EFFECTS OF ANKLE INVERSION/EVERSION STRENGTH AND ROM ON MEDIAL LATERAL SWAY IN YOUNG AND ELDERLY POPULATIONS

By

KIMBERLY LOY

Bachelor of Science in ATHLETIC TRAINING

Oklahoma State University

Stillwater, OK

2013

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2016

EFFECTS OF ANKLE INVERSION/EVERSION

STRENGTH AND ROM ON MEDIAL LATERAL SWAY

IN YOUNG AND ELDERLY POPULATIONS

Thesis Approved:

Jason DeFreitas, PhD

Thesis Adviser

Jennifer Volberding, PhD

Matthew O'Brien, PhD

ACKNOWLEDGEMENTS

I would like to express my appreciation to my committee chair and mentor, Professor Jason DeFreitas, PhD. He has helped me develop and mold an idea into a well-organized research design.

I would also like to thank my committee members, Professor Jennifer Volberding, PhD and Professor Matthew O'Brien, PhD for their guidance as well as for the time they spent reading and revising my thesis, I truly appreciate their efforts.

Thank you to all of the graduate student staff in the HHP department for their support, specifically Ryan Thiele, MS, ATC for all of his help and support.

I would like to express my sincere appreciation to family and friends who provided not only support and love but for also being so understanding to the countless hours spent reading and writing instead of spending quality time with them.

Name: KIMBERLY LOY

Date of Degree: May, 2016

Title of Study: EFFECTS OF ANKLE INVERSION/EVERSION STRENGTH AND ROM ON MEDIAL LATERAL SWAY IN YOUNG AND ELDERLY POPULATIONS

Major Field: HEALTH & HUMAN PERFORMANCE

Abstract:

Many elderly individuals often suffer from severe falls due to a lack of postural stability. Fall prevention programs are often too advanced for elderly populations with a more sedentary lifestyle or injuries. Programs that emphasize lower leg muscles and the ankle joint could be more helpful to those individuals. The purpose of this study was to determine the effect that ankle IV/EV strength and ROM have on medial-lateral sway in young and elderly populations. Ankle IV/EV strength was measured using a custom built device connected to a load cell adaptor. Ankle range of motion was measured using an electro goniometer, and a Biodex balance system was used to determine medial-lateral sway. Pearson r correlations were done for each dependent variable of each group to obtain predictive values on ROM, MVC, and M-L stability index data. An alpha of $\leq .05$ was used to determine statistical significance. Our findings indicated a significant relationship between EV MVC and M-L Sway ($P = 0.011$; $r = -0.730$), EV MVC and EV PROM ($P = 0.015$; $r = 0.709$), as well as, EV MVC and AROM ($P = 0.035$; $r = 0.637$) for the elderly group. No significant relationships between ankle IN/EV MVC's, ROM and M-L sway in the young group or IN MVC and ROM in the elderly group. The results of this study may have been altered due to the mobile equipment malfunction. The participants in the elderly group had to come to the lab on campus and were more active than anticipated. Also, the average age of the elderly group was younger than anticipated.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

Hypotheses 2
Purpose 3

II. METHODS 4

Research Design 4
Participants/ Subjects 4
Sampling Method 5
Data Collection 5
Warm Up and ROM 6
MVC's 6
Signal Acquisition and Processing 6
Balance 7
Statistical Analysis 7

III. RESULTS 8

IV. Discussion 11

Purpose/Hypotheses 11
Comparison of Literature 11
Restatement of Results 13
Limitations/ Future Directions 13
Conclusion 14

REFERENCES 15

APPENDICES 18
Appendix A: Definition of Terms 18
Appendix B: Assumptions/Limitations 28
Appendix C: Literature Review 19
Appendix D: Vita 28

LIST OF TABLES

Table Page

1.1 9
1.2 9
1.3 9
1.4 9
2 9

LIST OF FIGURES

Figure Page

1 10
2 10
3 10

CHAPTER I

INTRODUCTION

Elderly individuals often suffer from fatal or debilitating falls due to the inability to recover from a loss of balance during daily physical activities.[1] It is estimated that 45% of elderly individuals will fall at least once per year.[2] Furthermore, falls increase in severity with increases in age and are a primary cause of unintentional fatal injuries in those over the age of 80.[2] Poor balance in the elderly can be attributed to several different physiological factors related to aging, such as decreased muscle strength and range of motion, increased joint stiffness, and an overall decrease in visual, vestibular, and somatosensory function.[3] Although visual, vestibular and somatosensory functions are known to be contributing factors in maintaining balance[4], they are not as easily altered as muscle strength and joint range of motion and stiffness.

Therefore, elderly individuals are now being encouraged to participate in exercise-based fall prevention programs that include balance, agility, and strength training.[5] According to Pijinappels et al., lower body resistance training programs can help to improve balance in the elderly.[1] Other fall prevention programs that have shown to be effective in improving balance include, but are not limited to, aerobic dance and stability ball training.[2] However, some elderly individuals are not capable of performing such programs safely, due to injury, and/ or lack of physical activity. Without a safe, exercise-based, fall prevention program that is easily performed, barely mobile elderly individuals will be less likely to regain mobility and return to daily activity. Due to a lack of mobility, an exercise-based program involving only the ankle joint and lower leg muscles may be more beneficial to less active elderly individuals until they can safely perform full body exercises.

The effect of lower extremity strength on balance has been heavily researched; however, most of these studies focus on the effect of hip and thigh strength on balance.[1] Yet, there hasn't been much research done on the effect of ankle strength, stiffness, and range of motion on balance. The few studies that have examined the effect of ankle strength on balance mainly focus on the effect of dorsi flexor (DF)- and plantar flexor (PF) strength on anterio–posterior (A-P) sway.[6] According to Ribeiro et al.,[6] strengthening the DF and PF muscles can improve A-P sway and functional mobility in the elderly. However, recent studies have reported that instability in the medio-lateral (M-L) direction is a better predictor of fall risk in the elderly.[7] Furthermore, falls in the M-L direction often result in hip fracture, which can lead to diminished quality of life and in some cases fatality.[7] Therefore, more research needs to be done on the causes of increased M-L sway in the elderly population.

Previous methods used to assess balance include, Tinetti Performance Oriented Balance and Mobility Assessments,[8] measuring center-of-pressure displacements on commercially designed force platforms,[3,9,10] and analyzing postural sway using motion analysis systems.[11] For this study used a Biodex Balance System (BBS), which will allowed us to calculate a medial-lateral stability index and an overall stability index during static and dynamic conditions[12]. The results of this study attempted to answer the following questions. Will ankle inversion and eversion strength correlate with postural sway and balance? Will ankle range of motion correlate with postural sway and balance? Will correlations of the dependent variables be dependent on age?

It was hypothesized that inversion (IV) and eversion (EV) strength, and ankle range of motion effect M-L sway in young and elderly populations and that ankle inversion and eversion strength decreases with age, as well as, range of motion decreases with age. It was also hypothesized that these dependent variables will have more of an effect on balance in the elderly individuals than in the younger individuals. The purpose of this study is to examine the effect of lower leg strength and ankle range of motion and stiffness on balance in young and elderly populations.

CHAPTER II

METHODS

Research Design

Participants were acquired using flyers placed around campus at Oklahoma State University and assisted living centers in Stillwater, OK in order to find young and elderly individuals. Participants were asked to refer other individuals in order to increase the sample size. Participants were split into two groups: a young group (YG), between the ages of 18 and 35, and an elderly group (EG) over the age of 65. Participants were then interviewed to obtain health and demographic information. Once they were approved to participate in the study they were familiarized with the testing protocol used for the study, and tested for ankle strength, range of motion, and stability.

Participants/ Subjects

The sample for this study is apparently healthy individuals. Each participant was between the ages of 18 and 35 or over the age of 65. The minimum age for the YG was 18 to avoid the need for parental involvement. The maximum age for the YG was 35 to avoid the high degree of variability regarding the aging process in the middle-aged population. The young group consisted of 3 males and 16 females (N=19, mean age (yrs) = 22.26 ± 4.45, height (m)= 1.69 ± 0.09, mass (kg) = 69.80 ± 15.40). The minimum age for the EG was 65 because individuals of this age tend to be more sedentary and have poor balance. The elderly group consisted of 5 males and 6 females (N=11, mean age (yrs) = 69.09 ± 3.70, height (m) = 1.70 ± 0.12, mass (kg) = 76.82 ±

12.94). Participants had no preexisting neuromuscular conditions, recent surgeries, recent injury or any ailment that could have prohibited their participation. This sample size was chosen in order to have a large enough representation of the population while also being small enough to manage the extensive testing for each subject. The participants accurately represent the population because the participants as well as the population are physically active as well as sedentary individuals who may or may not have balance issues.

Sampling method

Convenience sampling and snowball sampling was used to find participants for this study. Flyers were hung and handed out around the Oklahoma State University campus and at nearby assisted living facilities that state the criteria for participation and contact information. Volunteers were asked to let other individuals they know, that fit the criteria, about the study and how they can participate as part of the snowball sampling.

Data Collection

The EG volunteers were contacted through the assisted living center's staff and schedules were constructed for testing based on their availability. Participants set up a time to meet with the researcher at the Applied Musculoskeletal and Human Physiology Research Laboratory.

During the meeting, participants were familiarized with the testing protocol. Once the subjects verbally agreed to participate in the study and completed the approved IRB consent document, the subjects were asked to complete a Par-Q Exercise Readiness questionnaire, and a demographic questionnaire. The testing session lasted between 30-60 minutes.

Immediately after the participant filled out the appropriate paperwork, their ankle strength, ankle range of motion and balance was measured. Ankle strength was measured using a load cell attached to a custom built apparatus that allows for ankle inversion and eversion.

Maximal voluntary contractions (MVC's) were measured and recoded twice for ankle inversion and ankle eversion on the dominant leg. Passive and active ankle inversion and eversion range of motion, of the dominant leg, was measured and recorded twice using a commercially designed goniometer. Stability measurements were conducted on a Biodex balance system to assess ML postural sway.

Procedures

Warm Up and ROM

Each participant was familiarized with the movement of ankle inversion and eversion as a warm up prior to ROM testing. Passive and active ankle inversion and eversion ROM was measured using a electric biaxial goniometer. Electrogoniometers, when attached firmly and securely across the joint, provide precise, accurate, and reliable joint range of motion.[36] The electrogoniometer was placed along the Achilles tendon, with the end-blocks in parallel and fixed to the skin and/or sock with medical tape[37] in order to accurately measure ankle inversion and eversion ROM.

MVC's

Ankle inversion and eversion strength was measured using a custom built apparatus connected to a load cell adaptor. The participant was asked to perform two MVC's of ankle inversion and eversion lasting 3 seconds each.

Signal Acquisition and Processing

Joint angle from the electrogoniometer was collected with a 16-channel Biopac (MP150WSW, Biopac Systems Inc., Goleta, CA) system and analyzed with their AcqKnowledge

4.0 software. Force data from the load cell was collected with a 16-channel Bagnoli System (DelSys Inc., Boston, MA) and analyzed with their EMGworks software.

Balance

Medial-Lateral postural sway was measured using a biodex balance system (BBS). The BBS calculates M-L stability index by measuring, in degrees, the tilt about the M-L axis.[12] The M-L stability index will be obtained via the computer screen on the biodex balance system.[12]

Statistical Analysis

Pearson r correlations were done for each dependent variable for each group to obtain predictive values on ROM, MVC, and M-L stability index data. An alpha of $\leq .05$ was used to determine statistical significance. Procedures described by Pedhazur were intended to be used to compare the linear slope coefficients and y-intercepts of young and elderly for each significant correlation. [38] An alpha of ≤ 0.10 was going to be used for the individual slope and y-intercept comparisons to minimize type 2 error.[38] This comparison would have produced a common regression coefficient between the conditions being tested and help determine significant difference.[38] All statistics were performed using SPSS software package (IBM, Armonk, NY, USA).

CHAPTER III

RESULTS

Pearson r correlations were performed for each dependent variable of each group to obtain predictive values on ROM, MVC, and M-L stability index data. An alpha of $\leq .05$ was used to determine statistical significance. Procedures described by Pedhazur were not used to compare the linear slope coefficients and y-intercepts for each dependent variable due to the lack of significant correlations between dependent variables. Our findings indicated no significant relationships between ankle IN/EV MVC, ROM and M-L sway in the young group. However, a significant relationship was found between EV MVC and M-L Sway ($P = 0.011$; $r = -0.730$), EV MVC and EV PROM ($P = 0.015$; $r = 0.709$), as well as, EV MVC and AROM ($P = 0.035$; $r = 0.637$) for the elderly group. The p-values for each correlation tested are shown in Tables 1.1-1.4. The means and standard deviations for each variable and group are shown in Table 2. The significant correlations are shown below in Figures 1-3.

There were no significant relationships between IN/EV MVC, ROM, or M-L sway in the young group. Changes in IV/EV MVC and IV/EV ROM in the young group did not affect M-L stability. There were also no significant relationships between IN MVC, IN ROM, or M-L sway in the elderly group. Changes in IN MVC and IN ROM did not affect M-L stability in the elderly group. However, there was a significant relationship between EV MVC and EV AROM/PROM and M-L sway. Indicating that increases in EV MVC and EV PROM/AROM affect M-L sway in the elderly group.

Table 1.1 Young Group Inv Sig.

	INV_MVC	INV_PROM	INV_AROM	M-L_Sway
INV_MVC		0.53	0.888	0.096
INV_PROM	0.53		0.001	0.959
INV_AROM	0.888	0.001		0.765
M-L_Sway	0.096	0.959	0.765	

Table 1.2 Young Group Ev Sig.

	EV_MVC	EV_PROM	EV_AROM	M-L_Sway
EV_MVC		0.272	0.514	0.497
EV_PROM	0.272		0.001	0.632
EV_AROM	0.514	0.001		0.348
M-L_Sway	0.497	0.632		

Table 1.3 Elderly Group Inv Sig.

	INV_MVC	INV_PROM	INV_AROM	M-L_Sway
INV_MVC		0.507	0.553	0.572
INV_PROM	0.507		0.096	0.545
INV_AROM	0.553	0.096		0.248
M-L_Sway	0.572	0.545	0.248	

Table 1.4 Elderly Group Ev Sig.

	EV_MVC	EV_PROM	EV_AROM	M-L_Sway
EV_MVC		0.015*	0.035*	0.011*
EV_PROM	0.015*		0	0.052
EV_AROM	0.035*	0		0.095
M-L_Sway	0.011*	0.052	0.095	

Tables 1.1-1.4: INV and EV MVC p-values of correlations for each group. *Correlation is significant at the 0.05 level (2-tailed).

Table 2

	Age	**Inv MVC (N)**	**Ev MVC (N)**	**Inv Prom (°)**	**Ev Prom (°)**	**Inv Arom (°)**	**Ev Arom (°)**	**M-L Sway**
Young	22.26±4.45	65.89±32.72	30.29±16.50	46.79±9.15	25.31±5.60	33.23±9.55	22.16±5.92	0.12±0.01
Old	69.09±3.70	75.28±26.20	41.14±15.30	40.34±11.01	25.93±5.50	31.69±9.16	21.54±5.24	0.18±0.09

Table 2: Means ± SD for each variable and group.

Figure 1: Correlation between EV MVC and EV PROM in the Elderly Group

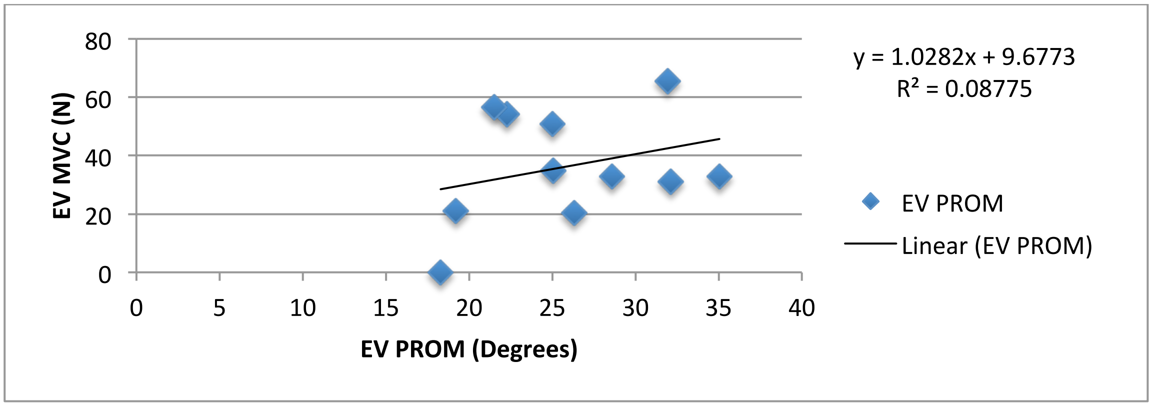


Figure 2: Correlation between EV MVC and EV AROM in the Elderly Group

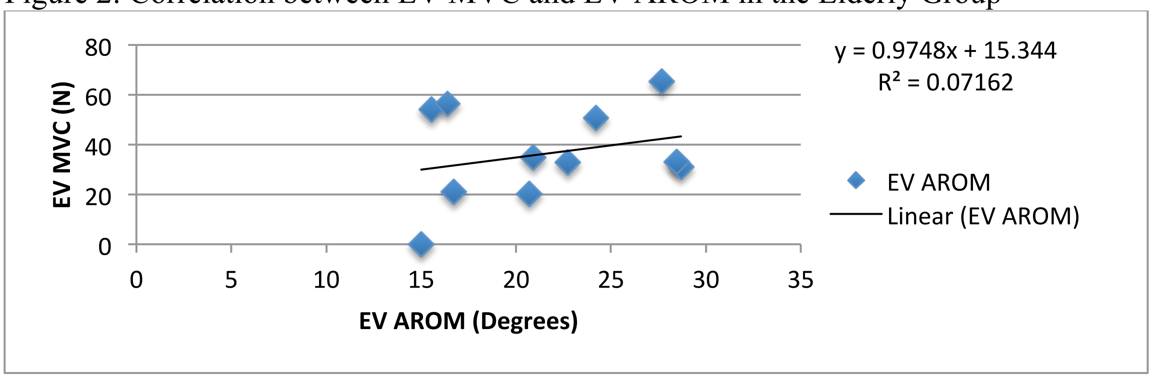
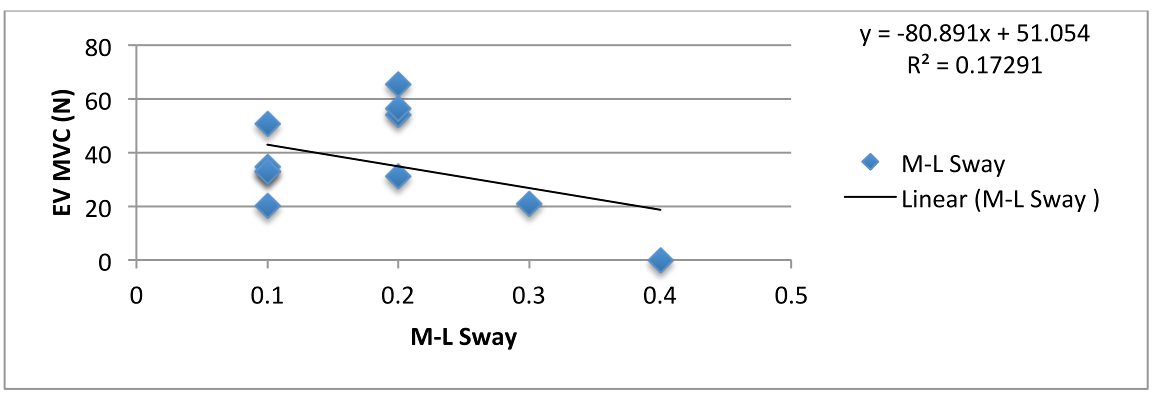


Figure 3: Correlation between EV MVC and M-L Sway in the Elderly Group



CHAPTER IV

DISCUSSION

Purpose/ Hypothesis

It was hypothesized that inversion (IV) and eversion (EV) strength, and ankle range of motion would effect M-L sway in young and elderly populations and that ankle inversion and eversion strength, as well as, ankle range of motion would decrease with age. It was also hypothesized that these dependent variables would have more of an effect on balance in the elderly individuals than in the younger individuals. The purpose of this study was to examine the effect of lower leg strength and ankle range of motion on balance in young and elderly populations. If a link between the measured dependent variables and balance is found, these variables may be the focus of future interventions targeting fall-prevention.

Comparison of Literature

The relationship between EV MVC and EV AROM, EV PROM, and M-L Sway in the elderly group, indicates that elderly individuals with stronger EV MVC have higher EV AROM/PROM and better balance in the M-L plane. Although no studies have been performed on IV/EV strength, Ribeiro et al., reported that an increase in strength of the dorsi- and plantar flexor muscles of the ankle causes a decrease in anterior-posterior (A-P) postural sway, thus improving balance.[6] Other researchers have also concluded that plantar flexor strength is strongly associated with A-P sway and an increase in plantar flexor strength could increase balance performance in the elderly.[19] Similarly, the results of this study suggest that increased EV strength in elderly populations may cause a decrease in M-L sway.

Some studies have reported that increased dorsi- and plantar flexion PROM decreases A-P sway[22,22] However another study concluded, an increase passive ankle range of motion actually increases postural sway and muscle activity.[24] Furthermore, Mecagni et al., concluded that the function of ankle range of motion differs between static and dynamic settings.[25] Our findings did not show a significant relationship between AROM or PROM and M-L sway. Our findings did however show a significant relationship between EV MVC and EV AROM/PROM. Suggesting that individuals with greater EV AROM/PROM may have stronger EV MVCs. No significant relationships were found between IV AROM/PROM and M-L sway and IV MVC.

The lack of a significant relationship between ankle IV/EV strength and ROM and balance in the young group could be due to the younger participants relying on vision and somatosensory inputs rather than increased muscle activity. The results of this study suggest that the elderly populations may rely more on ankle EV to maintain M-L stability than younger populations. Deficiencies in vision and somatosensory inputs in elderly populations have been known to cause elderly individuals to rely on increased muscle activity and stiffness to decrease sway displacement.[3] Previous studies have reported relationships between decreased PROM and increased levels of joint stiffness.[39] Even though the means of PROM between the two groups did not vary, joint stiffness could be a factor affecting balance in the elderly population.

According to Piirainen et al., elderly individuals have higher amounts of postural sway than younger populations.[9] The results of this study did not show a higher amount of M-L sway in elderly individuals than in young individuals. Hypothetically, IV/EV MVC's and IV/EV AROM/PROM should have been higher in the younger group than in the elderly group, which was not observed in this study. This could be due to the high activity levels of the participants in the elderly group. The individuals in the elderly group were anticipated to lead a sedentary lifestyle. However due to the elderly groups mean age being much lower than expected, the participants in the elderly group were fairly active individuals.

Restatement of Results

The hypothesis that inversion (IV) and eversion (EV) strength effect M-L sway in young and elderly populations was only partially supported by the result of this study. Our findings did show a significant relationship between EV strength and M-L sway in the elderly group, but did not find any significant relationships between IV strength and M-L sway in the elderly group or IV/EV strength and M-L sway in the young group. The hypothesis that ankle range of motion effects M-L sway in young and elderly populations and that ankle inversion and eversion strength decreases with age, as well as, range of motion decreases with age, was not supported by the results of this study. However, the hypothesis that the dependent variables would have more of an effect on balance in the elderly individuals than in the younger individuals was partially supported by the results of this study. Eversion MVC strength did have more of an effect on M-L sway in the elderly group than it did in the young group.

Limitations/ Future Directions

Furthermore, the hypothesized results of this study may have been altered due to the malfunction of the mobile equipment that was going to be used so testing could take place in a retirement home. Due to the malfunction, the participants in the elderly group had to come to the lab on campus, causing a loss of sedentary participants and increase in participants that were much more active than anticipated. This also caused the average age of the elderly group to be younger than anticipated. Further studies should be done to compare the young population with an older aged group of sedentary adults.

Conclusion

Although not all hypotheses were supported by this study, significant relationships were found between EV MVC and EV AROM/PROM and M-L sway in the elderly group. This relationship does suggest a greater reliance on muscle strength and joint ROM to maintain M-L stability in the elderly group than in the young. This finding could provide evidence for future studies to further assess the effect of ankle strength and ROM on balance in elderly populations. If these findings are supported in future studies, IV/EV ankle-strengthening protocols may be used to help prevent falls and increase M-L stability in elderly populations.

REFERENCES

1. Pijnappels M, Reeves ND, Maganaris CN, van Dieen JH. Tripping without falling; lower limb strength, a limitation for balance recovery and a target for training in the elderly. *J Electromyogr Kinesiol.* 2008;18(2):188-196.
2. Rogers ME, Fernandez JE, Bohlken RM. Training to reduce postural sway and increase functional reach in the elderly. *J Occup Rehabil.* 2001;11(4):291-298.
3. Singh NB, Taylor WR, Madigan ML, Nussbaum MA. The spectral content of postural sway during quiet stance: influences of age, vision and somatosensory inputs. *J Electromyogr Kinesiol.* 2012;22(1):131-136.
4. Chevutschi A, D'Houwt J, Pardessus V, Thevenon A. Immediate effects of talocrural and subtalar joint mobilization on balance in the elderly. *Physiother Res Int.* 2015;20(1):1-8.
5. Mackey DC, Robinovitch SN. Mechanisms underlying age-related differences in ability to recover balance with the ankle strategy. *Gait Posture.* 2006;23(1):59-68.
6. Ribeiro F, Teixeira F, Brochado G, Oliveira J. Impact of low cost strength training of dorsi- and plantar flexors on balance and functional mobility in institutionalized elderly people. *Geriatr Gerontol Int.* 2009;9(1):75-80.
7. Aoki M, Nishihori T, Jiang Y, Nagasaki S, Wakaoka T, Ito Y. Damping control of balance in the medial/lateral direction and the risk of falling in the elderly. *Geriatr Gerontol Int.* 2013;13(1):182-189.
8. Laughton CA, Slavin M, Katdare K, et al. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait Posture.* 2003;18(2):101-108.
9. Piirainen JM, Linnamo V, Cronin NJ, Avela J. Age-related neuromuscular function and dynamic balance control during slow and fast balance perturbations. *J Neurophysiol.* 2013;110(11):2557-2562.
10. Melzer I, Kurz I, Oddsson LI. A retrospective analysis of balance control parameters in elderly fallers and non-fallers. *Clin Biomech (Bristol, Avon).* 2010;25(10):984-988.
11. Fujimoto M, Hsu W-L, Wollacott MH, Chou L-S. Ankle dorsiflexor strength relates to the ability to restore balance druing backward support surface translation. *Gait & Posture.* 2013;38:812-817.
12. Cachupe WJC, Shifflett B, Kahanov L, Wughalter EH. Reliability of biodex balance system measures. *Measurement in Physical Education and Exercise Science.* 2001;5(2):97-108.
13. Vlutters M, Boonstra TA, Schouten AC, van der Kooij H. Direct measurement of the intrinsic ankle stiffness during standing. *J Biomech.* 2015;48(7):1258-1263.

14. Lark SD, Buckley JG, Bennett S, Jones D, Sargeant AJ. Joint torques and dynamic joint stiffness in elderly and young men during stepping down. *Clinical Biomechanics.* 2003;18:848-855.
15. Ryan ED, Herda TJ, Costa PB, et al. Passive properties of the muscle-tendon unit: the influence of muscle cross-sectional area. *Muscle Nerve.* 2009;39(2):227-229.
16. In: Donald Venes MD, M.S.J., ed. *Taber's Cyclopedic Medical Dictionary* 21 ed: F.A. Davis Company; 2009.
17. Docherty CL, Arnold BL, Zinder SM, Granata K, Gansneder BM. Relationship between two proprioceptive measures and stiffness at the ankle. *Journal of Electromyography and Kinesiology.* 2004;14(3):317-324.
18. Aberg AC, Frykberg GE, Halvorsen K. Medio-lateral stability of sit-to-walk performance in older individuals with and without fear of falling. *Gait Posture.* 2010;31(4):438-443.
19. Bok SK, Lee TH, Lee SS. The effects of changes of ankle strength and range of motion according to aging on balance. *Ann Rehabil Med.* 2013;37(1):10-16.
20. Schrager MA, Kelly VE, Price R, Ferrucci L, Shumway-Cook A. The effects of age on medio-lateral stability during normal and narrow base walking. *Gait Posture.* 2008;28(3):466-471.
21. Citaker S, Guclu-Gunduz A, Yazici G, Bayraktar D, Nazliel B, Irkec C. Relationship between lower extremity isometric muscle strength and standing balance in patients with multiple sclerosis. *NeuroRehabilitation.* 2013;33(2):293-298.
22. Gajdosik RL. Relation of age and passive properties of an ankle dorsiflexion stretch to the timed one-leg stance test in older women. *Percept Mot Skills.* 2006;103(1):177-182.
23. Menz HB, Morris ME, Lord SR. Foot and ankle characteristics associated with impaired balance and functional ability in older people. *J Gerontol A Biol Sci Med Sci.* 2005;60(12):1546-1552.
24. Lima BN, Lucareli PR, Gomes WA, et al. The acute effects of unilateral ankle plantar flexors static- stretching on postural sway and gastrocnemius muscle activity during single-leg balance tasks. *J Sports Sci Med.* 2014;13(3):564-570.
25. Mecagni C, Smith JP, Roberts KE, O'Sullivan SB. Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlational study. *Phys Ther.* 2000;80(10):1004-1011.
26. Bottaro A, Casadio M, Morasso PG, Sanguineti V. Body sway during quiet standing: is it the residual chattering of an intermittent stabilization process? *Hum Mov Sci.* 2005;24(4):588-615.
27. Rozendaal LA, van Soest AJ. Stabilization of a multi-segment model of bipedal standing by local joint control overestimates the required ankle stiffness. *Gait Posture.* 2008;28(3):525-527; author reply 528-529.

28. Edwards WT. Effect of joint stiffness on standing stability. *Gait Posture.* 2007;25(3):432-439.
29. Morasso PG, Schieppati M. Can muscle stiffness alone stabilize upright standing? *Journal of Neurophysiology* 1999;83:1622-1626.
30. Casadio M, Morasso PG, Sanguineti V. Direct measurement of ankle stiffness during quiet standing: implications for control modelling and clinical application. *Gait Posture.* 2005;21(4):410-424.
31. Papegaaij S, Taube W, Baudry S, Otten E, Hortobagyi T. Aging causes a reorganization of cortical and spinal control of posture. *Front Aging Neurosci.* 2014;6(28):28.
32. Collins JJ, De Luca CJ, Burrows A, Lipsitz LA. Age-related changes in open-loop and closed-loop postural control mechanisms. *Exp Brain Res.* 1995;104(3):480-492.
33. Izquierdo M, Aguado X, Gonzalez R, Lopez JL, Hakkinen K. Maximal and explosive force production capacity and balance performance in men of different ages. *Eur J Appl Physiol Occup Physiol.* 1999;79(3):260-267.
34. Amiridis IG, Hatzitaki V, Arabatzi F. Age-induced modifications of static postural control in humans. *Neuroscience Letters.* 2003;350(3):137-140.
35. Lacraz G, Rouleau AJ, Couture V, et al. Increased Stiffness in Aged Skeletal Muscle Impairs Muscle Progenitor Cell Proliferative Activity. *PLoS One.* 2015;10(8):e0136217.
36. Rowe PJ, Myles CM, Hillmann SJ, Hazlewood ME. Validation of Flexible Electrogoniometry as a Measure of Joint Kinematics. *Physiotherapy.* 2001;87(9):479-488.
37. Bronner S, Agraharasamakulam S, Ojofeitimi S. Reliability and validity of a new ankle electrogoniometer. *J Med Eng Technol.* 2010;34(5-6):350-355.
38. Pedhazur EJ, Schmelkin LP. *Measurement, design, and analysis: an integrated approach.* Hillsdale, N.J.: Lawrence Erlbaum Associates; 1991.
39. Ty B. Palmer, & Joel T. Cramer. Reliability of manual versus automated techniques for assessing passive stiffness of the posterior muscles of the hip and thigh *Journal of Sports Sciences.* 2013;31(8):867-877.

APPENDICES

Appendix A:

Definition of Terms

- Balance training: “Exercises that improve a person’s agility and gait stability while preventing falls ”.[16]
- Muscle stiffness: “the combination of active and passive stiffness, defined as the ratio of change in force to change in length”.[17]
- Dorsiflexion: “Movement of a part at a joint to bend the part toward the dorsum, or posterior aspect of the body”.[16]
- Plantarflexion: “Extension of the foot so that the forepart is depressed with respect to the position of the ankle”.[16]
- Invert (Inversion): “To bend the foot in at the ankle so that the sole is facing toward the inside of the leg”.[16]
- Eversion: “Turning [the ankle] outward”.[16]
- Postural Sway: “Forward and backward movement of the body with motion occurring around the ankle joints when the feet are fixed on the floor”.[16]

Appendix B:

Assumptions

- For this study, it was assumed that the participants answered the background information truthfully and correctly follow the instructions that are given to them throughout the course of the study.
- It is assumed that maximal effort will be given during MVC testing.

Appendix C:

LITERATURE REVIEW

The purpose of this study is to examine the effect of lower leg strength and ankle range of motion and stiffness on balance in young and elderly populations. This literature review will provide detailed descriptions on the effects of lower leg and ankle characteristics on balance. It will encompass the effects of lower leg strength, ankle range of motion, and ankle stiffness on balance in young and elderly populations. The first segment of the review will explain how postural sway plays a role in balance. The second aspect of the review will provide insight as to how ankle strength affects balance. The third aspect of the review will discuss the effect of ankle range of motion and stiffness on balance. As a final point, a review on the effects of age on balance will be included.

Postural Sway

Several studies have linked increased fall risk with an increase in postural sway.[10] According to Singh et al., postural sway can be significantly influenced by several factors including age, vestibular, vision, and somatosensory inputs.[3] Although vestibular, vision, and somatosensory inputs are known to play a role in balance,[3] they may not be as easy to treat as other age related influences on balance. Other researchers have linked increases in postural sway to an age-related increase in lower-extremity muscle activity during quiet stance.[8] This increase in lower extremity muscle activity can be associated with a decrease in lower extremity muscle mass and a reduction in force-generating capacity while standing.[10] Therefore, weakness in the lower extremity could result in an elderly individuals inability to produce enough force to correct his/her center of gravity and prevent a fall after a loss of balance.[10]

It is well known that the risk of falling and fall related injuries increases with age.[5] Most falls reported in the elderly population occur during walking and sit-to-walk tasks, such as getting out of a chair.[18] Therefore, the focus of common research has been on the effect of A-P postural sway on fall risk, since it is the direction of walking.[7] According to Ribeiro et al., Bok et al., and Fujimoto et al., a decrease in A-P sway results in better balance and a decrease in fall risk.[6,11,19]

However, recent studies have associated a greater fall risk with increased sway in the M-L direction.[7] Schrager et al. suggest, instability during walking occurs predominantly in the M-L direction and M-L instability during stance and gait is a major risk factor for falls in the elderly.[20] Furthermore, elderly individuals that fall in the M-L direction often suffer from more debilitating falls, such as hip fractures, which can result in a diminished quality of life.[7] Yet, there hasn't been a lot of research done on the cause of M-L instability in the elderly population. Consequently, the cause of M-L falls in the elderly needs to be studied more closely in order to reduce the risk of such debilitating falls.

Lower Leg Strength

Decreased mobility and balance impairments in elderly populations are often associated with muscle weakness in the lower limbs.[6] Thus, several studies have been conducted on the effect of lower limb resistance training on balance and functional mobility in the elderly.[2] Lower limb strength plays a major role in balance recovery and the strength of an individual's legs can be used to identify fall risk.[1] According to Citaker et al., strengthening the whole lower extremity improves balance and resistance training should be added to rehabilitation and balance training programs.[21] Therefore, elderly individuals are being encouraged to participate in balance training programs, that include lower extremity strength training, in order to reduce their risk of falling.[6] However, some of the balance programs that have been suggested may be too difficult for sedentary elderly individuals and individuals' dependent on assistive devices, such as walkers and wheel chairs. Consequently, a strength-training program, that involves only the ankle, may be a better starting point for a less active population.

Given that, until recently, most falls were thought to occur in the A-P direction, most of the research on the effect of ankle strength on balance has focused on dorsi- and plantar flexor strength on A-P sway. According to Ribeiro et al., an increase in strength of the dorsi- and plantar flexor muscles of the ankle causes a decrease in A-P postural sway, thus improving balance.[6] Other researchers have also concluded that plantar flexor strength is strongly associated with A-P sway and an increase in plantar flexor strength could increase balance performance in the elderly.[19] Nonetheless, it has recently been reported that M-L sway may play a larger role in balance and may be a better predictor of falls in the elderly than A-P sway.[20] Yet, little research has been done on the effect of ankle strength on M-L sway. In the same way that dorsi- and plantar flexor strength effects A-P sway, inversion and eversion could play a major role in M-L sway. It is probable that an increase in inversion and eversion strength could decrease M-L sway and improve balance. In addition, an improvement in M-L stability could lessen the risk of debilitating or life threatening falls.[18] Therefore, further research needs to be done on the effect of inversion and eversion strength on M-L sway and balance.

ROM

Along with increases in postural sway and decreases in stability and muscle strength, aging is also associated with decreases in joint range of motion.[22] Ankle flexibility is strongly correlated with postural sway and stability in elderly populations.[23] Moreover, decreased ankle dorsiflexion range of motion can attribute to an increase in fall risk in elderly populations.[22] Therefore, increasing the maximal angle of dorsiflexion at the ankle could enhance balance and should be included in balance training programs.[22]

Conversely, the results of a study conducted by Lima et al., concluded that static-stretching to increase passive ankle range of motion actually increases postural sway and muscle activity.[24] Though, the increase in postural sway and muscle activity was only temporary and the subjects of this particular study were young healthy individuals.[24] Furthermore, Mecagni et al., concluded that the function of ankle range of motion differs between static and dynamic settings.[25] Chevutschi et al., discovered that an increase in dorsi- and plantar flexion effectively decreases postural sway during static stance.[4] However, Chevutschi et al., also observed that an increase in dorsi- and plantar flexion range of motion increases postural sway and decreases stability in dynamic settings.[4] More research needs to be done to determine whether increased or decreased ankle range of motion is more important to the desired outcome of an overall increase in stability in elderly populations. Additionally, most research on the effect ankle range of motion on balance focuses on dorsi- and plantar flexion range of motion on A-P sway and very little research has been done on the effect of inversion and eversion range of motion on M-L sway. Given that M-L sway is associated with greater fall risk,[7] further research should focus on the effect of inversion and eversion range of motion on M-L sway.

Muscle Stiffness

Similar to ROM, muscle stiffness may also play a role in postural sway and maintaining balance.[26] The amount of muscle activation at a joint can determine the level of joint stiffness and can protect a joint by preventing excessive joint translations caused by external perturbations to prevent injury.[17] The correlation between muscle activation and joint stiffness may explain why some people tilt slightly forward when standing.[26] Tilting slightly forward causes constant muscle activation at the ankle joint and increases intrinsic ankle stiffness.[26] Intrinsic ankle stiffness can be determined by rotating the foot and measuring the torque response.[13]

Recent research suggests ankle stiffness contributes to static balance and the amount postural sway.[13] Determining the minimum level of ankle stiffness required to stabilize the ankle could determine the role of ankle stiffness in maintaining balance.[27] Edwards claims "joint stiffness alone may be sufficient to control stability and that a minimum ankle joint stiffness defines a threshold for stability."[28] Conversely, Morasso & Schieppati suggest that ankle stiffness alone is not enough to maintain upright stance.[29] Moreover, Casadio et al., imply there is a level of critical stiffness needed to maintain balance without neural intervention.[30] For instance, if ankle stiffness is at or beyond the critical level, stability can be maintained without further compensation but, if the amount of ankle stiffness falls below the critical level, active stabilization is needed to maintain stability.[30]

In contrast, Bottaro et al., imply that stiffness aids in reducing the rate of postural sway rather than playing a direct role in maintaining upright stance.[26] Further research is needed to determine the exact role of ankle stiffness in maintaining balance, as well as, the amount of stiffness that may be needed to reduce fall risk.

Effects of Aging

As people age, structural and functional changes occur in the neuromotor system.[31] These changes often result in decreased nerve conduction velocity and response amplitude, slowed motor performance, decreased joint position sense and increased muscle co-activation.[31] All of these changes play a role in postural control and may be the cause of decreased stability in the elderly population.[31] Decreased stability in elderly populations can lead to a decrease in mobility and an increase in fall risk.[20] According to Piirainen et al., elderly individuals have higher amounts of postural sway and take longer to recover balance when exposed to external perturbations than younger populations.[9]

Age related changes in the postural control system contribute to the increase in postural sway seen in elderly individuals[8]. The postural control system maintains upright stance through open and closed-loop control mechanisms[8]. Open-loop mechanisms function for a short-term, without sensory feedback, and are responsible for the steady-state activity levels of the postural muscles[8]. Whereas, closed-loop mechanisms operate over a longer term, with sensory feedback, and correspond to the visual, vestibular, and somatosensory systems.[8] The open-loop postural control mechanisms are less stable and are utilized for a longer period of time in the elderly than in younger adults, which suggests a greater delay before closed-loop mechanisms are utilized in the elderly[32]. The change in open-loop postural control mechanisms, seen in elderly individuals, may be due to an increase in lower limb muscle activity, which can cause larger noise-like fluctuations across joints and increase the amount of short-term postural sway[8].

Furthermore, elderly individuals exhibit increased levels of muscle co-activation in response to postural perturbations and during quiet standing when compared to younger individuals. Melzer et al., suggest that the increase in muscle co-activation is a strategy, used by the elderly, to increase proprioceptive input and compensate for a decrease in lower limb muscle strength and power[10]. Additionally, Laughton et al. imply that weakness in the lower limbs could impair an elderly individuals ability to maintain balance and increasing muscle co-activation in the lower limbs is an attempt to increase stability after a loss of muscle strength[8]. Age-related increases in muscle co-activation may also compensate for the deterioration of sensory and neuromuscular control mechanisms by increasing the firing rate and recruitment of primary afferents; which enhances closed-loop postural control mechanisms and joint proprioception.[8] However, it has also been reported that co-activation of the lower limb muscles may be responsible for the increase in short-term postural sway, seen in elderly individuals. Still, it is unknown whether increased muscle activity is a compensation strategy to reduce short-term postural sway or a contributing factor of increased short-term postural sway[8].

Regardless, decreased muscle strength in the lower limbs has been identified as one of the key factors contributing to fall risk in elderly populations.[19] This loss of muscle strength can be attributed to age related alterations in the muscles.[1] Elderly individuals often exhibit smaller muscle size than younger individuals; which could be due to a decrease in the size and number of muscle fibers, changes in the internal arrangement of muscle fibers, and a reduction in force per unit area of single fibers and whole muscle.[1] According to Mackey and Robinovitch, elderly women with a history of falls have decreased ankle muscle strength and speed of muscle response compared to healthy young women.[5] In addition to longer reaction time, elderly individuals also display slower torque development once onset has occurred; which could be due to the age related loss of fast twitch muscle fibers.[5] Izquierdo et al. found that elderly individuals show impaired balance with age related decreases in force development.[33] Age related deficits in muscle strength, rate of force development, and speed of response all make it difficult for elderly individuals to coordinate appropriate muscle action patterns necessary to prevent a fall.[1] Muscle patterns for postural movement include those of the hip, the ankle, or a combination of both.[34] Compared to young individuals, elderly individuals tend to show an overreliance on hip joint action when maintaining balance and preventing a fall.[34] Elderly individuals increase muscle activity at the hip and ankle when exposed to increased postural demands, whereas younger individuals only increase muscle activity at the ankle.[34] The added activity of the hip muscles in elderly individuals could be due to insufficient torque production at the ankle, a greater loss of motor units in the distal muscles than in the proximal muscles, and an insufficient proprioceptive contribution from the foot and ankle.[34] The increased muscle activity at the hip may also be a strategy to compensate for decreased ROM at the ankle.

Elderly individuals are also known to have decreased ankle joint ROM, which has been associated with impairments in balance[25] and increased postural sway in elderly individuals.[23] Ankle ROM is crucial for maintaining postural control at the initial stance phase of walking.[19] A minimum of 10 degrees of dorsiflexion[25] and 20 degrees of plantar flexion is required for functional movement patterns during walking.[4] As age increases, ankle inversion, eversion, dorsi- and plantarflexion decreases, which may require elderly individuals to alter movement patterns during walking and compromise balance.[25] Decreased dorsiflexion ROM has been strongly associated with increased sway in the A-P direction[22] and decreased eversion ROM has been associated with increased sway in the M-L direction.[19] However, ankle ROM deficits in the elderly population are not irreversible.[4] Chevutschi et al. reported passive mobilization at the ankle joint causes immediate, short-term improvements in dorsi- and plantarflexion ROM, which could improve static balance.[4]

Similar to ankle ROM, ankle stiffness is also known to be a factor of instability in elderly populations.[4] Elderly populations tend to show increased ankle stiffness when compared to younger populations.[7] Age related changes in the extracellular matrix (ECM) of skeletal muscle play a large role in the increase of muscle stiffness.[35] As age increases, the accumulation of cross-linked collagen, a component of ECM in skeletal muscle, also increases.[35] According to Lacraz et al., this increase in collagen is responsible for the increase in muscle stiffness found in elderly populations.[35] As suggested previously, ankle stiffness is thought to contribute to static balance and the amount postural sway in both young and elderly populations.[13]

Conclusion

In conclusion, age related changes in lower leg strength, ankle stiffness, and ankle ROM are all major determinants of postural sway and fall risk in the elderly.[13,1,23] According to Schrager et al., instability during walking occurs predominantly in the M-L direction and M-L instability during stance and gait is a major risk factor for falls in the elderly.[20] Furthermore, weakness in the lower extremity could result in an elderly individuals inability to produce enough force to correct his/her center of gravity and prevent a fall after a loss of balance.[10] Since M-L sway and muscle weakness in the lower extremity have been associated with increased fall risk in elderly populations,[7] more research needs to be done on the effects of inversion and eversion strength, ankle stiffness, and ankle ROM on postural sway and balance in elderly populations.

VITA

Kimberly Michelle Loy

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF ANKLE INVERSION/EVERSION STRENGTH AND ROM ON MEDIAL LATERAL SWAY IN YOUNG AND ELDERLY POPULATIONS

Major Field: Health & Human Performance

Biographical:

Education:

Completed the requirements for the Master of Science in Health & Human Performance with an option in Applied Exercise Science at Oklahoma State University, Stillwater, Oklahoma in May 2016.

Completed the requirements for the Bachelor of Science in Athletic Training at Oklahoma State University, Stillwater, Oklahoma in July 2013.

Experience:

Graduate Teaching Assistant – Department of Health and Human Performance
Aug 2014- Dec 2015

Professional Memberships:

The Honor Society of Phi Kappa Phi Fall 2015 – Present
National Strength and Conditioning Association Spring 2016

Awards:

Betty Abercrombie Memorial Endowed Scholarship Award Spring 2015