et al., 2005). However, participants may still have prioritized one task over the other, and which could influence their performance during dual-task walking, though this was not accounted for in the current study. Third, our sample had fewer male than female participants, and thus group \times gender interaction effects found here may be biased and should be treated with caution.

In conclusion, young adults who are obese exhibited less effective executive function compared to their non-obese counterparts, suggesting altered selective attention, semantic memory, and working memory. Adding a talking task to walking increased the risk of tripping. Executive function was also weakly correlated with gait during dual-task walking, suggesting it may contribute to a higher risk of falling.

References

- Abernethy, B., 1988. Dual-task methodology and motor skills research: some applications and methodological constraints. *Journal of Human Movement Studies*, 14(3): 101-132.
- Adams, R., Parsons, O., 2003. *Neuropsychology for clinical practice: etiology, assessment, and treatment of common neurologic disorders*. American Psychological Association, Washington DC.
- Aldridge, J.M., 2009. The effect of concurrent cell phone use and walking on gait characteristics. UNLV Theses/Dissertation/Professional Papers/Capstones. Paper 1131.
- Anstey, K.J., von Sanden, C., Luszcz, M.A., 2006. An 8-year prospective study of the relationship between cognitive performance and falling in very old adults. *Journal of American Geriatric Society*, 54(8): 1169-1176.

Beauchet, O., Dubost, V., Herrmann, F.R., Kressing, R.W., 2005. Stride-to-stride variability while backward counting among healthy young adults. *Journal of Neuroengineering Rehabilitation*, 2: 26.

Benton, A.L., Hamsher, K., Sivan, A.B., 1976. *Multilingual aphasia examination*. University of Iowa, Iowa City, IA.

Bootsma-van der Wiel, A., Gussekloo, J., de Craen A.J., van Exel, E., Bloem, B.R., Westendorp, R.G., 2003. Walking and talking as predictors of falls in the general population: the Leiden 85-plus study. *Journal of American Geriatric Society*, 51: 1466-1471.

Brauer, S.G., Woollacott, M., Shumway-Cook, A., 2002. The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders. *Gait Posture*, 15: 83-93.

Brown, L.A., Sleik, R.J., Winder, T.R., 2002. Attentional demands for static postural control after stroke. *Archives of Physics and Medical Rehabilitation*, 83: 1732-1735.

Camicioli, R., Howleson, D., Lehman, S., Haye, J., 1997. Talking while walking: the effect of a dual task in aging and Alzheimer's disease. *Neurology*, 48:955-958.

Della, S.S., Baddeley, A., Pagagno, C., Spinnier, H., 1995. Dual-task paradigm: a means to examine the central executive. *Annals of New York Academy Science*, 769:161-171.

De Hoon, E.W., Allum, J.H., Carpenter, M.G., et al., 2003. Quantitative assessment of the stops walking while talking test in the elderly. *Archives of Physics and Medical Rehabilitation*, 84:838-842.

Elliott, R., 2003. Executive function and their disorders. *British Medical Bulletin*, 65(1): 49-59.

Fjeldstad, C., Fjeldstad, A.S., Acree, L.S., Nickel, K.J., Gardner, A.W., 2008. The influence of obesity on falls and quality of life. *Dynamic Medicine*, 7 (4): 27 February.

Foster, J.K., Lidder, P.G., Sunram, S.I., 1998. Glucose and memory: fractionation of enhancement effects? *Psychopharmacology (Belgium)*, 137(3): 259-270.

Fraizer, E.V., Mitra, S., 2008. Methodological and interpretive issues in posture-cognition dual-tasking in upright stance. *Gait Posture*, 27(2): 271-279.

Fuster, J.M., 1999. Synopsis of function and dysfunction of the frontal lobe. *Acta Psychiatrica Scand Supplement*, 395: 1-57.

Goethals, I., Audenaert, K., Van de W.C., Dierckx, R., 2004. The prefrontal cortex: insight from functional neuroimaging using cognitive activation tasks. *European Journal of Nuclear Medicine and Molecular Imaging*, 31: 408-416.

Golfman-Rakic, P.S., 1998. The cortical dopamine system: role in memory and cognition. *Advanced Pharmacology*, 42: 707-711.

Gustafson, D., Lissener, L., Bengtsson, C., Bjorkelund, C., Skoong, I., 2004. A 24-year follow-up of body mass index and cerebral atrophy. *Neurology*, 63(10): 1878-1881.

Hausdorff, J.M., Rios, D., Edelberg, H.K., 2001. Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Archives of Physical Medicine and Rehabilitation*, 82: 1050-1056.

Hausdorff, J.M., 2009. Gait dynamics in Parkinson's disease: common and distinct behavior among stride length, gait variability, and fractal-like scaling. *Chaos*, 19: 026113.

Holtzer, R., Verghese, J., Xue, X., Lipton, R.B., 2006. Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychology*, 20: 215-223.

Jensen, A.R., 1965. Scoring the Stroop test. *Acta Psychologica*, 24: 398-408.

Kerr, B., Condon, S.M., McDonald, L.A., 1985. Cognitive spatial processing and the regulation of posture. *Journal of Experimental Psychology*, 11:617-622.

Khandoker, A.H., Lynch, K., Karmakar, C.K., Begg, R.K., Palaniswami, M., 2010. Toe clearance and velocity profiles of young and elderly during walking on sloped surfaces. *Journal of Neuroengineering and Rehabilitation*, 7: 18.

Kim, H., Brunt, D., 2003. The effects of a dual-task on obstacle crossing in healthy elderly and young adults. *Archives of Physical Medicine and Rehabilitation*, 88(10): 1309-1313.

Kunter, M.H., Nachtsheim, C.J., Neter, J., Li, W., 2004. *Applied linear statistical Models*. Irwin: McGraw-Hill, Columbus.

Learmonth, Y.C., Sandroff, B.M., Pilutti, L.A., Klaren, R.E., Ensari, I., Riskin, B.J., Holtzer, R., Motl, R.W., 2014. Cognitive motor interference during walking in multiple sclerosis using an alternate-letter alphabet task. *Archives of Physical Medicine and Rehabilitation*, article in press.

Lezak, M.D., Howieson, D.B., Loring, D.W., 2004. *Neuropsychological assessment*, 4th edition. Oxford University Press, Inc.; New York.

Lindenberger, U., Marsiske, M., Baltes, P.B., 2000. Memorizing while walking: increase in dual-task costs from young adulthood to old age. *Psychological Aging*, 15: 417-436.

Lundin-Olsson, L., Nyberg, L., Gustafson, Y., 1997. "Stops walking when talking" as a predictor of falls in elderly people. *Lancet*, 349:617.

Maki, B.E., 1997. Gait changes in older adults: predictors of falls or indicators of fear. *Journal of American Geriatric Society*, 45(3): 313-320.

Mickelborough, J., van der Linden, M.L., Richards, J., Ennos, A.R., 2000. Validity and reliability of a kinematic protocol for determining foot contact events. *Gait & Posture*, 11: 32-37.

Mesulam, M.M., 1998. From sensation to cognition. *Brain*, 121: 1013-1052.

Miller, J.L., Couch, J., Schwenk, K., Long, M., Towler, S., Theriaque, D.W., He, G., Liu, Y., Driscoll, D.J., Leonard, C.M., 2009. Early childhood obesity is associated with compromised cerebellar development. *Development of Neuropsychology*, 34(3): 272-283.

Mills, P.M., Barrett, R.S., Morrison, S., 2008. Toe clearance variability during walking in young and elderly men. *Gait & Posture*, 28(1): 101-107.

Monsell, S., 2003. Task switching. *Trends in Cognitive Sciences*, 7(3): 134-140.

Montero-Odasso, M., Verghese, J., Beauchet, O., Hausdorff, J.M., 2012. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. *Journal of American Geriatric Society*, 60(11): 2127-2136.

Nagamatsu, L.S., Voss, M., Neider, M.B., Gaspar, J.G., Handy, T.C., Kramer, A.F., Liu-Ambrose, T.Y.L., 2011. Increased cognitive load leads to impaired mobility decisions in seniors at risk for falls. *Physiological Aging*, 26(2): 253-259.

Oh-Park, M., Holtzer, R., Xue, X., Verghese, J., 2010. Conventional and robust quantitative gait norms in community dwelling older adults. *Journal of the American Geriatrics Society*, 58(8): 1512-1518.

Persad, C.C., Giordani, C., Chen, H.C., Ashton-Miller, J.A., Alexander, N.B., Wilson, C.S., Berent, S., Guire, K., Schultz, A.B., 1995. Neuropsychological predictors of complex obstacle avoidance in healthy older adults. *Journal of Gerontology, Series B Psychological Sciences and Social Sciences*, 50(5): 272-277.

Plotnik, M., Giladi, N., Dagan, Y., Hausdorff, J.M., 2011. Postural instability and fall risk in Parkinson's disease. Impaired dual tasking, pacing, and bilateral coordination of gait during the "ON" medication state. *Experimental Brain Research*, 210: 529-538.

Reinert, K.R.S., Poe, E.K., Barkin, S.L., 2013. The relationship between executive function and obesity in children and adolescents: a systematic literature review. *Journal of Obesity*, Article ID 820956.

Reitan, R.M., 1958. Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual Motor Skill*, 8: 271-276.

Seidler, R.D., Bernard, J.A., Burutolu, T.B., Fling, B.W., Gordon, M.T., Gwin, J.T., Kwak, Y., Lipps, D.B., 2010. Motor control and aging: links to age-related brain structural, functional, and biomechanical effects. *Neuroscience Biobehavior Review*, 34: 721-733.

Sheridan, P.L., Solomont, J., Kowall, N., Hausdorff, J.M., 2003. Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. *Journal of American Geriatric Society*, 51:1633-1637.

Shumway-Cook, A., Woollacott, M.H., 2002. *Motor control theory and practical applications*. Lippincott Williams and Wilkins, PA, USA.

Springer, S., Giladi, N., Peretz, C., Yogev, G., Simon, E.S., Hausdorff, J.M., 2006. Dual-tasking effects on gait variability: the role of aging, falls, and executive function. *Movement Disorder*, 21: 950-957.

Rosen, W.G., 1980. Verbal fluency in aging and dementia. *Journal of Clinical Neuropsychology*, 2(2): 135-146.

Taki, Y., Kinomura, S., Sato, K., Goto, R., Wu, K., Kawashima, R., Fukuda, H., 2011. Correlation between gray/white matter volume and cognition in healthy elderly people. *Brain and Cognition*, 75(2): 170-176.

Taylor, M.E., Delbaere, K., Mikolaizak, A.S., Lord, S.R., Close, J.C.T., 2013. Gait parameter risk factors for falls under simple and dual task conditions in cognitively impaired older people. *Gait & Posture*, 37(1): 126-130.

Tombaugh, T.N., 2004. Trail making test A and B: normative data stratified by age and education. *Archives of Clinical Neuropsychology*, 19(2): 203-214.

Tombu, M., Jolicoeur, P., 2003. A central capacity-sharing model of dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance*, 29(1): 3-18.

Upton, G., Cook, I.T., 1996. *Understanding Statistics*. Oxford University Press, Oxford, England.

Uustal, H., Baerga, E., 2004. *Gait analysis in Physical medicine and Rehabilitation Board Review*, Cuccurullo, S., ed. Demos Medical Publishing, New York.

Verghese, J., Buschke, H., Viola, L., et al., 2002. Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. *Journal of American Geriatric Society*, 20:1572-1576.

Verghese, J., Kuslansky, g., Holtzer, R., Katz, M., Xue, X., Buschke, H., Pahor, M., 2006. Walking while talking: effect of task prioritization in the elderly. *Archives of Physical Medicine and Rehabilitation*, 88(1):50-53.

Wechsler, D., 1981. *Wechsler adult intelligence scale-revised*. San Antonio, TX; Psychological Corp, Harcourt Brace Inc.

Willette, A.A., Kapogiannis, D., 2014. Does brain shrink as the waist expands? *Ageing Research Reviews*, Epub ahead.

Woollacott, M., Shumway-Cook, A., 2002. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture*, 16(1): 1-14.

World Health Organization (WHO) *Physical status: the use and interpretation of anthropometry: report of a WHO Expert Committee*. Published 1995. Geneva, Switzerland:

WHO Technical Report Series 854; p378 http://whqlibdoc.who.int/trs/WHO_TRS_854.pdf

Accessed March 31st, 2014.

Wu, X., Lockhart, T.E., Yeoh, H.T., 2012. Effects of obesity on slip-induced fall risks among young obese males. *Journal of biomechanics*, 45(6): 1042-1047.

Yamaguchi, T., Yano, M., Onodera, H., Hokkirigawa, K., 2012. Kinematics of center of mass and center of pressure predict friction requirement at shoe-floor interface during walking. *Gait & Posture*, 38(2): 209-214.

Yogev, G., Hausdorff, J.M., Giladi, N., 2008. The role of executive function and attention in gait. *Movement disorders*, 23(3):329-472.

Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E.S., Hausdorff, J.M., 2005. Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? *European Journal of Neuroscience*, 22: 1248-1256.

Chapter 4 Differences between Obese Fallers and Non-fallers after a Laboratory-Induced Slip

Abstract

Biomechanical and physiological factors such as gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size may influence fall risks among individuals who are obese. The goal of this study was to investigate differences in these factors between obese fallers and non-fallers after a laboratory-induced slip, and to investigate the strength of association between these same factors and measurements related to slip severity and slip outcome. Nineteen obese young adults from the university population participated in the study. Participants' gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size measures were obtained. An unexpected slip was introduced in a laboratory setting to obtain slip severity related measures and slip outcome. Results indicated obese fallers exhibited better selective attention, stronger lower extremity muscle strength, lower BMI and smaller waist circumference. Results also indicated increased slip severity was associated with faster walking speed, longer step length, higher RCOF, worse working memory, and lower BMI. Slower reactive recovery response was also associated with lower BMI. As such, better selective attention and stronger muscle strength exhibited limited benefit in slip recovery among individuals who are obese. Altered gait pattern, and working memory may be factors by which obesity increased slip severity, and lower BMI among individuals who are obese may increase slip-induced fall risks.

Keywords: Obesity, slip-induced falls, BMI, gait, executive function

4.1 Introduction

Over the past four decades, the prevalence of obesity in the United States has more than doubled from 15% to 35.7% (Flegal et al., 1998; Kuczmarski et al., 1994; Flegal et al. 2002; Flegal et al., 2010). Individuals who are obese fall almost twice as often (27% vs. 15%) as non-obese individuals (Fjeldstad et al. 2008), and falls have been identified as the most common (~36%) cause of injuries among individuals who are obese (Matter et al. 2007). In the occupational domain, from 1997 to 2004, obese workers slipped and fell more frequently, and filed more workers' compensation claims subsequently than non-obese workers (Ostbye et al., 2007). The high and increasing prevalence of obesity, coupled with the elevated risk of falls and subsequent injury associated with obesity, results in a major health concerns.

An attempt to recover balance to avert a fall after a postural perturbation can be considered as five distinct stages (Wu and Yeoh, 2014): initiation, detection, perception, action selection, and action execution. Initiation is the triggering event (i.e. slip, trip, or loss of balance) that may lead to a fall accident. Detection is the process whereby sensory inputs (from the proprioceptive, visual, and vestibular systems) that indicate a triggering event are transmitted to central nervous system. Perception is the interpretation process within the central nervous system that decodes the raw sensory information (Wickens and Hollands, 2000). Action selection is the process that transfers the perceived information about the environment into action (Wickens and Hollands, 2000). Action execution is the muscle coordination process for motion generations. A breakdown or impairment in any of these stages can increase the likelihood of a fall.

Biomechanical and physiological changes associated with obesity can have an adverse effect on these stages, and therefore increase the likelihood of falling. For example, changes in gait and posture may increase fall initiation risk by increasing the likelihood of slipping or tripping (DeVita and Hortobagyi 2003; Fabris de Souza et al. 2006; Lai et al. 2008; Spyropoulos et al. 1991; Wu et al., 2012). Deteriorations in plantar sensitivity and proprioception may delay detection (Dowling and Steel 2001; Wang et al., 2008; Wu and Madigan, 2014). Deficits in executive function (an umbrella term for cognitive processes that regulate, control, and manage other cognitive processes (Elliott, 2003)) may contribute to inappropriate attentional resources allocation during complex situations (i.e. slip), leading to improper perception and action selection. Lower relative muscle strength and increased body size may limit physical capabilities and the effectiveness of action execution to recover balance and avert a fall. (Anandacoomarasamy et al., 2008; Hita-Contreras et al., 2012).

The primary goal of this study was to investigate differences in biomechanical and physiological factors between obese fallers and non-fallers after a laboratory-induced slip. The specific factors investigated included gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size. The secondary goal of this study was to investigate the strength of association between these same factors and measurements related to slip severity. It was hypothesized that 1) fallers would exhibit altered gait pattern, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size compared to non-fallers; 2) altered gait pattern, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size would be associated with increased slip severity. Results from this study can help focus future studies investigating

the specific mechanisms by which obese individuals fall, and possibly intervention studies aimed at modifying these factors and reduce fall risk.

4.2 Methods

Nineteen young adults (age=21.4±3.0 years; BMI = 33.0±2.9 kg/m²; 14 females and 5 males) from the university population completed this study. Participants were required to have a BMI above 30 kg/m². All participants were free from any self-reported foot pain or known neurological or musculoskeletal condition that affected their performance in this study. This study was approved by Virginia Tech Institutional Review Board, and all participants provided written informed consent prior to testing.

Participants completed three experimental sessions, one per day on three separate days, and the order of presentation of these sessions was randomized across participants. During session one, body size, plantar sensitivity, and executive function were measured. During session two, strength was measured at hip, knee, and ankle. During session three, gait characteristics were measured, and an unexpected slip was introduced to assess slip severity and whether each participant was able to recover balance and avert a fall.

Body size measurements included minimum waist circumference, body mass, and body height (for calculating BMI). Plantar sensitivity was assessed using a custom platform and procedure described elsewhere (Wu & Madigan, 2014). Plantar sensitivity was operationalized as the force threshold at which an increasing force applied to the plantar surface was first perceived, and the force threshold at which a decreasing force was last

perceived. Measurements were obtained immediately upon standing, and at two locations on the plantar surface of the dominant foot (calcaneus and the head of the third metatarsal).

Executive function was assessed using four separate tests. The Trail Making Test was used for divided attention, visuomotor tracking, and cognitive flexibility, and consisted of two parts (A and B) (Reitan, 1958). Both parts of the test consist of 25 circles on a piece of paper. In part A, the circles are numbered from 1 to 25, and the participants were asked to draw lines to connect the numbers in ascending order. In part B, the circles include both numbers (1-13) and letters (A-L). Participants were asked to draw lines to connect the circles in an ascending pattern, but with the added task of alternating letters between the numbers (i.e. 1-A-2-B-3-C). Performance was assessed by the time spent to complete the task, and a shorter time indicated better performance. The Digit Span test was used to assess working memory, and consisted of two subtests (forward and backward) (Wechsler, 1981). Performance was assessed by the difference between the forward and backward subtest scores, and a smaller difference indicated better working memory. The Stroop test was used for selective attention, and consisted of three subtests of the card-based version of the color-word test (Jensen, 1965): the color naming subtest (A), the word naming subtest (B), and the color-word naming subtest (C). Performance was assessed by the time required to name 100 items in each trial, and a shorter time indicated better performance. The Verbal Fluency test was used to assess semantic memory, and involved asking participants to name as many words as possible that start with a given letter (A) (i.e. words starts with letter 'p') and as many words as possible in a given category domain (B) (i.e. fruit), each for 60 seconds (Benton et al., 1976 and Rosen, 1980). Performance was assessed by the number of correct words named, and a higher number of correct words indicated better performance.

Strength tests included the maximum isometric joint torques, and were measured at the ankle (plantar flexion and dorsiflexion), knee (extension and flexion), and hip (extension and flexion) (Anderson et al., 2007). Testing was performed on the right lower extremity, and using a Biodex System 3 dynamometer (Biodex Medical Systems, Inc., Shirley, New York, USA). Ankle and knee testing was performed with the standard manufacturer attachment, while hip testing was performed in an upright position with the body stabilized in a custom frame and the knee immobilized at roughly full extension (Anderson and Madigan, 2014). Isometric muscle strength was measured at four different angles equally spaced throughout the respective range of motion of each joint. Maximum isometric joint torque was determined as the largest of three maximum voluntary exertions performed at the approximate joint angles (Anderson et al., 2007). Joint torque and angle were recorded at 200 Hz from the dynamometer and low-pass filtered in software using a 5 Hz, fourth order, Butterworth filter (Anderson et al., 2007). Prior to strength testing, each joint was passively moved through two full cycles of joint motion at 5°/s while participants remained relaxed, and data obtained during these cycles were used to correct strength measurements for gravitational moments and to model passive elastic joint torques (Anderson et al., 2010). All strength measures were normalized to a percentage of body mass (yielding relative strengths).

Gait and slip measurements were performed while participants walked along a 9-m-long walkway at a self-selected speed. Participants wore a T-shirt, tight-fitting pants, and dress shoes (hard PVC soles). Participants were instructed that “you may or may not be slipped depending on which group you are assigned to”, in order for participants to not be sure whether or not they would be slipped (in reality, all participants were slipped). Practice

walking trials were first performed, to allow participants to acclimate to the experimental setup, and to determine the appropriate start point along the walkway so that they naturally and consistently stepped on a force platform embedded within the walkway. After each trial (walking from one end of the walkway to the other), participants were asked to stop at the end of the walkway and not turn around until instructed to do so (to provide the investigator time to prepare for the next trial). Five trials were collected, in which participants' feet landed on the platform in the desired sequence (non-dominant foot before the force platform and dominant foot on the force platform). After another one to five walking trials, an unexpected slip was induced by covering the force platform (0.9×0.9 m) integrated in the walkway with vegetable oil, which reduced the coefficient of friction to ~0.12 (Lockhart et al., 2005, Troy et al., 2008). A full-body harness system was used throughout all walking and slipping trials to prevent a fall to the floor in the event of an unsuccessful balance recovery after slipping. A load cell (Cooper Instruments and Systems, Warrenton, VA) in series with the harness connection to an overhead rail was used to determine whether or not balance was successfully recovered (see below). A six degree-of-freedom force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) was embedded in the center of the walkway. Ground reaction forces were sampled at 1000 Hz from the force platform, and low-pass filtered at 40Hz. Three reflective markers were attached, over the left and right calcaneus and the right side of the upper back. The positions of the three reflective markers were sampled at 100 Hz using a six-camera VICON MX motion analysis system (VICON Motion Systems Inc., Lake Forest, CA, USA), and low-pass filtered with at 6 Hz. Both force platform and marker data were filtered using a 4th order Butterworth zero-lag filter.

Gait measurements obtained from the walking trials included walking speed, step length, and peak required coefficient of friction (RCOF). Walking speed was obtained as the mean horizontal speed of the back marker. Step length was derived as the anterior-posterior distance between consecutive heel strikes. RCOF was the peak value of time-varying ratio of resultant shear ground reaction force (including both anterior-posterior and medial-lateral components) to the vertical ground reaction force (Wu et al., 2012). Heel strike was identified from ground reaction forces—when the vertical ground reaction forces exceeded 10N (Lockhart et al., 2003).

Slip measurements included three slip severity related measures (slip distance, peak slip speed, and non-slipping foot reaction time), and slip outcome (fall or recovery). Slip severity related measures are directly related to slip outcomes, with more severe slips associated with higher chances of fall. Slip distance was the distance travelled by the slipping foot from the time of heel strike to the time that either the heel came to a stop or the heel displaced vertically from the force platform (Troy et al., 2008). Peak slip speed was the highest horizontal heel sliding speed during the slip event. Non-slipping foot reaction time was the duration from the time of slipping foot heel strike to the time of non-slipping foot heel strike. A longer non-slipping foot reaction time is associated with increased slip distance (Marigold et al., 2003), and was used to quantify the reactive recovery response. Participants were characterized as fallers if the peak load cell force exceeded 50% of the participants' body weight, or non-fallers if the peak load cell force was less than 30% of the participants' body weight (Yang and Pai, 2011). Participants were excluded from subsequent analysis if the peak load cell force was between 30% and 50% of his/her body weight. None of the participants were excluded based upon this criterion.

To address hypothesis one, a one-way between-subject analyses of variance was used to investigate differences between fallers and non-fallers. Gait speed was used as covariate in the analyses. Dependent variables included three measures of gait characteristics (gait speed, step length, and RCOF), four measures of plantar sensitivity (plantar sensitivity under calcaneus and head of the 3rd metatarsal while force was increasing and decreasing), eight measures of executive function (Trail Making test A and B completion times, Digit Span score, Stroop A, B and C completion time, Verbal Fluency test scores A and B), six measures of muscle strength (ankle dorsiflexion, ankle plantar flexion, knee extension, knee flexion, hip flexion, and hip extension relative muscle strength), two measures of body size (BMI, and waist circumference), and three measures of slip characteristics (slip distance, peak slip speed, and non-slipping foot reaction time). A log transform on plantar sensitivity and lower extremity relative muscle strength measures was performed prior to the analyses to achieve a normal distribution of residuals.

To address hypothesis two, bivariate correlation analysis was performed between three slip severity related measures, and measures of gait characteristics, plantar sensitivity, executive function, muscle strength, and body size. The strength of correlations was characterized using the Pearson product-moment correlation coefficient (r) as strong (0.6-0.8), moderate (0.4-0.6), and weak (0.2-0.4) (Kunter et al., 2001). JMP Pro 10 (SAS Institute Inc., Cary, NC, USA) was used to carry out all statistical analyses with a significance level of significance of $p \leq 0.05$, and comparisons that approached significance ($0.05 < p < 0.10$) were also noted.

4.3 Results

All 19 participants were successfully slipped, nine (7 females and 2 males) fell after slipping and ten (7 females and 3 males) did not fall. Slip severity related measures did not differ between fallers and non-fallers, including slip distance, peak slip speed and non-slipping foot reaction time. Gait characteristics did not differ between fallers and non-fallers, including gait speed, step length, and RCOF. Plantar sensitivity did not differ between fallers and non-fallers. However, several differences in biomechanical and physiological factors were found (Table 4-1, Table 4-2). Fallers exhibited 16.7% shorter Stroop test A completion time. Fallers also exhibited 11.0% shorter Stroop test B completion time, but this result only approached statistical significance. Fallers exhibited 50.0% higher relative plantar flexion strength, and 31.6% higher relative hip extension strength. Fallers also exhibited 10.0% lower BMI, and 11.1% smaller waist circumference (Figure 4-1).

Bivariate analyses revealed several significant correlations with slip severity related measures (Figure 4-2 & Figure 4-3). Walking speed, and step length were both positively correlated with slip distance and peak slip speed, while RCOF was positively correlated with peak slip speed, and all these correlations were characterized as moderate in strength. Digit Span test score and BMI were negatively correlated with slip distance and peak slip speed, and these correlations were characterized as moderate to strong in strength. Negative correlation of moderate strength between BMI and non-slipping foot reaction time was also found. No other correlations were significant.

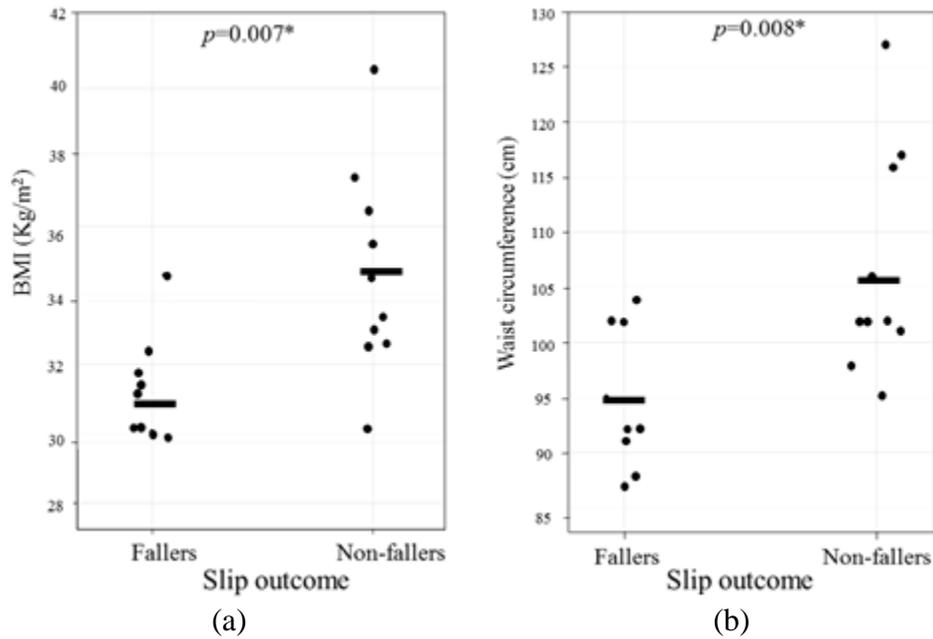


Figure 4-1 Differences in body size measures between fallers and non-fallers with p -values, horizontal bars representing the means, and * indicated $p \leq 0.05$ (a: BMI, b: waist circumference)

Table 4-1 Mean (standard deviation), and p -values of gait characteristics, executive function, body size and slip severity related measures for fallers and non-fallers, with * indicates $p \leq 0.05$

Measures	Fallers (N = 9)	Non-fallers (N = 10)	p -value
Gait characteristics			
Gait speed(m/s)	1.3(0.2)	1.2(0.1)	0.420
Step length(cm)	72.3(7.4)	69.4(7.0)	0.387
RCOF	0.22(0.02)	0.22(0.02)	0.447
Executive function			
TMT_A (s) ¹	23.9 (7.4)	22.7 (6.5)	0.720
TMT_B (s)	48.3 (13.6)	49.3 (11.3)	0.864
Digit Span	1.9 (1.5)	2.4 (1.1)	0.409
Stroop_A (s)	46.9 (4.9)	56.3 (9.7)	0.019*
Stroop_B (s)	35.1 (3.0)	39.4 (6.9)	0.055
Stroop_C (s)	87.1 (10.2)	93.4 (13.0)	0.146
VF (category) ²	16.5 (5.8)	17.1 (4.8)	0.814
VF (letter)	16.5 (5.0)	16.8 (3.9)	0.888
Body size			
BMI	31.2(1.6)	34.6(2.9)	0.007*
WC (cm) ³	94.7(6.4)	106.5(10.1)	0.008*
Slip severity related measures			
Slip distance (cm)	50.6(36.2)	41.2(32.3)	0.560
Peak slip speed (m/s)	1.1(0.6)	0.8(0.5)	0.338
NS reaction time (s) ⁴	0.2(0.1)	0.4(0.2)	0.103

Note: 1. TMT: Trail Making Test; 2. VF: Verbal Fluency; 3. WC: waist circumference; 4. NS reaction time: non-slipping foot reaction.

Table 4-2 Median (interquartile range), and *p*-values of plantar sensitivity and lower extremity muscle strength for fallers and non-fallers, with * indicates $p \leq 0.05$

Measures	Fallers (N = 9)	Non-fallers (N = 10)	<i>p</i> -value
Plantar sensitivity			
Calcaneus_increasing (g) ¹	32.5(78.8)	35.1(40.0)	0.550
Calcaneus_decreasing (g) ²	17.5(13.8)	13.0(21.6)	0.137
3 rd _increasing (g) ³	27.0(18.0)	25.5(25.9)	0.972
3 rd _decreasing (g) ⁴	13.5(11.0)	10.6(10.5)	0.769
Muscle strength			
DF (Nm/kg) ⁵	0.4(0.1)	0.3(0.2)	0.603
PF (Nm/kg) ⁶	1.5(0.3)	0.9(0.5)	0.016*
KE (Nm/kg) ⁷	2.0(0.5)	2.0(0.8)	0.914
KF (Nm/kg) ⁸	1.1(0.4)	1.1(0.4)	0.528
HF (Nm/kg) ⁹	1.4(0.6)	1.4(0.5)	0.670
HE (Nm/kg) ¹⁰	2.4(0.5)	1.9(0.9)	0.025*

Note: 1. Calcaneus_increasing: plantar sensitivity measured at calcaneus when force was increasing; 2. Calcaneus_decreasing: plantar sensitivity measured at calcaneus when force was decreasing; 3. 3rd_increasing: plantar sensitivity measured at the head of the third metatarsal when force was increasing; 4. 3rd_decreasing: plantar sensitivity measured at the head of the third metatarsal when force was decreasing; 5. DF: Dorsiflexion; 6. PF: Plantar flexion; 7. KE: knee extension; 8. KF: knee flexion; 9. HF: hip flexion; 10. HE: hip extension.

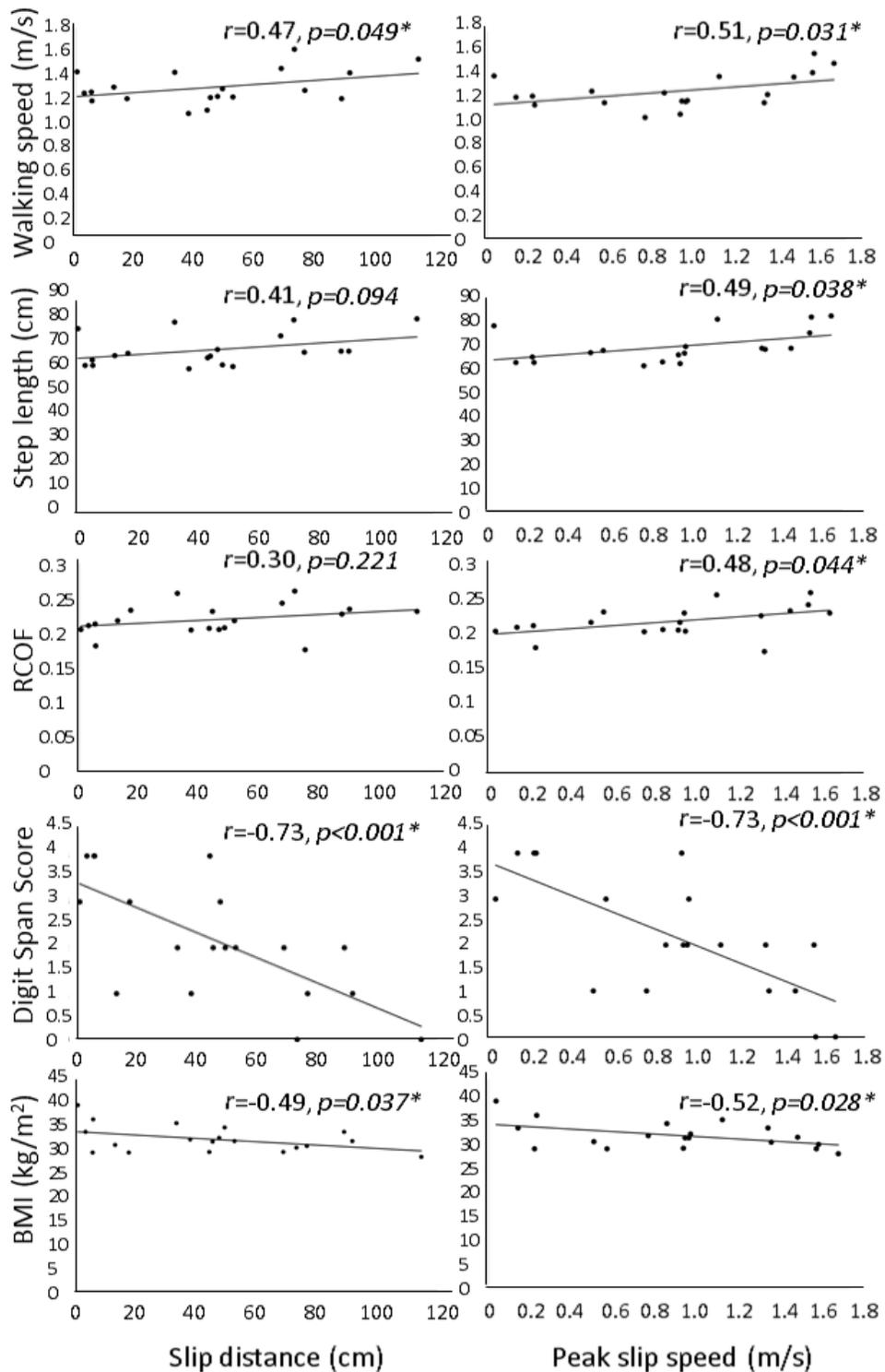


Figure 4-2 Scatter plots of correlations between slip severity (slip distance and peak slip speed) and gait measures (walking speed, step length, and RCOF), Digit Span test score, and BMI with r and p values, and * indicated $p \leq 0.05$

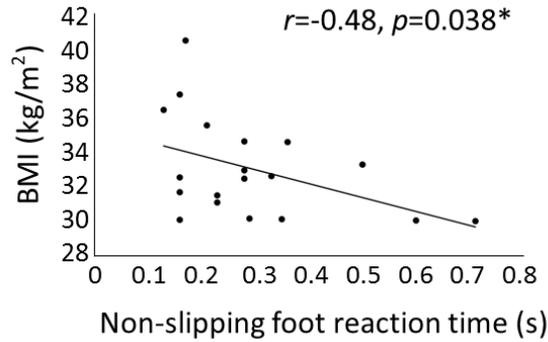


Figure 4-3 Scatter plots of correlation between BMI and non-slipping foot reaction time, with r and p values, and * indicated $p \leq 0.05$.

4.4 Discussion

The primary goal of this study was to investigate differences in biomechanical and physiological factors between obese fallers and non-fallers after a laboratory-induced slip. The specific factors investigated included gait, plantar sensitivity, executive function, lower extremity muscle strength, and body size. It was hypothesized that fallers would exhibit altered gait, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size compared to non-fallers. Our results indicated that fallers exhibited shorter Stroop A and B completion time, stronger ankle plantar flexion, and hip extension relative muscle strength, and lower BMI. Therefore, the first hypothesis was rejected. The secondary goal of this study was to investigate the strength of association between these same factors and slip measurements that related to slip severity. It was hypothesized that altered gait, worse plantar sensitivity, executive function, lower extremity muscle strength, and larger body size would be associated with increased slip severity. Bivariate analyses indicated that increased slip severity related measures were associated with faster walking speed, longer step length, higher RCOF, lower Digit Span test score, and lower BMI, and the strength of the correlations were characterized as moderate to strong. Therefore, our

second hypothesis was partially supported. Considering all results, altered gait pattern, and working memory among individuals who are obese may be factors by which obesity increased slip severity among obese participants.

Our measurements exhibited comparable values to other studies. The mean slip distance of 45.6 cm across all participants in the current study was comparable, although slightly higher to the mean value of 40 cm reported by Tsai and Powers (2013). The mean peak slip speed of 0.94 m/s across all participants from the current study was also comparable to mean of 0.65 m/s and 1.12 m/s reported earlier by Cham & Redfern (2001) and Wyszomierski et al. (2009), respectively. Gait parameters, scores from executive function tests, and relative muscle strength found here were also comparable to other studies. The current mean RCOF and walking speed of 0.22 and 1.3 m/s was comparable to a mean of 0.20 and 1.3m/s reported previously (Kim & Kim, 2014; Yamaguchi et al., 2012) among young adults. Our mean Trail Making A completion time of 24.1 s and Trail Making B completion time of 46.5 s agreed with previous study of ~21 s and ~55 s for a group of young participants aged 18-34 (Tombaugh, 2004). Our mean digit span score of 2.2 agreed with, although slightly higher than previous study of 1.5, among young healthy adults (Foster et al., 1998). Our mean Stroop A, B and C completion time of 54.1 s, 38.4 s and 87.8 s agreed with previous study of 58.2 s, 38.1 s and 100.4 s, respectively (Jensen, 1965). Our mean knee extension relative muscle strength of 2.2 Nm/kg also agreed with previous study of 2.3 Nm/kg (Maffioletti et al., 2007).

Interestingly, our results revealed that fallers exhibited lower BMI and smaller waist circumference compared to non-fallers, and lower BMI was associated with increased slip

severity. These results were unexpected given the higher rate of falls reported among obese adults in an epidemiological study (Fjeldstad et al., 2008), and biomechanics study involving induced slips (Allin, 2014). One possible explanation may be that individuals with higher BMI had made some type of adaptation that reduced their risk of falling from slip, whereas individuals with lower BMI had not. Possible adaptations could involve an altered gait pattern that reduces the risk of slip initiation (Moyer et al., 2007; Redfern and Bidanda, 1994). However, fallers and non-fallers exhibited no difference in selected gait characteristics, and BMI was not significantly correlated with gait parameters (bivariate correlation was performed between BMI and gait characteristics), suggesting 1) individuals with higher BMI may not adapt proactively in the way they walk; 2) the differences between fallers and non-fallers are not likely an artifact of our experimental setup. Adaptations could also involve adaptive responses to slippery surface (Gordon, et al., 1995; Lam et al., 2006; Tjemestrom et al., 2002; Weber et al., 1998). Previous studies reported that after repeated exposure to simulated slip-perturbation, young adults were able to improve their response to slippery surface (Bhatt et al., 2006), and such improvement was caused by modulation of feedforward and feedback motor control systems (Tjemestrom et al., 2002). Therefore, individuals with higher BMI may improve their recovery response through their prior experience of falling, exhibiting as reduced slip distance and peak slip speed and quicker non-slipping foot reaction. In fact, a quicker stepping response of the non-slipping foot aids the recovery process by widening the base-of-support, and thus reduced slip distance (Marigold et al., 2003). Fallers also exhibited shorter Stroop A and B completion time (indicating a better selective attention), and stronger lower extremity relative muscle strength, which are considered beneficial in the perception, action selection and action execution stages of slip recovery (Buracchino et al., 2011; Cham and Redfern,

2001). However, fallers and non-fallers exhibited no difference in slip severity related measures (slip distance, peak slip speed, and non-slipping foot reaction time), suggesting that better selective attention and stronger muscle strength exhibited limited benefit in slip recovery among obese participants.

In the current results, higher RCOF, and longer step length were associated with increased slip severity. These findings are consistent with previous studies among healthy young and older adults (Moyer et al., 2007; Redfern and Bidanda, 1994). Redfern and Bidanda (1994) indicated that RCOF directly related to the biomechanics of slips and falls. RCOF measures have been previously implicated as an important predictor related to slip severity (Redfern and Bidanda, 1994). Moyer et al. (2007) studied how gait parameters influenced slip-induced fall risk among 16 young and 11 older adults, and found that greater step length was associated with hazardous slips, leading to higher chances of falls. Longer step length was directly associated with increased slip-induced falls as they may influence the RCOF (Espy et al., 2010; Moyer et al., 2007). Longer step length would also decrease the center-of-mass to the margin of the base-of-support, and thus increase the likelihood of slip-induced falls (Espy et al., 2010). Faster walking speed was also associated with increased slip severity, as faster walking speed may influence the required ratio between horizontal and vertical forces (RCOF) (Gray, 1989), thus increase the slip initiation risks.

Lower Digit Span scores were associated with increased slip severity. This finding agreed with a previous study, which reported significant difference in digit span scores between fallers and non-fallers, who suffered Parkinson's disease (Denny et al., 2014). The

Digit Span task depends on working memory (Beauchet et al., 2005; Wechsler, 1981), which is often considered as an important component of executive function (Anderson et al., 2008; Baddeley, 1992). Studies suggest an independent association of executive function with balance, mobility and risk of falls among chronic (Liu-Ambrose et al., 2006) and subacute stroke patients (Rapport et al., 1993), and older adults (Buracchino et al., 2011). Therefore, a greater slip severity may be related to alterations in executive function, more specifically working memory.

Two limitations of the current study are to be noted. First, participants were instructed that “you may or may not be slipped depending on which group you are assigned to”. Therefore, anticipation effects may have existed. However, none of the participants verbally indicated, after the slip trial, that they were aware of the slippery surface beforehand. Second, and as with all cross-sectional studies, other differences between fallers and non-fallers not assessed here could have also contributed to the results we found. For example, subtle differences in gait speed or step length, although not statistically significant, could have contributed to differences between fallers and non-fallers.

In conclusion, obese fallers exhibited better selective attention, stronger lower extremity muscle strength, lower BMI and smaller waist circumference, suggesting that better selective attention and stronger muscle strength exhibited limited benefit in slip recovery among obese participants. Increased slip severity was associated with faster walking speed, longer step length, higher RCOF, worse working memory, and lower BMI. Slower reactive recovery response was also associated with lower BMI. As such, altered

gait pattern, and working memory may be factors by which obesity increased slip severity, and lower BMI among individuals who are obese may increase slip-induced fall risks.

Reference

Allin, L. 2014. Falls from slip among individuals who are obese. Master thesis, Virginia Tech.

Anandacoomarasamy, A., Caterson, I., Sambrook, P., Fransen, M., March L., 2008. The impact of obesity on the musculoskeletal system. *International Journal of Obesity*, 32: 211-222.

Anderson, D.E., Madigan, M.L., 2014. Healthy older adults have insufficient hip range of motion and plantar flexor strength to walk like healthy young adults. *Journal of Biomechanics*, Epub Ahead.

Anderson, D.E., Nussbaum, M.A., Madigan, M.L., 2010. A new method for gravity correction of dynamometer data and determining passive elastic moments at the joints. *Journal of Biomechanics*, 43(6): 1220-1223.

Anderson, D.E., Madigan, M.L., Nussbaum, M.A., 2007. Maximum voluntary joint torque as a function of joint angle and angular velocity: model development and application to the lower limb. *Journal of Biomechanics*, 40(14): 3105-3113.

Anderson, V., Jacobs, R., Anderson, P.J., 2008. Executive functions and the frontal lobes: a lifespan perspective. Psychology Print, New York.

Baddeley, A., 1992. Working memory. *Science*, 225: 556-559.

Bhatt, T., Wang, E., Pai, Y.C., 2006. Retention of adaptive control over varying intervals: prevention of slip-induced backward balance loss during gait. *Journal of Neurophysiology*, 95(5): 2913-2922.

Beauchet, O., Dubost, V., Aminian, K., Gonthier, R., Kressig, R.W., 2005. Dual-task-related gait changes in the elderly: does the type of cognitive task matter? *Journal of Motor Behavior*, 37: 259–264

Benton, A.L., Hamsher, K., Sivan, A.B., 1976. *Multilingual aphasia examination*. University of Iowa, Iowa City, IA.

Buracchio, T.J., Mattek, N.C., Dodge, H.H., Hayes, T.L., Pavel, M., Howieson, D.B., Kaye, J.A., 2011. Executive function predicts risk of falls in older adults without balance impairment. *BMC Geriatrics*, 11:74.

Cham, R., Redfern, M.S., 2001. Lower extremity corrective reactions to slip events. *Journal of Biomechanics*, 34(11): 1439-1445.

Denny, D., Brown, D., Galusha, J., Lobue, C., Dewey, R., Lacritz, L., 2014. A-27 differences in Cognitive abilities among fallers and non-fallers in Parkinson's disease. *Archives of Clinical Neuropsychology*, 29(6): 513.

De Vita, P., Hortobagyi, T., 2003. Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics* 36(9), 1355-1362.

Dowling, A. M., Steel, J., 2001. What are the effects of gender and obesity on foot structure in children? *Fifth Symposium on Footwear Biomechanics*, Zurich, Switzerland.

Elliott, R., 2003. Executive function and their disorders. *British Medical Bulletin*, 65(1): 49-59.

Espy, D.D., Yang, F., Bhatt, T., Pai, Y.C., 2010. Independent influence of gait speed and step length on stability and fall risk. *Gait Posture* 32(3), 378-382.

Fabris, S. M., Valezi, A.C., Fabris de Souza, S.A., Faintuch, J., Ceconello, I., Junior, M.P., 2006. Computerized baropodometry in obese patients. *Obesity Surgery*, 16(12): 1574-1578.

Fjeldstad, C., Fjeldstad, A.S., Acree, L.S., Nickel, K.J., Gardner, A.W., 2008. The influence of obesity on falls and quality of life. *Dynamic Medicine*, 7 (4): 27 February.

Flegal, K.M., Carroll, M.D., Ogden, C.L., Curtin, L.R., 2010. Prevalence and trends in obesity among US adults, 1999-2008. *The Journal of American Medical Association*, 303(3): 235-241.

Flegal, K.M., Carroll, M.D., Ogden, C.L., Johnson, C.L., 2002. Prevalence and trends in obesity among US adults, 1999-2000. *The Journal of American Medical Association*, 288(14): 1723-1727.

Flegal, K.M., Carroll, M.D., Kuczmarski, R.J., Johnson, C.L., 1998. Overweight and obesity in the United States: prevalence and trends, 1960-1994. *International journal of Obesity related Metabolism Disorders*, 22(1): 39-47.

Foster, J.K., Lidder, P.G., Sunram, S.I., 1998. Glucose and memory: fractionation of enhancement effects? *Psychopharmacology (Belgium)*, 137(3): 259-270.

Gray, B.E., 1989. Slips, stumbles, and falls: pedestrian footwear and surfaces, STP, 1103. American Society for Testing and Materials: 39-54.

Gordon, C.R., Fletcher, W.A., Milvill, J.G., Edgerton, V.R., 1995. Adaptive plasticity in the control of locomotor trajectory. *Experimental Brain Research*, 102:540-545.

Hita-Contreras, F., Martinez-Amat, A., Lomas-Vega, R., Alvarez, P., Mendoza, N., Romero-Franco, N., Aranega, A., 2012. Relationship of body mass index and body fat distribution with postural balance and risk of falls in Spanish postmenopausal women. *Menopause*, 20(2): 202-208.

Jensen, A.R., 1965. Scoring the Stroop test. *Acta Psychology*, 24: 398-408.

Kim, W.S., Kim, E.Y., 2014. Comparing self-selected speed walking of the elderly with self-selected slow, moderate, and fast speed walking of young adults. *Annuals Rehabilitation Medicine*, 38(1): 101-108.

Kuczmarski, R.J., Flegal, K.M., Campbell, S.M., Johnson, C.L., 1994. Increasing prevalence of overweight among US adults: the National Health and Nutritional Examination Surveys, 1960 to 1991. *The Journal of American Medical Association*, 272(3): 205-211.

Kunter, M.H., Nachtsheim, C.J., Neter, J., Li, W., 2004. *Applied linear statistical Models*. Irwin: McGraw-Hill, Columbus.

Lai, P.P., Leung, A.K., Li, A.N., Zhang, M., 2008. Three-dimensional gait analysis of obese adults. *Clinical Biomechanics*, 23(Supplment 1): S2–S6.

Lam, T., Anderschitz, M., Dietz, V., 2006. Contribution of feedback and feedforward strategies to locomotor adaptations. *Journal of Neurophysiology*, 95(2): 766-773.

Liu-Ambrose, T., Pang, M.Y., Eng, J.J., 2006. Executive function is independently associated with performances of balance and mobility in community-dwelling older adults after mild stroke: implications for falls prevention. *Cerebrovasc Disorders*, 23: 203-210.

Lockhart, T.E., Woldstad, J.C., Smith, J.L., 2003. Effects of age-related gait changes on the biomechanics of slips and falls. *Ergonomics*, 46(12): 1136-1160.

Lockhart, T.E., Smith, J.L., Woldstad, J.C., 2005. Effects of aging on the biomechanics of slips and falls. *Human factors*, 47(4): 708-729.

Maffiuletti, N.A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., Lafortuna, C.L., Satorio, A., 2007. Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *European Journal of Applied Physiology*, 101: 51-59.

Marigold, D.S., Bethune, A.J., Patla, A.E., 2003. Role of the unperturbed limb and arms in

the reactive recovery response to an unexpected slip during locomotion. *Journal of Neurophysiology*, 89(4): 1727-1737.

Matter, K.C., Sinclair, S.A., Hostetler, S.G., Xiang, H., 2007. A comparison of the characteristics of injuries between obese and non-obese inpatients. *Obesity (Silver Spring)*, 15(10): 2384-2390.

Mingardot, J., Olivier, I., Promayon, E., Nougier, V., 2010. Obesity impact on the attentional cost for controlling posture. *PLoS One*, 5(12): e14387.

Moyer, B.E., Chambers, A.J., Redfern, M.S., Cham, R., 2007. Gait parameters as predictors of slip severity in younger and older adults. *Ergonomics*, 49(4): 329-343.

Ostbye, T., Dement, J.M., Krause, K.M., 2007. Obesity and workers' compensation. *Archived International Medicine*, 167: 766-773.

Rapport, L.J., Webster, J.S., Flemming, K.L., Lingberg, J.W., Godlewski, M.C., Brees, J.E., Abadee, P.S., 1993. Predictors of falls among right-hemisphere stroke patients in the rehabilitation setting. *Archives of Physical Medicine Rehabilitation*, 74: 621-626.

Redfern, M.S., Bidanda, B., 1994. Slip resistance of the shoe floor interface under biomechanically-relevant conditions. *Ergonomics*, 37(3): 511-524.

Reitan, R.M., 1958. Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual Motor Skill*, 8: 271-276.

Rosen, W.G., 1980. Verbal fluency in aging and dementia. *Journal of Clinical Neuropsychology*, 2: 135-146.

Spyropoulos, P., Pisciotta, J.C., Pavlou, K.N., Cairns, M.A., Simon, S.R., 1991. Biomechanical gait analysis in obese men. *Archives of physics and medical rehabilitations*, 72: 1065-1070.

Tombaugh, T.N., 2004. Trail making test A and B: normative data stratified by age and education. *Archives of Clinical Neuropsychology*, 19(2): 203-214.

Tjemstrom, F., Fransson, P.A., Hafstrom, A., Magnusson, M., 2002. Adaptation of postural control to perturbations- a process that initiates long-term motor memory. *Gait & Posture*, 15(1): 75-82.

Troy, K.L., Donovan, S.J., Marone, J.R., Bareither, M.L., Grabiner, M.D., 2008. Modifiable performance domain risk-factors associated with slip-related falls. *Gait Posture*, 28(3): 461-465.

Tsai, Y.J., Powers, C.M., 2013. The influence of footwear sole hardness on slip characteristics and slip-induced falls in young adults. *Journal of Forensic Science*, 58(1): 46-50.

Wang, L., Li, J.X., Xu, D.Q., Hong, Y.L., 2008. Proprioception of ankle and knee joints in obese boys and nonobese boys. *Medical Science Monitor*, 14(3): 129-135.

Weber, K.D., Fletcher, W.A., Gordon, C.R., Jones, G.M., Block, E.W., 1998. Motor learning in the “podokinetic” system and its role in spatial orientation during locomotion. *Experimental Brain Research*, 120(3): 377-385.

Wechsler, D., 1981. Wechsler adult intelligence scale-revised. San Antonio, TX; Psychological Corp, Harcourt Brace Inc.

Wickens, C.D., Hollands, J.G., 2000. *Engineering psychology and human performance* 3rd Edition. Upper Saddle River, NJ: Prentice-Hall.

Wu, X., Lockhart, T.E., Yeoh, H.T., 2012. Effects of obesity on slip-induced fall risks among young obese males. *Journal of biomechanics*, 45(6): 1042-1047.

Wu, X., Madigan M.L., 2014. Impaired plantar sensitivity among the obese is associated with increased postural sway. *Neuroscience Letters*. Epub Ahead.

- Wu, X., Yeoh, H.T., 2014. Intrinsic factors associated with pregnancy falls. *Workplace health and Safety*, 62(10): 403-408.
- Wyszomieriski, S.A., Chambers, A.J., Cham, R., 2009. Knee strength capabilities and slip severity. *Journal of Applied Biomechanics*, 25(2): 140-148.
- Yamaguchi. T., Yano, M., Onodera, H., Hokkirigawa, K., 2012. Kinematics of center of mass and center of pressure predict friction requirement at shoe-floor interface during walking. *Gait & Posture*, 38(2): 209-214.
- Yang, F., Pai, Y.C., 2011. Automatic recognition of falls in gait-slip: a harness load cell based criterion. *Journal of Biomechanics*, 44(12): 2243-2249.
- Yang, F., Anderson, F.C., Pai, Y.C., 2008. Predicted threshold against backward balance loss following a slip in gait. *Journal of Biomechanics*, 41: 1823-1831.

Chapter 5 Conclusion and Future Implications

Over the past four decades, the prevalence of obesity in the United States among adults aged 20-74 has more than doubled from 15% to 35.7% (Flegal et al., 1998; Kuczmarski et al., 1994; Flegal et al. 2002; Flegal et al., 2010). This high prevalence is problematic because obesity is associated with numerous health problems including an increased risk of falls and subsequent injury. Individuals who are obese fall almost twice as often (27% vs. 15%) compared to non-obese individuals (Fjeldstad et al. 2008), and falls have been identified as the most common (~36%) cause of injuries in individuals who are obese (Matter et al. 2007). Thus, it is important to understand factors affecting falls in individuals who are obese to help develop effective intervention solutions to mitigate falls among these individuals.

Three studies were carried out to investigate the factors affecting fall risks among individuals who are obese. The first study explored the relationship between plantar sensitivity and postural sway among individuals who are obese. Obesity increases postural sway during quiet standing (Teasdale et al., 2013), and may do so, at least in part, due to impaired plantar sensitivity. Therefore, it is important to understand the relationship. The second study was designed to understand the association between executive functions and fall risks among individuals who are obese. The higher rates of falls among individuals who are obese could partly result from a relative inability, related to obesity, to effectively allocate attention to balance maintenance during multi-task conditions, leading to gait and postural control changes, and resulting in higher fall risks. Therefore, it is important to understand the association. The third study investigated differences in biomechanical and

physiological factors between obese fallers and non-fallers after a laboratory-induced slip. These studies are to our knowledge, the first investigated factors contributing to increased fall risks among individuals who are obese. The results from these studies provided insight to the factors through which obesity impairs balance, and provided useful insight for future efforts aimed at developing interventions to mitigate the deleterious effects of obesity on balance.

Results from the first study (Chapter 2) indicated individuals who are obese exhibited reduced plantar sensitivity and increased postural sway, and impaired plantar sensitivity was associated with increased postural sway, characterized as weak to moderate in strength. As such, impaired plantar sensitivity among individuals who are obese may be one of factors, through which obesity degrades standing balance among these same individuals. Therefore, improvements in plantar sensitivity may be able to help obese individuals' balance control. Results from the second study (Chapter 3) indicated that obesity may impair semantic memory, selective attention, and working memory. These impairments were associated with gait during dual-task walking, suggesting they may contribute to a higher risk of falling. Results from the third study (Chapter 4) suggested that altered gait pattern and working memory, lower BMI among individuals who are obese may be factors by which obesity increased slip-induced fall risks.

5.1 Overall conclusion

Reduced plantar sensitivity, impairments in executive function, altered gait pattern were associated with deficits in standing and walking balance control, and increased slip severity among individuals who are obese. Therefore, appropriate fall

prevention/intervention program targeting at some or all of these factors may be considered as solutions to decrease fall risks for obese individuals.

5.2 Future studies

This dissertation work incorporated unbalanced sample size between genders, and thus was not able to detect unbiased gender main effect or interactive effects involving gender. Future study may be carried out with balanced sample size between genders to study the gender differences that may influence falls in individuals who are obese. Our study also found obese individuals with higher BMI associated with reduced slip severity and faster non-slipping foot reaction time. However, the mechanism of such association was not clear. Future study may be carried out to understand the mechanism.

5.3 Plan for publications

Study one is published on Neuroscience Letters in 2014. Study two was submitted to Journal of Perceptual & Motor Skills, and is currently under revision. Study three will be submitted to American Society of Biomechanics as a conference abstract.

5.4 Intervention implications

No study to date has provided an effective solution to reduce falls in individuals who are obese, especially when they are exposed to large perturbations (i.e. slip). Therefore, more appropriate interventions programs may be warranted to attenuate fall risks in individuals who are obese. Several intervention programs could be used to prevent falls in individuals who are obese based upon the results from this dissertation work.

Excessive body fat are associated with a number of major cardiovascular diseases, Alzheimer's disease and metabolic diseases (Dobbelsteyn et al., 2001; Hsieh and Muto , 2006; Shiwaku et al., 2005; Woo et al., 2002; Zimmet et al., 2005). Therefore, weight loss is critical for improving the overall health in obese individuals (Pi-Sunyer 2002), and may be considered as one of the appropriate approaches to mitigate fall risks in individuals who are obese (Matrangola and Madigan 2009). Weight loss has the potential to improve balance and reduce the risks of falls (Maffiuletti et al., 2005; Teasdale et al., 2007). Maffiuletti et al. (2005) investigated the effects of weight loss as well as balance training on balance during single limb stance. Balance training consisted of repeated exposures to the balance task, i.e. single limb stance. This study found that weight loss by itself may not be effective for improving balance, when combined with balance training, obese individuals' single limb standing balance improved significantly. Strength training was also used in conjunction with weight loss interventions to attenuate decreases in muscle mass and strength from losing weight in another study (Matrangola and Madigan 2009). This study showed that less weight loss was needed compared to increased strength for a unit improvement in standing balance recovery ability, which suggested that weight loss may be a more powerful intervention than strength training in improving balance recovery using an ankle strategy. Therefore, the combination of weight loss and balance training/strength training may be effective solutions for individuals who are obese to mitigate risk of falling.

Resistance training have the capability of improving body mass composition, muscle strength, sensorimotor stability, functional mobility, gait speed and executive functions, and improvements in any of these characteristics can reduce fall risks in the elderly (Anderson and Behm, 2005; Bashiri, et al., 2011; Carroll, et al., 2001; Liu-Ambrose

et al., 2010; Roberts et al., 2012). Therefore, it can be an effective fall intervention solution (Gillespie et al., 2012) for individuals who are obese. Obese individuals, who are more likely to be physically sedentary (Lakka and Bouchard, 2005), may respond favorably to muscle strengthening training (Roberts et al., 2012). Therefore, resistance-training program may be a good candidate for fall intervention in individuals who are obese.

Reference

- Anderson, K., Behm, D.G., 2005. The impact of instability resistance training on balance and stability. *Sports Medicine*, 35(1): 43-53.
- Bashiri, J., Hadi, H., Razavi, S.D., Bashiri, M., 2011. Effect of resistance-balance training on dynamic balance in active elderly males. *Annals of Biological Research*, 2(5): 689-695.
- Carroll, T.J., Barry, B., Riek, S., Carson, R.G., 2001. Resistance training enhances the stability of sensorimotor stability. *Proceedings of the Royal Society of Biological Sciences*, 268: 1464.
- Dobbelsteyn, C.J., Joffres, M.R., MacLean, D.R., Flowerdew, G., The Canadian Heart health Survey Research Group, 2001. A comparative evaluation of waist circumference, waist-to-hip ratio and body mass index as indicators of cardiovascular risk factors. The Canadian Heart health Survey. *International Journal of Obesity*, 25: 652-661.
- Fjeldstad, C., Fjeldstad, A.S., Acree, L.S., Nickel, K.J., Gardner, A.W., 2008. The influence of obesity on falls and quality of life. *Dynamic Medicine*, 7 (4): 27 February.
- Flegal, K.M., Carroll, M.D., Ogden, C.L., Curtin, L.R., 2010. Prevalence and trends in obesity among US adults, 1999-2008. *The Journal of American Medical Association*, 303(3): 235-241.

Flegal, K.M., Carroll, M.D., Ogden, C.L., Johnson, C.L., 2002. Prevalence and trends in obesity among US adults, 1999-2000. *The Journal of American Medical Association*, 288(14): 1723-1727.

Flegal, K.M., Carroll, M.D., Kuczmarski, R.J., Johnson, C.L., 1998. Overweight and obesity in the United States: prevalence and trends, 1960-1994. *International journal of Obesity related Metabolism Disorders*, 22(1): 39-47.

Gillespie, L.D., Robertson, M.C., Gillespie, W.J., Sherrington C., Gates S., Clemson, L.M., Lamb, S.E., 2012. Interventions for preventing falls in older people living in the community (review). *The Cochrane Collaboration*. John Wiley & Sons, Ltd.

Hsieh, S.D., Muto, T., 2006. Metabolic syndrome in Japanese men and women with special reference to the anthropometric criteria for the assessment of obesity: proposal to use the waist-to-height ratio. *Preventive Medicine*, 42: 135-139.

Kuczmarski, R.J., Flegal, K.M., Campbell, S.M., Johnson, C.L., 1994. Increasing prevalence of overweight among US adults: the National Health and Nutritional Examination Surveys, 1960 to 1991. *The Journal of American Medical Association*, 272(3): 205-211.

Lakka, T.A., Bouchard, C., 2005. Physical activity, obesity and cardiovascular diseases. *Handbook of Experimental Pharmacology*, 170: 137-163.

Liu-Ambrose, T., Davis, J.C., Nagamatsu, L.S., Hsu, C.L., Katarynych, L.A., Khan, K.M., 2010. Changes in executive functions and self-efficacy are independently associated with improved usual gait speed in older women. *BMC Geriatrics*, 10: 25.

Maffioletti, N. A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., Lafortuna C.L., Sartorio A., 2007. Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *European Journal of Applied Physiology*, 101(1): 51-59.

Matrangola, S. L., Madigan, M.L., 2009. Relative effects of weight loss and strength training on balance recovery. *Medical Science and Sports Exercise*, 41(7): 1488-1493.

Matter, K.C., Sinclair, S.A., Hostetler, S.G., Xiang, H., 2007. A comparison of the characteristics of injuries between obese and non-obese inpatients. *Obesity (Silver Spring)*, 15(10): 2384-2390.

Pi-Sunyer, F.X., 2002. The obesity epidemic: pathophysiology and consequences of obesity. *Obesity*, 10(S12): 97S-104S.

Roberts, C.K., Croymans, D.M., Aziz, N., Butch, A.W., Lee, C.C., 2012. Resistance training increases SHBG in overweight/obese, young men. *Metabolism*, 62(5): 725-733.

Shiwaku, K., Annurad, E., Enkhamma, B., Nogi, A., Kitajima, K., Yamasaki, M., Yoneyama, T., Oyusuren, T., Yamane, Y., 2005. Predictive values of anthropometric measurements for multiple metabolic disorders in Asian populations. *Diabetes Research and Clinical Practice*, 69: 52-62.

Teasdale, N., Hue, O., Marcotte, J., Berrigan, F., Simoneau, M., Dore, J., Marceau, P., Marceau, S., Tremblay, A., 2007. Reducing weight increases postural stability in obese and morbid obese men. *International Journal of Obesity*, 31: 153-160.

Weiss, E.P., Racette, S.B., Villareal, D.T., Fontana, K., Steger-May, K., Schechtman, K.B., Klein, S., Ehsani, A.A., Holloszy, J.O., Washington University School of Medicine CALERIE Group, 2007. Lower extremity muscle size and strength and aerobic capacity decrease with caloric restriction but not with exercise-induced weight loss. *Journal of Applied Physiology*, 102(2): 634-640.

Woo, J., Ho, S.C., Yu, A.L.M., Sham, A., 2002. Is waist circumference a useful measure in predicting health outcomes in the elderly? *International Journal of Obesity*, 26:1349-1355.

Zimmet, P., Magliano, D., Matsuzawa, Y., Alberti, G., Shaw, J., 2005. The metabolic syndrome: a global public health problem and a new definition. *Journal of Atheroscler Thromb*, 12: 295-300.

Appendix A

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants In Research Projects Involving Human Subjects

Title of the Research Study

Improving safety guidelines for the construction industry

Principal Investigators

Maury Nussbaum, Ph.D. 231-6053
Industrial and Systems Engineering

Michael J. Agnew, Ph.D.
Industrial and Systems Engineering

Kevin Davy, Ph.D.
Human Nutrition, Foods, and Exercise

Michael L. Madigan, Ph.D.
Engineering Science and Mechanics

I. Purpose of this Study

Fall-related injuries are a major medical problem that costs billions of dollars annually in treatment and care. The purpose of this study is to better understand situations where falls can occur in the construction industry, and to use this knowledge to improve safety guidelines.

II. Procedures

A. Participant Selection

Up to 396 subjects aged 20-30 or 50-80 will be recruited. Individuals will be required to pass a screening questionnaire to exclude participants based on self-reported medical conditions that may increase their risk of injuring themselves or affecting the experimental results. Adults aged 65 and over will be required to have a minimum bone mineral density of the femoral neck of 0.65 g/cm² as assessed by x-ray.

Exclusion criteria – if you have any of the following conditions, you will not be allowed to participate:

- 1) Any of the following bone and joint problems: osteoporosis; knee or hip replacement; moderate to severe arthritis; chronic back or neck pain; surgery on the neck, spine, or knee.
- 2) Any of the following neurological problems: previous stroke resulting in weakness of one or both legs; Parkinson's disease; pinched spinal nerves causing pain or affecting gait; history of a detached retina.

- 3) Any of the following muscle problems: persistent muscle weakness; muscle wasting conditions; unrepaired inguinal hernia.
- 4) Any of the following cardiovascular problems: tire easily and have difficulty breathing during normal walking; congestive heart failure; cardiomyopathy; uncorrected aortic aneurysm; circulatory deficiencies in the feet associated with chronic diabetes; hemophilia; taking significant doses of anticoagulants.

B. Experimental Protocol

You will be asked to complete up to three experimental sessions.

Session 1 will be conducted in Dr. Madigan's lab (208 Norris Hall) and will take about 1.5 hours to complete. Upon arriving in the lab, the experimental protocol will be explained to you, and you will have the opportunity to ask questions. During this session, you will be asked to repeatedly walk along a walkway under 8 different experimental conditions, for a total of 24 trials. Reflective markers placed on your body will allow researchers to measure body movements during walking.

Session 2 will also be conducted in Dr. Madigan's lab (208 Norris Hall) and will take about 2 hours to complete. If your age is 65 or older, you will first be walked to another lab for a low-energy x-ray to make sure your hip bone is strong. Upon arriving back in the lab, the experimental protocol will be explained to you, and you will have the opportunity to ask questions. During this session, you will first be asked to stand as still as possible to evaluate your balance during quiet standing. Next, you will be asked to walk repeatedly along a walkway. During a randomly selected walk down the walkway, the experimentors may attempt to make you slip or trip. Should this happen, simply attempt to recover your balance and continue to walk to the end of the walkway. You will wear a harness suspended from an overhead support beam to prevent a fall in the event of a loss of balance.

Session 3 will be conducted in Dr. Madigan's lab (208 Norris Hall) and will take about 1.5 hours to complete. Upon arriving in the lab, the experimental protocol will be explained to you, and you will have the opportunity to ask questions. During this session, multiple measurements of leg strength will be collected. You will be seated on a specialized chair in our lab that measures muscle strength. When prompted by the investigator, you will be asked to push as hard as you can against the chair using muscles at either your right ankle, knee, or hip. These tests will be repeated multiple times while positioning your right ankle, knee, or hip at various joint angles.

III. Risks

Although this study involves the use of safety equipment to prevent contact with the floor during an experimentally induced fall, it does involve more than minimal risk for individuals with bone, joint, or muscle problems. For that reason, individuals with any of the exclusionary criteria have been excluded from the study. If you are aged 65 or older,

you will be exposed to small levels of x-ray radiation during hip scans, similar to the amount of radiation you are exposed to during a long-distance airline flight.

If you happen to fall and are “caught” by the safety harness, this could jolt you and as a result you could experience minor muscle pain (similar to those encountered in regular daily activities) or joint pain (neck, shoulder, knee, ankle). We have tested over 150 subjects in this and similar experiments to date. Out of these subjects, one experienced a minor ankle when her foot was put down awkwardly after slipping.

In the event that you are injured while participating in the study, you will be responsible for any expense associated with emergency medical treatment, as neither the researchers nor the University have money set aside for medical treatment expenses.

IV. Benefits

The scientific community will benefit through the additional information that is expected to result from the completion of this study. This information will improve our understanding of situations where falls can occur in the construction industry, and contribute to the improvement of safety guidelines.

No promise or guarantee of benefits has been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

The results of this research study may be presented in reports, publications, and presentations. Subject identity will not be disclosed in any situation. Subjects will only be identified using a unique identifying number assigned during your experiment.

Experiments will be videotaped to assist with our analysis, and possibly to show in a report, publication, or presentation. The tapes will be maintained under the supervision of the project PI's, stored in a laboratory with restricted access, and kept for the foreseeable future for documentation purposes.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation

You will be paid \$20/session for your participation. If you complete all three sessions, you will be paid a total of \$60.

VII. Freedom to Withdraw

You are free to withdraw from the study at any time without penalty. If you choose to withdraw, you will be paid \$10/hour for the sessions completed before withdrawal (up to a maximum of \$20/session).

VIII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities: accurately report my age, gender, and history of musculoskeletal injuries.

IX. Subject's Permission

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

Subject signature
Date

Witness
Date

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research related injury to the subject, I may contact:

<u>Investigator:</u>	Maury Nussbaum, PhD	231-6053	
	nussbaum@vt.edu		
<u>ISE Head:</u>	Don Taylor, PhD	231-9079	
	don.taylor@vt.edu		
<u>Chair, IRB:</u>	David M. Moore, DVM	231-4991	moored@vt.edu

Appendix B

ELSEVIER LICENSE TERMS AND CONDITIONS

Feb 26, 2015

This is a License Agreement between Xuefang Wu ("You") and Elsevier ("Elsevier") provided by Copyright Clearance Center ("CCC"). The license consists of your order details, the terms and conditions provided by Elsevier, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

Supplier	Elsevier Limited The Boulevard, Langford Lane Kidlington, Oxford, OX5 1GB, UK
Registered Company Number	1982084
Customer name	Xuefang Wu
Customer address	250 Durham Hall BLACKSBURG, VA 24061
License number	3576630388206
License date	Feb 26, 2015
Licensed content publisher	Elsevier
Licensed content publication	Neuroscience Letters
Licensed content title	Impaired plantar sensitivity among the obese is associated with increased postural sway
Licensed content author	None
Licensed content date	7 November 2014
Licensed content volume number	583
Licensed content issue number	n/a
Number of pages	6
Start Page	49
End Page	54
Type of Use	reuse in a thesis/dissertation
Portion	full article
Format	electronic

Are you the author of this Elsevier article?	Yes
Will you be translating?	No
Title of your thesis/dissertation	Toward understanding factors affecting falls among individuals who are obese
Expected completion date	Mar 2015
Estimated size (number of pages)	80
Elsevier VAT number	GB 494 6272 12
Permissions price	0.00 USD
VAT/Local Sales Tax	0.00 USD / 0.00 GBP
Total	0.00 USD
Terms and Conditions	

INTRODUCTION

1. The publisher for this copyrighted material is Elsevier. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at <http://myaccount.copyright.com>).

GENERAL TERMS

2. Elsevier hereby grants you permission to reproduce the aforementioned material subject to the terms and conditions indicated.

3. Acknowledgement: If any part of the material to be used (for example, figures) has appeared in our publication with credit or acknowledgement to another source, permission must also be sought from that source. If such permission is not obtained then that material may not be included in your publication/copies. Suitable acknowledgement to the source must be made, either as a footnote or in a reference list at the end of your publication, as follows:

"Reprinted from Publication title, Vol /edition number, Author(s), Title of article / title of chapter, Pages No., Copyright (Year), with permission from Elsevier [OR APPLICABLE SOCIETY COPYRIGHT OWNER]." Also Lancet special credit - "Reprinted from The Lancet, Vol. number, Author(s), Title of article, Pages No., Copyright (Year), with permission from Elsevier."

4. Reproduction of this material is confined to the purpose and/or media for which permission is hereby given.

5. Altering/Modifying Material: Not Permitted. However figures and illustrations may be altered/adapted minimally to serve your work. Any other abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of Elsevier Ltd. (Please contact Elsevier at permissions@elsevier.com)

6. If the permission fee for the requested use of our material is waived in this instance, please be advised that your future requests for Elsevier materials may attract a fee.

7. Reservation of Rights: Publisher reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

8. License Contingent Upon Payment: While you may exercise the rights licensed immediately upon issuance of the license at the end of the licensing process for the transaction, provided that you have disclosed complete and accurate details of your proposed use, no license is finally effective unless and until full payment is received from you (either by publisher or by CCC) as provided in CCC's Billing and Payment terms and conditions. If full payment is not received on a timely basis, then any license preliminarily granted shall be deemed automatically revoked and shall be void as if never granted. Further, in the event that you breach any of these terms and conditions or any of CCC's Billing and Payment terms and conditions, the license is automatically revoked and shall be void as if never granted. Use of materials as described in a revoked license, as well as any use of the materials beyond the scope of an unrevoked license, may constitute copyright infringement and publisher reserves the right to take any and all action to protect its copyright in the materials.

9. Warranties: Publisher makes no representations or warranties with respect to the licensed material.

10. Indemnity: You hereby indemnify and agree to hold harmless publisher and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

11. No Transfer of License: This license is personal to you and may not be sublicensed, assigned, or transferred by you to any other person

without publisher's written permission.

12. **No Amendment Except in Writing:** This license may not be amended except in a writing signed by both parties (or, in the case of publisher, by CCC on publisher's behalf).

13. **Objection to Contrary Terms:** Publisher hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and publisher (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

14. **Revocation:** Elsevier or Copyright Clearance Center may deny the permissions described in this License at their sole discretion, for any reason or no reason, with a full refund payable to you. Notice of such denial will be made using the contact information provided by you. Failure to receive such notice will not alter or invalidate the denial. In no event will Elsevier or Copyright Clearance Center be responsible or liable for any costs, expenses or damage incurred by you as a result of a denial of your permission request, other than a refund of the amount(s) paid by you to Elsevier and/or Copyright Clearance Center for denied permissions.

LIMITED LICENSE

The following terms and conditions apply only to specific license types:

15. **Translation:** This permission is granted for non-exclusive world **English** rights only unless your license was granted for translation rights. If you licensed translation rights you may only translate this content into the languages you requested. A professional translator must perform all translations and reproduce the content word for word preserving the integrity of the article. If this license is to re-use 1 or 2 figures then permission is granted for non-exclusive world rights in all languages.

16. **Posting licensed content on any Website:** The following terms and conditions apply as follows: Licensing material from an Elsevier journal: All content posted to the web site must maintain the copyright information line on the bottom of each image; A hyper-text must be

Posting licensed content on Electronic reserve: In addition to the above the following clauses are applicable: The web site must be password-protected and made available only to bona fide students registered on a relevant course. This permission is granted for 1 year only. You may obtain a new license for future website posting.

17. **For journal authors:** the following clauses are applicable in addition to the above:

Preprints:

A preprint is an author's own write-up of research results and analysis, it has not been peer-reviewed, nor has it had any other value added to it by a publisher (such as formatting, copyright, technical enhancement etc.).

Authors can share their preprints anywhere at any time. Preprints should not be added to or enhanced in any way in order to appear more like, or to substitute for, the final versions of articles however authors can update their preprints on arXiv or RePEc with their Accepted Author Manuscript (see below).

If accepted for publication, we encourage authors to link from the preprint to their formal publication via its DOI. Millions of researchers have access to the formal publications on ScienceDirect, and so links will help users to find, access, cite and use the best available version. Please note that Cell Press, The Lancet and some society-owned have different preprint policies. Information on these policies is available on the journal homepage.

Accepted Author Manuscripts: An accepted author manuscript is the manuscript of an article that has been accepted for publication and which typically includes author-incorporated changes suggested during submission, peer review and editor-author communications.

Authors can share their accepted author manuscript:

- – immediately
 - via their non-commercial person homepage or blog
 - by updating a preprint in arXiv or RePEc with the accepted manuscript
 - via their research institute or institutional repository for internal institutional uses or as part of an invitation-only research collaboration work-group

- directly by providing copies to their students or to research collaborators for their personal use
 - for private scholarly sharing as part of an invitation-only work group on commercial sites with which Elsevier has an agreement
- – after the embargo period
 - via non-commercial hosting platforms such as their institutional repository
 - via commercial sites with which Elsevier has an agreement

In all cases accepted manuscripts should:

- – link to the formal publication via its DOI
- – bear a CC-BY-NC-ND license - this is easy to do
- – if aggregated with other manuscripts, for example in a repository or other site, be shared in alignment with our hosting policy not be added to or enhanced in any way to appear more like, or to substitute for, the published journal article.

Published journal article (JPA): A published journal article (PJA) is the definitive final record of published research that appears or will appear in the journal and embodies all value-adding publishing activities including peer review co-ordination, copy-editing, formatting, (if relevant) pagination and online enrichment.

Policies for sharing publishing journal articles differ for subscription and gold open access articles:

Subscription Articles: If you are an author, please share a link to your article rather than the full-text. Millions of researchers have access to the formal publications on ScienceDirect, and so links will help your users to find, access, cite, and use the best available version.

Theses and dissertations which contain embedded PJAs as part of the formal submission can be posted publicly by the awarding institution with DOI links back to the formal publications on ScienceDirect.

If you are affiliated with a library that subscribes to ScienceDirect you have additional private sharing rights for others' research accessed under that agreement. This includes use for classroom teaching and internal training at the institution (including use in course packs and courseware programs), and inclusion of the article for grant funding purposes.

Gold Open Access Articles: May be shared according to the author-

selected end-user license and should contain a [CrossMark logo](#), the end user license, and a DOI link to the formal publication on ScienceDirect.

Please refer to Elsevier's [posting policy](#) for further information.

18. For book authors the following clauses are applicable in addition to the above: Authors are permitted to place a brief summary of their work online only. You are not allowed to download and post the published electronic version of your chapter, nor may you scan the printed edition to create an electronic version. **Posting to a repository:** Authors are permitted to post a summary of their chapter only in their institution's repository.

19. Thesis/Dissertation: If your license is for use in a thesis/dissertation your thesis may be submitted to your institution in either print or electronic form. Should your thesis be published commercially, please reapply for permission. These requirements include permission for the Library and Archives of Canada to supply single copies, on demand, of the complete thesis and include permission for Proquest/UMI to supply single copies, on demand, of the complete thesis. Should your thesis be published commercially, please reapply for permission. Theses and dissertations which contain embedded PJAs as part of the formal submission can be posted publicly by the awarding institution with DOI links back to the formal publications on ScienceDirect.

Elsevier Open Access Terms and Conditions

You can publish open access with Elsevier in hundreds of open access journals or in nearly 2000 established subscription journals that support open access publishing. Permitted third party re-use of these open access articles is defined by the author's choice of Creative Commons user license. See our [open access license policy](#) for more information.

Terms & Conditions applicable to all Open Access articles published with Elsevier:

Any reuse of the article must not represent the author as endorsing the adaptation of the article nor should the article be modified in such a way as to damage the author's honour or reputation. If any changes have been made, such changes must be clearly indicated.

The author(s) must be appropriately credited and we ask that you include the end user license and a DOI link to the formal publication on

ScienceDirect.

If any part of the material to be used (for example, figures) has appeared in our publication with credit or acknowledgement to another source it is the responsibility of the user to ensure their reuse complies with the terms and conditions determined by the rights holder.

Additional Terms & Conditions applicable to each Creative Commons user license:

CC BY: The CC-BY license allows users to copy, to create extracts, abstracts and new works from the Article, to alter and revise the Article and to make commercial use of the Article (including reuse and/or resale of the Article by commercial entities), provided the user gives appropriate credit (with a link to the formal publication through the relevant DOI), provides a link to the license, indicates if changes were made and the licensor is not represented as endorsing the use made of the work. The full details of the license are available at <http://creativecommons.org/licenses/by/4.0>.

CC BY NC SA: The CC BY-NC-SA license allows users to copy, to create extracts, abstracts and new works from the Article, to alter and revise the Article, provided this is not done for commercial purposes, and that the user gives appropriate credit (with a link to the formal publication through the relevant DOI), provides a link to the license, indicates if changes were made and the licensor is not represented as endorsing the use made of the work. Further, any new works must be made available on the same conditions. The full details of the license are available at <http://creativecommons.org/licenses/by-nc-sa/4.0>.

CC BY NC ND: The CC BY-NC-ND license allows users to copy and distribute the Article, provided this is not done for commercial purposes and further does not permit distribution of the Article if it is changed or edited in any way, and provided the user gives appropriate credit (with a link to the formal publication through the relevant DOI), provides a link to the license, and that the licensor is not represented as endorsing the use made of the work. The full details of the license are available at <http://creativecommons.org/licenses/by-nc-nd/4.0>. Any commercial reuse of Open Access articles published with a CC BY NC SA or CC BY NC ND license requires permission from Elsevier and will be subject to a fee.

Commercial reuse includes:

- – Associating advertising with the full text of the Article
- – Charging fees for document delivery or access
- – Article aggregation

- – Systematic distribution via e-mail lists or share buttons

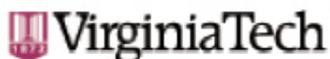
Posting or linking by commercial companies for use by customers of those companies.

20. Other Conditions:

Questions? customercare@copyright.com or +1-855-239-3415 (toll free in the US) or +1-978-646-2777.

Gratis licenses (referencing \$0 in the Total field) are free. Please retain this printable license for your reference. No payment is required.

Appendix C



Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4806 Fax 540/231-0958
email irb@vt.edu
website <http://www.irb.vt.edu>

MEMORANDUM

DATE: September 8, 2014
TO: Kevin Davy, Maury A Nussbaum, Michael Madigan, Xuefang Wu, Hoda Koushyar, Tina Rossi
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE: Effects of Obesity and Age on Fall Risk - Implications for Safety Guidelines
IRB NUMBER: 11-281

Effective September 8, 2014, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the Amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<http://www.irb.vt.edu/pages/responsibilities.htm>

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: **Full Review**
Protocol Approval Date: **April 14, 2014**
Protocol Expiration Date: **April 13, 2015**
Continuing Review Due Date*: **March 30, 2015**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Date*	OSP Number	Sponsor	Grant Comparison Conducted?
06/25/2012	10293906	National Institute for Occupational Safety & Health	Compared on 03/21/2011

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.