Utilizing Stochastic Resonance to Improve Agility and Rapid Stepping

by
Jessica Kirchner
B.S., University of Kansas, 2020

Submitted to the graduate degree program in Mechanical Engineering and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science

____

Chairperson: Dr. Carl Luchies

____

Dr. Lisa Friis

____

Dr. Sara Wilson

Date Defended: May 2, 2022

The Thesis Committee for Jessica Kirchner certifies that this is the approved

version of the following thesis:

Utilizing Stochastic Resonance to Improve Agility and Rapid Stepping

____

Chairperson: Dr. Carl Luchies

Date Approved: May 2, 2022

Abstract

Falls in older adults are multifactorial and include cognitive impairment, sensory deficits, medication use, impaired postural control and balance, reduced strength and flexibility, and impaired agility. For older adults with reoccurring falls, medical expenses due to falls can become expensive, highlighting the need for effective fall intervention methods. Agility training and stochastic resonance have both shown promise as effective intervention methods for fall rate reduction. The purpose of this study is to further understand the relationship between between agility, stochastic resonance, and voltional stepping.

The specific aims of this study are to (1) assess the influence of an agility warm-up on motor control during multidirectional stepping tasks performed as fast as possible, and to (2) investigate the impact that stochastic resonance vibration underfoot has on human agility and motor control during multidirectional stepping tasks performed as fast as possible. This study hypothesizes that (1) the agility warm-up will decrease reaction and completion time for multidirectional stepping, (2) stochastic resonance vibration will decrease the completion time for an agility task, and (3) stochastic resonance vibration will decrease reaction and completion time for multidirectional volitional stepping.

Five healthy young adults (age 25.6 ± 1.9 years) performed a series of agility and volitional stepping tasks before and after the administration of stochastic resonance-based vibration. Participants completed the protocol over two separate days for two conditions: vibration stimulus and placebo. The 505-agilty task was used for the warm-up and the agility tests. During the volitional stepping tasks, force data was collected using in-ground force plates. Time data was collected during the 505-agility task using timing gates.

Results of this study show promise of utilizing stochastic resonance as an effective method to help improve stepping speed. Stochastic resonance was shown to be equally effective as the agility

warm-up in decreasing swing time during the lateral step. Future work is needed to investigate effects of age, athleticism, and vibrational magnitudes for the use of stochastic resonance as an effective fall risk intervention method. Understanding the impact of these connections can help to create cheaper, more accessible, and effective alternative methods of fall intervention for high fall risk older adults.

Acknowledgements

There are many people that I am thankful for who have helped me get to where I am today. They have motivated me, supported me, laughed, and cried with me. Through the many ups and downs I have felt their support. Thank you to:

- Dr. Luchies for all your guidance and wisdom through my time working with you. As a professor you sparked my curiosity for biomechanics and as a mentor you allowed and encouraged me to follow my interests. Thank you for all our conversations and I am forever grateful for the knowledge I have learned from you.
- My fellow lab members, Di Bin, Victoria Blackwood, Eryn Gerber, Camilo Giraldo, Zaccur Nkrumah, Scott Ring, and Alex Wilson, for being mentors, friends, and test subjects. Your help and advice have meant a great deal to me.
- My friends for keeping me grounded and creating fun. You have all made my collegiate career an unforgettable experience. An extra special thanks to Rylee Goodson, Bailey Coolidge, and Kaelyn Thierolf for living with me and being the absolute best roommates.
- My family who has always encouraged me to be the best I can be. Thank you for showing me the value of education and for your continued support. Thank you for letting me do what I wanted and letting me be the weirdo I was meant to be.
- My wild and crazy pup Momo. You can't read but hopefully you know how much I love you for all the stupid silly things you do.

There are a countless number of more people who I would love to thank, but I think I've done enough writing for now. I hope you all know how special and valued you are.

Table of Contents

Abstract iii
Acknowledgements v
Chapter 1: Introduction 1
1.1 Background and Motivation 1
1.2 Specific Aims 3
1.3 Thesis Content 3
1.4 References 4
Chapter 2: Background 5
2.1 Older Adults and the Risk of Falling 5
2.1.1 The Prevalence of Falls in Older Adults 5
2.1.2 The Cost of Falls 5
2.2 Fall Risk Intervention Methods 6
2.2.1 Exercise Regimes and Increasing Strength 7
2.2.2 Agility Training 8
2.2.3 Stochastic Resonance Vibration 9
2.2.2 Vibration Threshold and Location 10
2.3 Stochastic Resonance Vibration and Agility 10
2.4 Gait Initiation and Stepping 12
2.4.1 Gait Initiation Phases and Parameters 12
2.4.2 Step Training Methods 12
2.5 Conclusion 13
2.6 References 14
Chapter 3: Utilizing Stochastic Resonance to Improve Agility and Rapid Stepping 16
3.1 Abstract 16
3.2 Introduction 17
3.3 Methods 20
3.3.1 Subjects 20
3.3.2 Vibratory Mat 20
3.3.3 Volitional Stepping Tasks 21
3.3.4 505 Agility Task 21
3.3.5 Testing Procedures 22
3.3.6 Data Collection and Analysis 23
3.3.7 Statistics 24
3.4 Results 25
3.4.1 505 Agility Task 25
3.4.2 Volitional Stepping Task in the Anterior Direction 26
3.4.3 Volitional Stepping Task in the Right Lateral Direction 28
3.5 Discussion 31
3.5.1 Effects of the 505 Agility Task on Stepping 31
3.5.2 Stochastic Resonance Effects on Agility 32
3.5.3 Stochastic Resonance Effects on Volitional Stepping 33
3.5.4 Lateral vs Anterior Stepping 34
3.5.5 Limitations 35
3.5.6 Future Work 36
3.6 Conclusion 36
3.7 References 38

Chapter 4: Conclusion 40
4.1 Study Summary 40
4.2 Future Works 41
4.3 References 42
Appendix A: Power Analysis and P-values 43
Appendix B: MATLAB Codes 44
Appendix B.1: Main Body 44
Appendix B.2: Raw Data Check 53
Appendix B.3: Data Filtering 57
Appendix B.4: Functions 59

List of Figures

Chapter 3: Agility and Rapid Stepping

Figure 1. Volitional Stepping Tasks 21
Figure 2. 505-Agility Task 22
Figure 3. Experimental Protocol 23
Figure 4. Stepping in the Anterior Direction 26
Figure 5. Average Anterior Step TIme 28
Figure 6. Stepping in the Right Lateral Direction 29
Figure 7. Average Right Lateral Step TIme 31

List of Tables

Chapter 3: Agility and Rapid Stepping

Table 1. Anterior and Right Lateral Variables 24
Table 2. 505-Agility Task Average Times 25
Table 3. Anterior Stepping Averages 27
Table 4. Right Lateral Stepping Averages 30
Table 5. Asymmetric Loading and Total Time 80% Power Sample Sizes 42
Table 6. Lift Off Duration and Swing Time 80% Power Sample Sizes 42
Table 7. Asymmetric Loading and Total Time P-values 42
Table 8. Lift Off Duration and Swing Time P-values 42

Chapter 1: Introduction

1.1 Background and Motivation

Falls affect between 30 to 40 percent of community-dwelling adults over the age of 65 and affect around 50 percent of adults over the age of 80 (Enderlin et al., 2015). Falls contribute to most injuries, disabilities, and premature deaths in older adults and account for more than $50 billion in annual medical costs (Florence et al., 2018; Khow & Visvanathan, 2017). As the population over 65 continues to rise with advancements in technology, these medical costs are also likely to keep rising. To help reduce these medical costs many fall risk intervention methods have been proposed and researched.

The causes of falls are multifactorial and include cognitive impairment, sensory deficits, medication use, impaired postural control and balance, reduced strength and flexibility, and impaired agility. To evaluate fall risk in older adults, a comprehensive assessment is typically completed by a physician who then recommends specific intervention strategies. These strategies can include education, the implementation of a strength and balance exercise routine, and an increase in vitamin D intake (Van Vost Moncada & Mire, 2017). For patients who were classified as high fall risk, strategies that include more extensive interventions are often recommended, including seeing a physical therapist for gait and balance improvement, addressing vision and home safety factors, modifying medications, and frequent physician follow-ups (Van Vost Moncada & Mire, 2017). For high-risk individuals, intervention can be expensive, time consuming and often require multiple visits to a clinic, reinforcing the need for more accessible, effective forms of intervention.

Exercise programs have been shown to be an effective method for reducing falls in older adults. Strength-based programs aimed at fixing muscle strength imbalances, increasing bone density, and improving overall muscle strength have shown positive results in improving postural sway and decreasing fall risk (Kim & O'Sullivan, 2013; Liu-Ambrose et al., 2004). Agility-based programs have also shown promise for decreasing fall risk. These program tend to be more accessible training programs that include multicomponent exercises utilizing perception and decision-making aspects which target cognitive function (Donath et al., 2016). These two forms of exercise interventions help to reduce fall risk in older adults, however, those with limited mobility due to injury, medication, or disease may not be able to complete these helpful programs.

As an alternative intervention method, stochastic resonance vibration has also been shown to be an effective method of reducing the risk of falling. Postural sway has been reduced with vibration in a wide range of subjects including older adults and young adult athletes with chronic ankle instability (Galica et al., 2009; Sierra-Guzman et al., 2018). Stochastic resonance is also being studied as a means of improving agility. Many studies on athletes and healthy-young populations have produced positive results when using stochastic resonance vibration to reduce agility. Although the long-term goal of this study is to help create and improve fall prevention methods, the knowledge gained from studying young athletic populations can still provide useful insight for future projects.

For older adults, agility is a necessary skill for helping reduce falls. Agility is vital for fall recovery and prevention by helping to counteract an unforeseen change of direction or speed from a trip or uneven surface. With better agility, older adults can react faster and more confidentially to avoid a fall event. Gait initiation is also affected by the agility level of older adults. When standing, if a balance perturbation occurs being able to step quickly is essential to regaining balance. Gaining more knowledge of the relationship between agility, gait initiation, and stochastic resonance vibration can aid in the advancement of intervention methods to reduce the risk of falling in older adults.

1.2 Specific Aims

The specific aims of this study are to (1) assess the influence of an agility warm-up on motor control during multidirectional stepping tasks performed as fast as possible, and to (2) investigate the impact that stochastic resonance vibration underfoot has on human agility and motor control during multidirectional stepping tasks performed as fast as possible. This study hypothesizes that (1) an agility warm-up will decrease reaction and completion time for multidirectional stepping, (2) stochastic resonance vibration will decrease the completion time for an agility task, and (3) stochastic resonance vibration will decrease reaction and completion time for multidirectional volitional stepping.

The long-term goal of this study is to contribute to the understanding of agility, gait initiation, and stochastic resonance vibration for the creation of new accessible, affordable, and effective intervention and fall prevention methods for older adults.

1.3 Thesis Content

This thesis contains 4 chapters:

- Chapter 1 introduces the current issue and provides the motivation for the purpose of the study within the thesis.
- Chapter 2 provides relevant background information about agility, stochastic resonance, gait initiation, and current intervention methods.
- Chapter 3 contains the background, methods, results, and discussion of a pilot study assessing the effects of stochastic resonance vibration on agility and gait initiation.
- Lastly, Chapter 4 summarizes the notable conclusions, evaluates the limitations of the study, and gives recommendations for future projects.

1.4 References

Donath, L., van Dieën, J., & Faude, O. (2016). Exercise-Based Fall Prevention in the Elderly: What About Agility? *Sports Medicine*, *46*(2), 143–149. https://doi.org/10.1007/s40279-015-0389-5

Enderlin, C., Rooker, J., Ball, S., Hippensteel, D., Alderman, J., Fisher, S. J., McLeskey, N., & Jordan, K. (2015). Summary of factors contributing to falls in older adults and nursing implications. *Geriatric Nursing*, *36*(5), 397–406. https://doi.org/10.1016/j.gerinurse.2015.08.006

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society*, *66*(4), 693–698. https://doi.org/10.1111/jgs.15304

Galica, A. M., Kang, H. G., Priplata, A. A., D'Andrea, S. E., Starobinets, O. V., Sorond, F. A., Cupples, L. A., & Lipsitz, L. A. (2009). Subsensory vibrations to the feet reduce gait variability in elderly fallers. *Gait and Posture*, *30*(3), 383–387. https://doi.org/10.1016/j.gaitpost.2009.07.005

Khow, K. S. F., & Visvanathan, R. (2017). Falls in the Aging Population. *Clinics in Geriatric Medicine*, *33*(3), 357–368. https://doi.org/10.1016/j.cger.2017.03.002

Kim, S. B., & O'Sullivan, D. M. (2013). Effects of Aqua Aerobic THerapy Exercise for Older Adults on Muscular Strength, Agility, and Balance to Prevent Falling during Gait. *J. Phys. Ther. Sci.*, *25*(8), 923–927.

Liu-Ambrose, T., Khan, K. M., Eng, J. J., Janssen, P. A., Lord, S. R., & McKay, H. A. (2004). Resistance and Agility Training Reduce Fall Risk in Women Aged 75 to 85 with Low Bone Mass: A 6-Month Randomized, Controlled Trial. *Journal of the American Geriatrics Society*, *52*(5), 657–665. https://doi.org/10.1111/j.1532-5415.2004.52200.x

Sierra-Guzman, R., Jimenez-Diaz, F., Ramirez, C., Esteban, P., & Abian-Vicen, J. (2018). Whole-Body-Vibration Training and Balance in Recreational Athletes With Chronic Ankle Instability. *Journal of Athletic Training*, *53*(4), 355–363.

Van Vost Moncada, L., & Mire, L. G. (2017). Preventing Falls in Older Patients. *Amerian Family Physician*, *96*(4), 240–247.

Chapter 2: Background

2.1 Older Adults and the Risk of Falling

2.1.1 The Prevalence of Falls in Older Adults

There is an estimated 703 million people globally that are over the age of 65 years. With advancements in technology improving quality of life, this number is estimated to reach 1.5 billion by 2050 (WHO, 2019). As the population of older adults increases, falls are becoming more prevalent and will likely continue to rise as the population ages. Falls contribute to most injuries, disabilities, and premature deaths in older adults (Khow & Visvanathan, 2017). Falls affect between 30 to 40 percent of community dwelling adults over the age of 65 and affect around 50 percent of adults over the age of 80 (Enderlin et al., 2015). The causes of these falls are multifactorial and include cognitive impairment, sensory deficits, medication use, impaired postural control and balance, reduced strength and flexibility, and impaired agility. Most often there is a combination of these factors that contribute to an increased risk of falling. This paper will explore the patient factors such as age and sensory deficits and their effect on falls. Identifying the risk factors is an important step in helping prevent numerous falls in the aging population.

2.1.2 The Cost of Falls

In the US, falls in older adults account for more than $50 billion in annual medical costs (Florence et al., 2018). These costs do not include the long-term expenses caused by falls such as loss of mobility, loss of independence, and reduced quality of life (Haddad et al., 2019). Inpatient and post-acute care costs rise significantly for older adults who have experienced a fall that requires hospitalization between 1 and 2.5 years after the fall (Bohl et al., 2012). Medical costs for older adults who experience fall-related injuries more than double their average annual medical expenditures, and nearly triple these costs if they require inpatient treatment (Hoffman et al., 2017). Fall prevention methods are an important aspect to reducing these costs as well as improving the quality of life of older adults.

To combat the rising medical expenditures of falls and fall-related injuries, many intervention strategies have been proposed and implemented. A fall risk assessment and intervention chart, provided by the American Academy of Family Physicians, details the steps required for providing a useful and individualized approach to fall risk interventions (Van Vost Moncada & Mire, 2017). This assessment classifies patients into three different categories: low, moderate, and high-risk individuals. For low-risk individuals, suggested intervention methods include education, the implementation of a strength and balance exercise routine, and an increase in vitamin D intake (Van Vost Moncada & Mire, 2017). High-risk individuals are recommended more extensive interventions, including seeing a physical therapist for gait and balance improvement, addressing vision and home safety factors, modifying medications, and frequent physician follow ups (Van Vost Moncada & Mire, 2017). For high-risk individuals, intervention can be a costly expense, reinforcing the need for more accessible, effective forms of intervention.

2.2 Fall Risk Intervention Methods

One contributor to falls in older adults is impaired gait and balance. Balance is thought to be a rapid synergistic interaction between various physiologic and cognitive processes that allows for fast and accurate responses to perturbation (Richardson, 2017). While walking, if an obstacle or a slight misstep causes a loss in balance, physiological systems work together to regain balance and avoid a fall. These systems include the visual, vestibular (accelerations and head rotation), and somatosensory (pressure and touch) systems. When one of these systems is not performing as it should, due to age, injury, or disease, regaining balance after a perturbation can be challenging or even impossible. Many proposed interventions for reducing falls in older adults aim to improve one or more of these systems.

2.2.1 Exercise Regimes and Increasing Strength

Various exercise routines have been proposed by previous work and aim to increase overall strength and balance (Clemson et al., 2019; Kim & O'Sullivan, 2013; Lichtenstein et al., 2020; Liu-Ambrose et al., 2004, 2019). These can be performed at home or in a group setting, both of which can help to keep the cost for the patient at a reasonable level while providing an effective form of intervention. In one study, a strength, agility, and a stretching regime was implemented for 25 weeks on high fall-risk elderly women with the aim of comparing the influence of these training programs on fall risk (Liu-Ambrose et al., 2004). They found that strength training reduced the risk of falling by 57%, compared to only a 20% reduction by the stretching-only group. These intervention programs were hypothesized to change the postural sway, leg strength, and hand reaction time, but only postural sway was significantly affected (Liu-Ambrose et al., 2004). Another study showed that for adults who have experienced a fall, their fall rate per year was significantly reduced when including an exercise routine into their post-fall care compared to the standard care plan (Liu-Ambrose et al., 2019). The exercise routine included 5 strengthening exercises for the lower extremities as well as 11 exercises focused on balance improvement and retention. Fall risk was assessed using the Physiological Profile Assessment composed of tests targeted towards muscular, visual, peripheral, and vestibular functions (Lord et al., 2003). While there was no significant change in fall risk, the number of falls for the exercise group was significantly lower than those receiving standard post-fall care. Participants in the exercise group experienced an average of 1.4 falls per person per year while those receiving standard care experienced a fall rate of 2.1 per person per year (Liu-Ambrose et al., 2019).

A study researching the effects of aqua aerobic therapy on muscular strength, agility and balance reported similar reduction in falls (Kim & O'Sullivan, 2013). The goal of this study was to create an exercise routine that aided fall prevention by increasing strength in the lower body and correcting muscle strength imbalances. Researchers collected gait kinetics and kinematics before, during, and after perturbation. Of the gait-related parameters that were collected, only stride time was significantly reduced after perturbation for those in the exercise group, indicating faster recovery from the perturbation (Kim & O'Sullivan, 2013). Strength training is proven to be an effective method at decreasing fall risk, but there are significant factors such as overall step time, step length, and reaction time, that do not show improvement with exercise alone.

2.2.2 Agility Training

Strength training programs are not the only exercise-based intervention method currently being studied. Agility training for balance improvement, as well as increased reaction time, is proposed as a fall prevention and fall risk reduction strategy. Agility is the ability to rapidly make whole-body changes of direction and speed (Miranda et al., 2016). It is an important component of fall recovery and helps improve overall balance and postural stability. After experiencing a perturbation, fast reactions are essential for fall prevention. In a study comparing strength and balance exercise programs with agility-based exercise programs, significant improvements to postural stability were found (Lichtenstein et al., 2020). It was shown that although agility training might not lead to greater postural stability than strength and balance training, it is at least as efficacious as those methods for improving postural stability in older adults (Lichtenstein et al., 2020).

Agility training also integrates multifunctional training practices rather easily. In a review of current exercise-based training programs for the elderly, it is stated that agility-based exercises also include perception and decision-making aspects that target cognitive function (Donath et al., 2016). It is also shown that the traditional strength and power-based exercise plans can be time- and energy-inefficient, requiring more effort to separately address balance, strength, and endurance (Donath et al., 2016). Agility-based training can have multicomponent exercises, therefore reducing the overall time and stamina needed to complete one training session (White et al., 2019). Agility-based exercise programs can provide additional or alternative training methods for older adults without taking away helpful gains made from a strength-based program.

2.2.3 Stochastic Resonance Vibration

While exercise-based interventions have been a widely supported method to improve strength, agility, postural stability and reduce falls in older adults, it is not always an accessible means of intervention. Some older adults, due to injuries, medications, or disability, may not be able to perform the required tasks that are key for exercise programs to be efficacious. In recent studies, stochastic resonance has shown promising results in aiding fall prevention. Stochastic resonance describes the presence of noise in a non-linear system that improves the output signal's quality when compared to no added noise (White et al., 2019). Stochastic resonance can be added to a weak, difficult to detect signal to create a stronger, detectable signal.

The human physiological system functions as a control system with feedback from the vestibular, visual, and somatosensory systems to help regulate motor output. Specifically, feedback from the somatosensory system helps to regulate balance and gait. With the addition of stochastic resonance to the somatosensory system, there is potential to improve balance in persons with somatosensory deficiencies such as the aging population (White et al., 2019). As evidence of this phenomenon, one study created insoles for an elderly population that delivered vibration to the subjects' feet. Vibration was calibrated for each participant to 90% of their sensory threshold (subthreshold). Subjects were asked to stand in a natural position with hands at their sides and eyes closed. They were then either given vibration or given no vibration and displacement of the head neck and truck was measured. From the extracted parameters, the researchers were able to find significant improvement in postural stability in nearly all measures, including maximum sway radius, anterior-posterior medial-lateral excursions (Priplata et al., 2003). Another study applied whole-body suprathreshold vibration to athletes who suffered from chronic ankle instability. The subjects completed multiple balance training exercises while either receiving vibration or not. From this study it was found that for those who received vibration had improved their balance test scores at the end of the training period (Sierra-Guzman et al., 2018). Although this study's population was not older adults, the athletes had an injury that affected their gait and balance. Looking at this study still provides insight into the effects of persons with gait deficiencies as seen in older populations. Using stochastic resonance vibration as a means of regulating the balance control system is a highly supported method of increasing postural control and balance.

2.2.2 Vibration Threshold and Location

For the study explored in this paper, subthreshold vibration was applied only at the soles of the feet. Both sub- and suprathreshold vibrations have been shown to improve balance and postural stability in older adults (Galica et al., 2009; White et al., 2019). Suprathreshold, however, has been shown to create destabilizing effects on postural control on those without somatosensory deficits. Suprathreshold, due to the noise level, influences the direction of sway whereas subthreshold helps augment postural performance by boosting pre-existing environmental stimuli (White et al., 2019). Looking at placement of vibration, the soles of the feet were chosen because of the importance of sensory feedback given by the feet while walking or standing. The mechanoreceptors in the soles of the feet play a major role in relaying information about surface stability.

2.3 Stochastic Resonance Vibration and Agility

There is further evidence that stochastic resonance vibration not only improves postural stability, but also improves agility. Agility requires quick reaction times to speed up, slow down, or change directions efficiently. Having good agility is vital for fall recovery and prevention by helping to counteract an unforeseen change of direction or speed from a trip or uneven surface. Improving agility through exercise alone does help reduce fall risk in older adults, but when there are limitations for activity of some older adults, stochastic resonance could provide an agility boost (Priplata et al., 2003).

Stochastic resonance has been widely used as an agility training method for athletes and active healthy young persons. Agility is an essential skill for athletes to have and improvement methods for agility have been widely studied in athletics. An athlete population is significantly different from high fall risk older adults but finding methods that have been shown to improve agility in healthy participants can give insight for creating new methods in other populations. One such study created shoe insoles to deliver vibration to athletes while completing a hexagonal agility task (Miranda et al., 2016). Participants were asked to hop to targets positioned in a hexagonal pattern and their total time and accuracy of task completion was recorded. The results showed a 0.12 second decrease in task completion time when the vibration was being applied (Miranda et al., 2016). The stochastic resonance vibration was able to help athletes change their direction faster and complete the task in less time. Another study found similar results after delivering whole body vibration to untrained healthy subjects (Wallmann et al., 2019). Participants completed a T-test for agility which requires subjects to run forward 5 meters, side shuffle to the left for 2.5 meters, side shuffle to the right for 5 meters, side shuffle back to center and then back pedal 5 meters to the starting line. After they were given an acute bout of whole-body vibration a decrease in T-test completion time was found (Wallmann et al., 2019).

However, there have also been some studies that show no improvement with whole body vibration. One study claims that because agility does not have the same specific motor and skill training as strength, power and speed, whole body vibration will not enhance performance on an agility task (Cochrane et al., 2004). Their results showed that there was no difference between the control group and those who received a vibration treatment on agility performance (Cochrane et al., 2004). In this study, participants were exposed to whole body over 9 days with multiple short vibration exposure sessions in one day, but testing took place 2 days later. Previous studies that showed agility enhancements occurred only when vibration was administered either right before or during the agility task.

2.4 Gait Initiation and Stepping

2.4.1 Gait Initiation Phases and Parameters

Along with decreased postural stability and agility, it is well documented that gait initiation and stepping are affected by aging. Common parameters studied in gait initiation and stepping studies include reaction time, weight shift time, foot lift-off time, and swing leg landing time. These parameters can be measured using force plates to collect ground force reactions during a stepping task (Brunt et al., 1991). The reaction time occurs at the onset of vertical force generation in the swing leg (McIlroy & Maki, 1993). This event marks the beginning of the weight shift phase as the stance leg begins to support the body during a step. As the swing leg is in the air the vertical force drops to zero and once the swing leg starts to contact the ground the vertical force increases as it takes over support for the stance leg to transition into the swing leg (Brunt et al., 1991). Other methods using shear force and center of pressure for example, can also be used to help identify the phases of gait initiation.

2.4.2 Step Training Methods

As age increases, reaction time and weight shift duration increase for voluntary and reaction stepping (Luchies et al., 2002; Okubo et al., 2021). Stepping tests have also been capable of distinguishing fallers from non-fallers; persons classified as fallers had higher task completion times as well as overall slower gait speeds (Okubo et al., 2021; Palumbo et al., 2016). With increased stepping times, older adults are more at risk of falling; to combat this, step training has been proposed as another intervention method to decrease step time. Step interventions include two different types: volitional step training and reactive step training. Volitional step training requires participants to step towards targets either by memorizing a stepping pattern or in response to a stimulus while reactive step training is a result of a perturbation (Okubo et al., 2017). These stepping interventions are shown to reduce the rate of falls by 52% and decrease the fall population by 49% by increasing older adults rapid stepping abilities (Okubo et al., 2017).

2.5 Conclusion

There is a large body of work that explores intervention methods for reducing falls and fall risk in older adults. Strength and agility-based exercise programs are effective; however, they can require a higher activity level and coordination that some older adults do not possess. Stochastic resonance vibration interventions may be a suitable solution for those who are unable to complete and exercise regime. The effect of stochastic resonance on postural stability has been widely studied but there is less work on the efficacy of stochastic resonance when used to improve agility in older adults. The idea of using vibration to improve agility has been more commonly researched in athletes and healthy young persons. By studying emerging methods for agility and gait initiation improvement in a healthy young population, this knowledge can be transferred to help develop intervention methods for older adults. If the techniques being studied are proven useful in a young healthy population the hope is that they will also be just as useful in an older or non-healthy population.

This study aims to investigate the relationship of agility and stochastic resonance on healthy young persons. It will compare the effects of an agility warm-up and stochastic resonance on gait initiation as well as the effects of stochastic resonance on agility. This study hypothesizes that that (1) an agiilty warm-up will decrease reaction and completion time for multidirectional voltional stepping , (2) stochastic resonance stimulation will decrease the completion time for an agility task and (3) stochastic resonance will decrease reaction and completion time for multidirectional voltional stepping. By answering these hypotheses, this study will increase the knowledge of the relation of agility and stichastic resonance on healthy young persons with the long term goal of finding an effective alternative for increasing agility in high fall risk older adults.

2.6 References

Bohl, A. A., Phelan, E. A., Fishman, P. A., & Harris, J. R. (2012). How are the costs of care for medical falls distributed? The costs of medical falls by component of cost, timing, and injury severity. *Gerontologist*, *52*(5), 664–675. https://doi.org/10.1093/geront/gnr151

Brunt, D., Lafferty, M. J., Mckeon, A., Goode, B., Mulhausen, C., & Polk, P. (1991). Invariant Characteristics of Gait Initiation. *American Journal of Physical Medicine and Rehabilitation*, *70*(4), 206–212.

Clemson, L., Stark, S., Pighills, A. C., Torgerson, D. J., Sherrington, C., & Lamb, S. E. (2019). Environmental interventions for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews*, *2019*(2). https://doi.org/10.1002/14651858.CD013258

Cochrane, D. J., Legg, S. J., & Hooker, M. J. (2004). the Short-Term Effect of Whole-Body Vibration Training on Vertical Jump,Sprint, and Agility Performance. *Journal of Strength and Conditioning Research*, *18*(4), 828–832. https://doi.org/10.1519/00124278-200411000-00025

Donath, L., van Dieën, J., & Faude, O. (2016). Exercise-Based Fall Prevention in the Elderly: What About Agility? *Sports Medicine*, *46*(2), 143–149. https://doi.org/10.1007/s40279-015-0389-5

Enderlin, C., Rooker, J., Ball, S., Hippensteel, D., Alderman, J., Fisher, S. J., McLeskey, N., & Jordan, K. (2015). Summary of factors contributing to falls in older adults and nursing implications. *Geriatric Nursing*, *36*(5), 397–406. https://doi.org/10.1016/j.gerinurse.2015.08.006

Florence CS, Bergen G, Atherly A, Burns ER, Stevens JA, Drake C. Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society,* 2018 March, DOI: 10.1111/jgs.15304

Galica, A. M., Kang, H. G., Priplata, A. A., D'Andrea, S. E., Starobinets, O. V., Sorond, F. A., Cupples, L. A., & Lipsitz, L. A. (2009). Subsensory vibrations to the feet reduce gait variability in elderly fallers. *Gait and Posture*, *30*(3), 383–387. https://doi.org/10.1016/j.gaitpost.2009.07.005

Haddad YK, Bergen G, Florence CS. Estimating the Economic Burden Related to Older Adult Falls by State. *Journal of Public Health Management Practice.* 2019;25(2): E17–E24. DOI: 10.1097/PHH.0000000000000816

Hoffman, G. J., Hays, R. D., Shapiro, M. F., Wallace, S. P., & Ettner, S. L. (2017). The Costs of Fall-Related Injuries among Older Adults: Annual Per-Faller, Service Component, and Patient Out-of-Pocket Costs. *Health Services Research*, *52*(5), 1794–1816. https://doi.org/10.1111/1475-6773.12554

Khow, K. S. F., & Visvanathan, R. (2017). Falls in the Aging Population. *Clinics in Geriatric Medicine*, *33*(3), 357–368. https://doi.org/10.1016/j.cger.2017.03.002

Kim, S. B., & O'Sullivan, D. M. (2013). Effects of Aqua Aerobic THerapy Exercise for Older Adults on Muscular Strength, Agility, and Balance to Prevent Falling during Gait. *J. Phys. Ther. Sci.*, *25*(8), 923–927.

Lichtenstein, E., Morat, M., Roth, R., Donath, L., & Faude, O. (2020). Agility-based exercise training compared to traditional strength and balance training in older adults: A pilot randomized trial. *PeerJ*, *2020*(4). https://doi.org/10.7717/peerj.8781

Liu-Ambrose, T., Davis, J. C., Best, J. R., Dian, L., Madden, K., Cook, W., Hsu, C. L., & Khan, K. M. (2019). Effect of a Home-Based Exercise Program on Subsequent Falls among Community-Dwelling High-Risk Older Adults after a Fall: A Randomized Clinical Trial. *JAMA - Journal of the American Medical Association*, *321*(21), 2092–2100. https://doi.org/10.1001/jama.2019.5795

Liu-Ambrose, T., Khan, K. M., Eng, J. J., Janssen, P. A., Lord, S. R., & McKay, H. A. (2004). Resistance and Agility Training Reduce Fall Risk in Women Aged 75 to 85 with Low Bone Mass: A 6-Month Randomized, Controlled Trial. *Journal of the American Geriatrics Society*, *52*(5), 657–665. https://doi.org/10.1111/j.1532-5415.2004.52200.x

Lord, S. R., Menz, H. B., & Tiedemann, A. (2003). A physiological profile approach to falls risk assessment and prevention. *Physical Therapy*, *83*(3), 237–252. https://doi.org/10.1093/ptj/83.3.237

Luchies, C. W., Schiffman, J., Richards, L. G., Thompson, M. R., Bazuin, D., & DeYoung, A. J. (2002). Effects of age, step direction, and reaction condition on the ability to step quickly. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *57*(4), M246–M249. https://doi.org/10.1093/gerona/57.4.M246

McIlroy, W. E., & Maki, B. E. (1993). Changes in early "automatic" postural responses associated with the prior-planning and execution of a compensatory step. *Brain Research*, *631*(2), 203–211. https://doi.org/10.1016/0006-8993(93)91536-2

Miranda, D. L., Hsu, W. H., Gravelle, D. C., Petersen, K., Ryzman, R., Niemi, J., & Lesniewski-Laas, N. (2016). Sensory enhancing insoles improve athletic performance during a hexagonal agility task. *Journal of Biomechanics*, *49*(7), 1058–1063. https://doi.org/10.1016/j.jbiomech.2016.02.022

Okubo, Y., Schoene, D., & Lord, S. R. (2017). Step training improves reaction time, gait and balance and reduces falls in older people: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(7), 586–593. https://doi.org/10.1136/bjsports-2015-095452

Okubo, Y., Schoene, D., Caetano, M. J., Pliner, E. M., Osuka, Y., Toson, B., & Lord, S. R. (2021). Stepping impairment and falls in older adults: A systematic review and meta-analysis of volitional and reactive step tests. *Ageing Research Reviews*, *66*(December 2020), 101238. https://doi.org/10.1016/j.arr.2020.101238

Palumbo, P., Klenk, J., Cattelani, L., Bandinelli, S., Ferrucci, L., Rapp, K., Chiari, L., & Rothenbacher, D. (2016). Predictive Performance of a Fall Risk Assessment Tool for Community-Dwelling Older People (FRAT-up) in 4 European Cohorts. *Journal of the American Medical Directors Association*, *17*(12), 1106–1113. https://doi.org/10.1016/j.jamda.2016.07.015

Priplata, A. A., Niemi, J. B., Harry, J. D., Lipsitz, L. A., & Collins, J. J. (2003). Vibrating insoles and balance control in elderly people. *Lancet*, *362*(9390), 1123–1124. https://doi.org/10.1016/S0140-6736(03)14470-4

Richardson, J. K. (2017). Imbalanced: The Confusing Circular Nature of Falls Research and a Possible Antidote. *American Journal of Physical Medicine and Rehabilitation*, *96*(1), 55–59. https://doi.org/10.1097/PHM.0000000000000591

Sierra-Guzman, R., Jimenez-Diaz, F., Ramirez, C., Esteban, P., & Abian-Vicen, J. (2018). Whole-Body-Vibration Training and Balance in Recreational Athletes With Chronic Ankle Instability. *Journal of Athletic Training*, *53*(4), 355–363.

Van Vost Moncada, L., & Mire, L. G. (2017). Preventing Falls in Older Patients. *Amerian Family Physician*, *96*(4), 240–247.

Wallmann, H. W., Bell, D. L., Evans, B. L., Hyman, A. A., Goss, G. K., & Paicely, A. M. (2019). the Effects of Whole Body Vibration on Vertical Jump, Power, Balance, and Agility in Untrained Adults. *International Journal of Sports Physical Therapy*, *14*(1), 55–64. https://doi.org/10.26603/ijspt20190055

White, O., Babic, J., Trenado, C., Johannsen, L., & Goswami, N. (2019). The promise of stochastic resonance in falls prevention. *Frontiers in Physiology*, *10*(JAN), 1–12. https://doi.org/10.3389/fphys.2018.01865

WHO. (2019). World Population Ageing 2019. In *World Population Ageing 2019*. http://link.springer.com/chapter/10.1007/978-94-007-5204-7_6

Chapter 3: Utilizing Stochastic Resonance to Improve Agility and Rapid Stepping

3.1 Abstract

***Background**:* Falls in older adults are multifactorial and include cognitive impairment, sensory deficits, medication use, impaired postural control and balance, reduced strength and flexibility, and impaired agility. Every year, falls in older adults account for more than $50 billion in medical costs, highlighting the need for effective intervention methods (Florence et al., 2018). Agility training and stochastic resonance have both shown promise as effective intervention methods for fall rate reduction. The purpose of this study is to further understand the relationship between between agility, stochastic resonance, and voltional stepping.

***Methods**:* Five healthy young adults (age 25.6 ± 1.9 years) performed a series of agility and volitional stepping tasks before and after the administration of stochastic resonance-based vibration. Participants completed the protocol over two separate days for two conditions: vibration stimulus and placebo. The 505-agilty task was used for the warm-up and the agility tests. During the volitional stepping tasks, force data was collected using in-ground force plates at 100 Hz and filtered with a 10 Hz low-pass Butterworth filter. Time data was collected during the 505-agility task using timing gates. Microsoft Excel software was used to perform two-sample t-tests ($\alpha = 0.05$) on desired parameter comparisons.

***Results**:* This study found that there was no significant effect ($p > 0.05$) of stochastic resonance on the 505-agility task. There was also no significant effect ($p > 0.05$) of the agility warm-up or stochastic resonance vibration on the anterior step direction. A significant decrease was found after warm-up ($p = 0.033$) and after vibration ($p = 0.008$) in the right lateral step direction. Both vibration and the agility warm-up led to a decrease ($p = 0.002$ and $p = 0.038$) in swing time during the lateral step.

***Conclusions**:* Results of this study show promise of utilizing stochastic resonance as an effective method to help improve stepping speed. Stochastic resonance was shown to be equally effective as the agility

warm-up in decreasing swing time during the lateral step. Future work is needed to investigate effects of age, athleticism, and vibrational magnitudes for the use of stochastic resonance as an effective fall risk intervention method. Understanding the impact of these connections can help to create cheaper, more accessible, and effective alternative methods of fall intervention for high fall risk older adults.

3.2 Introduction

Falls contribute to most injuries, disabilities, and premature deaths in older adults (Khow & Visvanathan, 2017). Falls affect between 30 to 40 percent of community dwelling adults over the age of 65 and affect approximately 50 percent of adults over the age of 80 (Enderlin et al., 2015). The causes of these falls are multifactorial and include cognitive impairment, sensory deficits, medication use, impaired postural control and balance, reduced strength and flexibility, and impaired agility. These falls account for more than $50 billion in annual medical costs, not including any long term expenditures related to loss of mobility, independence, and reduced quality of life (Florence et al., 2018; Haddad et al., 2019).

To combat the high cost of fall-related medical expenses, many intervention methods have been proposed. Once a patient's fall risk has been assessed by a physician, preventative measures such as exercise programs, education, modification of existing medications, physical therapy, and vision correction may be suggested depending on the severity of fall risk (Van Vost Moncada & Mire, 2017). For older adults at a high risk of falling, intervention can be a costly expense, which is why it is important to create more accessible, lower cost, effective interventions methods for these older adults.

Various exercise routines that have been proposed are aimed at increasing overall strength, balance, and agility. These can be performed at home or in a group setting, which can help keep the costs reasonable while still providing an effective form of intervention. One study found that when exercise was included into a patients post-fall care, their rate of falls per year was significantly reduced compared to those patients with a standard care plan (Liu-Ambrose et al., 2019). In a similar study, fall risk was reduced by 57% for groups who completed a strength training program post-fall, whereas those who completed a strength protocol only say a 20% reduction (Liu-Ambrose et al., 2004). In an agility focused study researchers were able to show that an agility-based exercise routine improved postural stability just as much as a strength based program (Lichtenstein et al., 2020). Agility based interventions could be considered more efficient than strength-based programs; agility integrates multifunctional training practices that target not only agility, but also cognitive functions through perception and decision-making (Donath et al., 2016). Strength training helps to increase muscle strength, bone density and postural sway, but it can require longer training sessions, as opposed to agility sessions that have more opportunity for combined, multicomponent exercises. Agility-based exercise programs can provide additional or alternative training methods for older adults without taking away helpful gains made from a strength-based program.

While exercise-based interventions have been a widely supported method to improve strength, agility, and postural stability, and reduce falls in older adults, it is not always an accessible means of intervention. Some older adults, due to injuries, medications, or disability, may not be able to perform the required tasks that are key for exercise programs to be efficacious. In recent studies, stochastic resonance stimulation has shown promising results in aiding fall prevention. Stochastic resonance describes the addition of noise to a non-linear system, improving the output signal's quality when compared to no added noise (White et al., 2019). Stochastic resonance can be added to a weak, difficult to detect signal to create a stronger, detectable signal. In one study, postural stability was significantly improved after receiving a subthreshold vibratory stimulation (Priplata et al., 2003). In another study that measured balance test performances on athletes with chronic ankle instability, balance scores improved after whole body vibration (Sierra-Guzman et al., 2018). Although this study does not include older adults, the knowledge gained from this study on injured athletes can potentially be applied to older adults with similar balance deficiencies. Using stochastic resonance vibration as a means of regulating the balance control system is a highly supported method of increasing postural control and balance.

While there have been numerous studies on stochastic resonance vibration and postural control in older adults, there has been significantly less work investigating the effects of vibration on agility. Because agility is a widely needed skill in athletics, many more studies on athletes and active young persons and vibration have been done. In a study that delivered vibration to athletes at the soles of their feet found that the athletes increased the speed of their agility task, reducing task time by 0.12 seconds (Miranda et al., 2016). Another study found similar decreases in agility task times after participants were exposed to whole-body vibration (Wallmann et al., 2019). In both studies, the vibration was able to help athletes change their direction faster and complete the tasks in less time. Similar to athletes, for older adults who experience a balance perturbation, it is imperitive that they change their direction quickly in order to recover and avoid falling. If stochastic resonance vibration can improve agility in athletes then it is hypothesized these findings will apply to older adults and can be used as a fall prevention strategy.

Step training is a more accessible and less physically strenous intervention method for high fall risk older adults than strength or agility training. Step training aims to counteract the negative effects of aging on reaction time and weight shift during volitional or reactonary stepping. There are two types of step intervention methods: volitional step training and reactive step training. Volitional step training requires participants to step towards targets either by memorizing a stepping pattern or in response to a visual or auditory stimulus, while reactive step training is a result of a perturbation (Okubo et al., 2017). These stepping interventions are shown to reduce the rate of falls by 52% and decrease the population of older adults who experience falls by 49% by increasing their rapid stepping abilities (Okubo et al., 2017). There is a skill level of agility needed to complete quick recovery steps in response to a balance perturbation. Through agility training or stochastic resonance vibration this skill level could be improved in older adults, however the connection between these factors has yet to be discovered.

The purpose of this study is to explore the relationship between agility, stochastic resonance, and voltional stepping. Current research has lead to the hypotheses that (1) an agiilty warm-up will decrease reaction and completion time for multidirectional voltional stepping , (2) stochastic resonance stimulation will decrease the completion time of the 505-agility task and (3) stochastic resonance will decrease reaction and completion time for multidirectional voltional stepping. Because the study of agility is traditionally done in athletes or healthy young persons, this study will explore these hypotheses in a healthy young population, with the goal of applying the knowledge gained from this study to an older adult population. The long-term goal of this work is to create a more accessible and cost effective intervention method that reduces the risk of falling in older adults.

3.3 Methods

3.3.1 Subjects

Five active healthy young female participants (age 25.6 ± 1.9 years) participated in this study. To reduce their risk of injury from participation, all participants were screened to have a minimum activity level of 30 minutes once a week with similar intensity to the 505-agility task. All participants had no previous injuries within one year related to the lower trunk consented to participation. Subjects were made aware of the risks of participation and gave written consent, as approved by the Institutional Review Board of The University of Kansas.

3.3.2 Vibratory Mat

The vibratory mat was constructed and validated as described by Giraldo, 2021. Small rotary motors (307-103, Precision Microdrives, UK) were embedded in the mat under the heel, first metatarsal, and fifth metatarsal of each foot. The mat outputs white noise at varying magnitude levels based on the subjects' individual sensing threshold. This threshold was found using a modified 421 protocol (Whorley, 2020). Vibration strength was set to 90% of the sensing threshold. The mat was placed on top of a force plate (AMTI, Watertown, MA) and kinetic data was recorded with a 16-bit A/D CED mkII and Spike2 (Cambridge Electronic Design, UK).

3.3.3 Volitional Stepping Tasks

Subjects were asked to perform two volitional stepping tasks, one in the anterior direction and one in the right lateral direction. Subjects were instructed to step as quickly as possible at a comfortable length with their right foot and bring their left foot over to match (Fig. 1) at the onset of a visual cue placed at eye level and triggered by a researcher. The trigger time was varied for each step to reduce anticipatory stepping from subjects. Subjects started with their feet at a standardized stance width of 17 cm, with toes pointing forward (McIlroy & Maki, 1997). Subjects completed three steps in the anterior direction followed by three steps in the right lateral direction thee sperate times for a total of nine steps in each direction. Subjects returned to the starting position after every step. The first two steps in each set of three were used as practice steps to acclimate the participant with each stepping task.

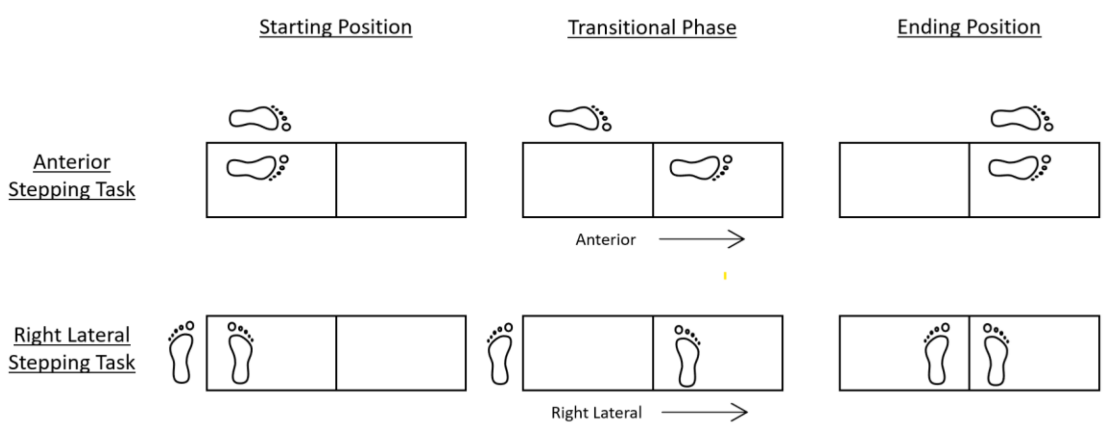

Figure 1. *Anterior and Right Lateral Volitional Stepping Tasks*

3.3.4 505 Agility Task

The 505-agility task was performed as described by Lancaster and Draper, 1985. The 505-agility task is a commonly used a validated method for studying agility. This task requires both a change in direction and a change in speed, both of which are characteristic of agility (Draper & Lancaster, 1985). A laser module and reflector were set on tripods to create a timing gate (Dashr Systems, Lincoln, NE) at the 10-meter mark (Fig. 2). The subject was instructed to sprint to the 15-meter mark and touch the mark with one foot before turning around and sprinting back to the starting line (Fig. 2). An observer visually checked that subjects hit the mark for each trial. Subjects were given a practice session with four trials before completing one baseline trial and one post-vibration trial.

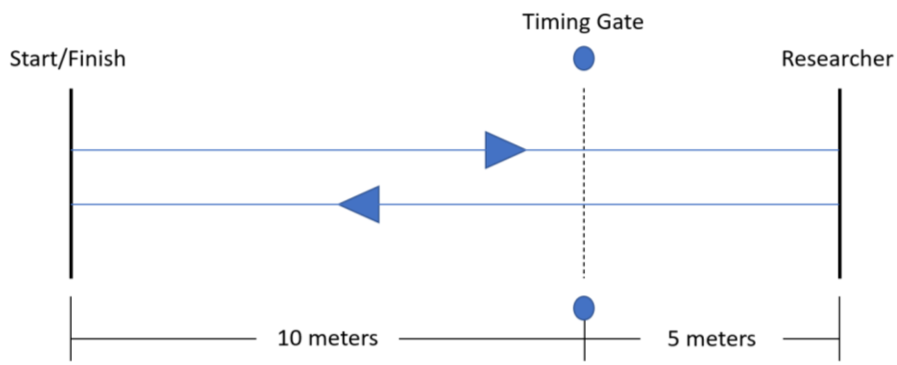

Figure 2. *505 Agility Task Set-Up*

3.3.5 Testing Procedures

Subjects completed their testing during two sessions completed over two days. The first testing session started with a walk through of the procedure and allowed participants to practice the stepping task before data collection. During each visit the testing procedure followed the steps in **Figure 3**. After the sensing threshold was found, the stimulation vibration magnitude was set to 90% of the subject's threshold. Subjects received vibration during the stimulation phase one day and received a placebo (no vibration) on the other day. The order of the sessions was randomized for each subject. During the 505-agility warm up, subjects completed 4 total runs over the course of 5 to 10 minutes. The intensity of this warm-up was instructed to start around 50% maximum effort and work their way up to full intensity.

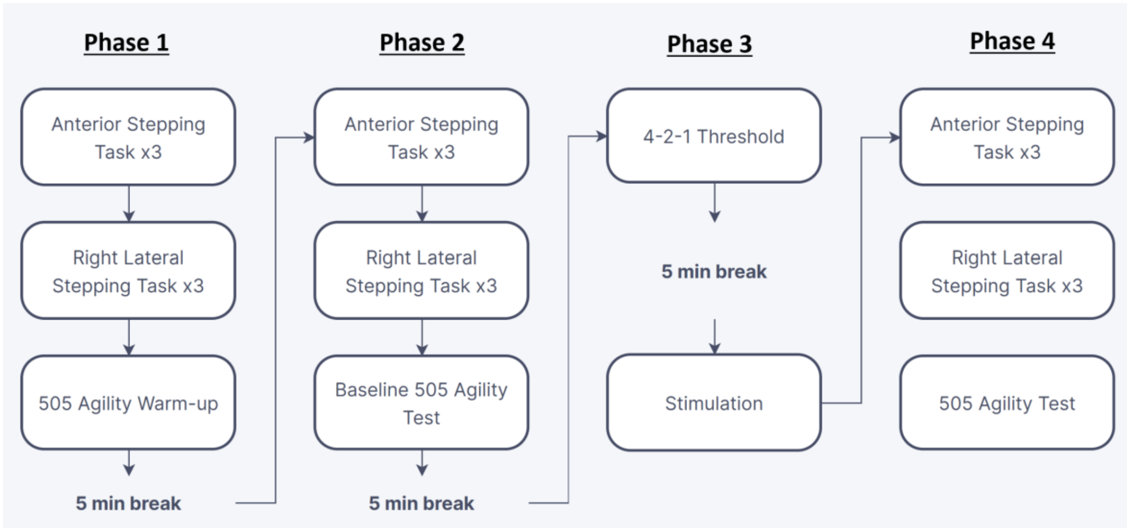

Figure 3. *Experimental Protocol*

3.3.6 Data Collection and Analysis

Foot-floor reaction data was collected using two in ground force plates (AMTI, Watertown, MA) at a frequency of 100 Hz and a 16-bit A/D data acquisition system (CED, Cambridge, England, UK). Data was filtered using a 10 Hz low-pass Butterworth filter. Data was analyzed with the MATLAB software (Mathworks, Natick, MA). Force plate data collected in the anterior and lateral right step directions was combined to create a singular force time series. 505-agility task data was collected using the Dashr 1-Gate System timing gate at 100 Hz (Dashr Systems, Lincoln, NE) with a smart-phone connected via Bluetooth through the Dashr app.

Parameters extracted from anterior step data were the onset of asymmetric loading, swing leg toe lift-off, swing time, and swing leg heel strike. These parameters mark the phases of gait initiation from vertical force, as described by Brunt and Zhao (Brunt et al., 1991; Zhao et al., 2021). The threshold for asymmetric loading was defined by an increase in the derivative of vertical force equivalent to 2% of the participants' static standing vertical force (Sparto et al., 2014). Similarly, toe lift-off and heel strike thresholds were set to 5% of the participants' static standing vertical force. Parameters for the right lateral stepping task were the onset of asymmetric unloading, stepping leg foot lift-off, swing time, and stepping leg foot strike. Thresholds for these parameters mirrored the anterior step parameter thresholds. These parameters were then used to calculate variables of interest, as described in Table 1.

Table 1. *Summary of the anterior and right lateral variables used for data comparison. Variables were calculated from parameters extracted from the stepping task time series.*

Variables	Definition
Anterior Direction	
Start of Asymmetric Loading	An increase in vertical loading on the swing leg occurs as the weight is shifted to the support leg For this study, this variable was used for the reaction time from the visual stimulus in the anterior direction.
Lift off Duration	The length of time between the start of asymmetric loading and the moment the swing leg lifts from the floor
Swing Time	Duration the swing leg is traveling in the air starting from the end of the lift off duration to the instant the heel of the swing leg strikes the ground
Total Step Time	Combined time of lift off and swing time durations
Right Lateral Direction	
Start of Asymmetric Unloading	A decrease in the stepping leg loading. For this study, this variable was used for the reaction time from the visual stimulus in the right lateral direction.
Foot Lift-off Duration	The length of time between the start of asymmetric unloading and the moment the stepping leg lefts from the floor
Swing Time	Duration of time the stepping foot is traveling in the air at the end of lift off and the instant the foot strikes the ground.
Total Step Time	Combined time of lift off and swing time durations

3.3.7 Statistics

All statistic calculations were completed in Microsoft Excel Spreadsheet Software (Microsoft, Redmond, WA). To analyze data across baseline (BL), post warm-up (PW) and post stimulation (PS) stepping tasks, two-sample right tailed t-tests were used for BL vs PW, BL vs PS, and PW vs PS comparisons across the stimulation testing session. These tests compared the total step completion times within the white and the placebo condition. If a comparison of total times was found to be significant, further testing was completed to identify which part, duration of lift-off or swing time, of the total step time was significant. A two-sample t-test was also used to compare the mean difference between stimulation and placebo conditions. For the 505-agility task, t-tests were used to compare median differences from the white and placebo conditions, as well as compare BL and PS results. Statistical significance for all tests was set to $p < 0.05$.

Due to the low sample size and exploratory nature of this study, some key assumptions were made to be able to complete the t-tests; It was assumed that given a larger sample number, the distribution would follow a normal distribution and the data would show homogeneity of variance. Because this is an exploratory study, the limitations of these assumptions were found to be acceptable.

3.4 Results

3.4.1 505 Agility Task

No significant difference ($p > 0.05$) was found across either 505-agility task conditions (Fig. 2). Within the vibration and placebo conditions, there was an increase of 0.10 ± 0.17 seconds and 0.04 ± 0.04 seconds from BL to PS respectively. Significance ($p = 0.421$) was not found when comparing the mean differences of the vibration and the placebo condition.

Table 2. *505-agility task average completion time for vibration and placebo conditions. T-test significance was set to alpha = 0.05.*

	Baseline Mean ± SD (sec)	**Post Stimulation** Mean ± SD (sec)	**p-value** BL vs PS
Vibration	3.07 ± 0.39	3.17 ± 0.40	0.868
Placebo	2.80 ± 0.36	2.84 ± 0.37	0.947

3.4.2 Volitional Stepping Task in the Anterior Direction

Figure 4 shows an example of right foot vertical force data taken during the anterior volitional stepping task. Four vertical lines are displayed on the graph to illustrate major time events, starting with the visual stimulus at 1 second ("Light On"). The change in vertical force seen after heel strike is due to the subject is bringing their left foot up to match the right foot in the ending position.

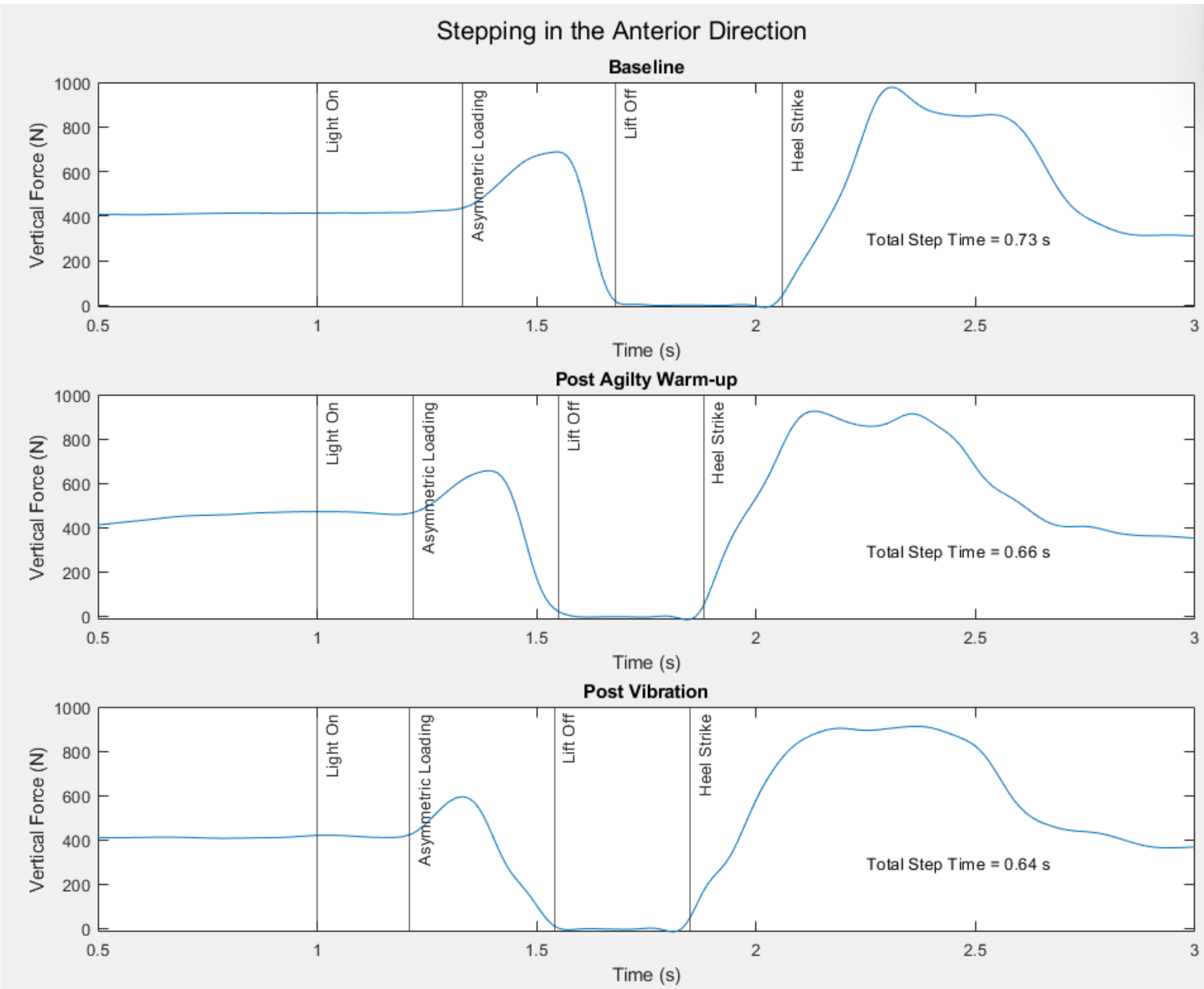

Figure 4. *Example of vertical force data for the anterior volitional stepping task. Parameter time events are marked with a vertical line and the total step time (from asymmetric loading to heel strike) is displayed on the graphs*.

No significant trend ($p > 0.05$) was found in either direction across the BL, PW, and PS trials in the placebo and vibration conditions for total time or the start pf asymmetric loading (Table 3). When comparing the placebo condition to the vibration condition in BL, PW, and PS trials no significant difference was found ($p > 0.05$). The average times were within 0.02 seconds in the BL, PW, and PS trials for the start of asymmetric loading in placebo and vibration trials. The average total times in the BL and PW were within 0.05 seconds for both conditions, and the placebo and vibration PS trials were 0.65 seconds and 0.66 seconds respectively (Table 3).

Table 3. *Average temporal data for volitional stepping in the anterior direction.*

	Asymmetric Loading			**Total Time**		
	Baseline Mean ± SD (sec)	**Post Warm-up** Mean ± SD (sec)	**Post Stimulation** Mean ± SD (sec)	**Baseline** Mean ± SD (sec)	**Post Warm-up** Mean ± SD (sec)	**Post Stimulation** Mean ± SD (sec)
Placebo	0.22 ± 0.08	0.23 ± 0.05	0.21 ± 0.04	0.63 ± 0.05	0.61 ± 0.06	0.65 ± 0.09
Vibration	0.24 ± 0.08	0.25 ± 0.05	0.20 ± 0.03	0.68 ± 0.07	0.66 ± 0.05	0.66 ± 0.02

The total step times were separated into lift-off duration and swing time (Fig. 5). Because there was no significance in the overall total time for the anterior stepping direction in the placebo and vibration conditions, no comparisons were made between the BL, PW, and PS lift-off and swing times.

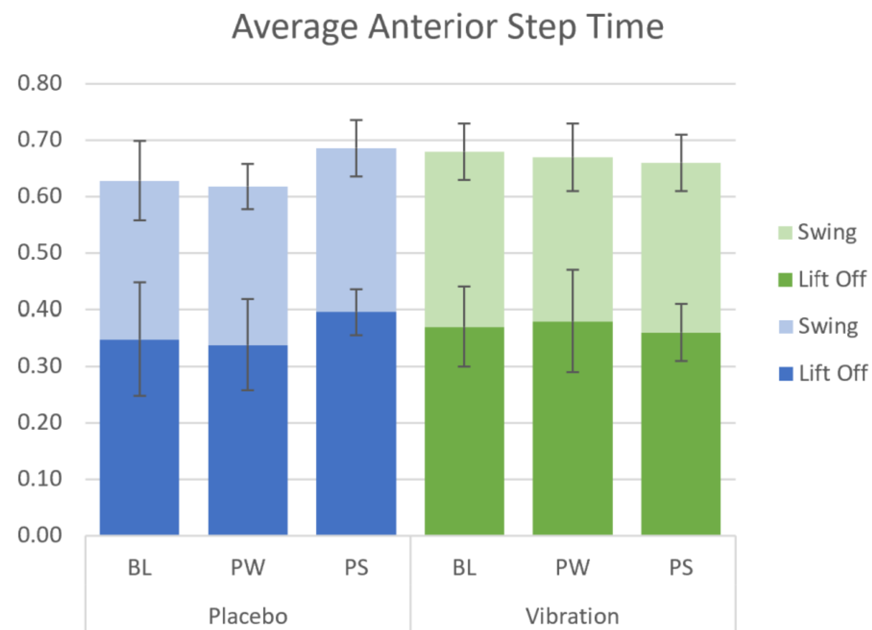

Figure 5. *Average total step time for the anterior direction separated into the lift-off and swing times. The lift-off is the bottom section while the swing time is the top portion. Placebo trials are on the left side (blue) and vibration trials are on the right (green). Standard deviations for each variable are also displayed on the bar graph.*

3.4.3 Volitional Stepping Task in the Right Lateral Direction

Figure 6 depicts example force data for BL, PW, and PS for the right lateral volitional stepping task. Four vertical lines are displayed at critical time events starting with the visual stimulus at 1 second ("Light On"). The increase in vertical force seen after the foot strike is due to the left foot moving over to the ending position. However, the force remains high, rather than returning to the initial magnitude seen between 0.5 and 1 second, because both feet are now on the force plate. The final vertical force (~950 N) is approximately two times the initial vertical force (~425 N) because it represents the combined force of both feet, as opposed to only the right foot vertical force in the start of the stepping task (Fig. 6).

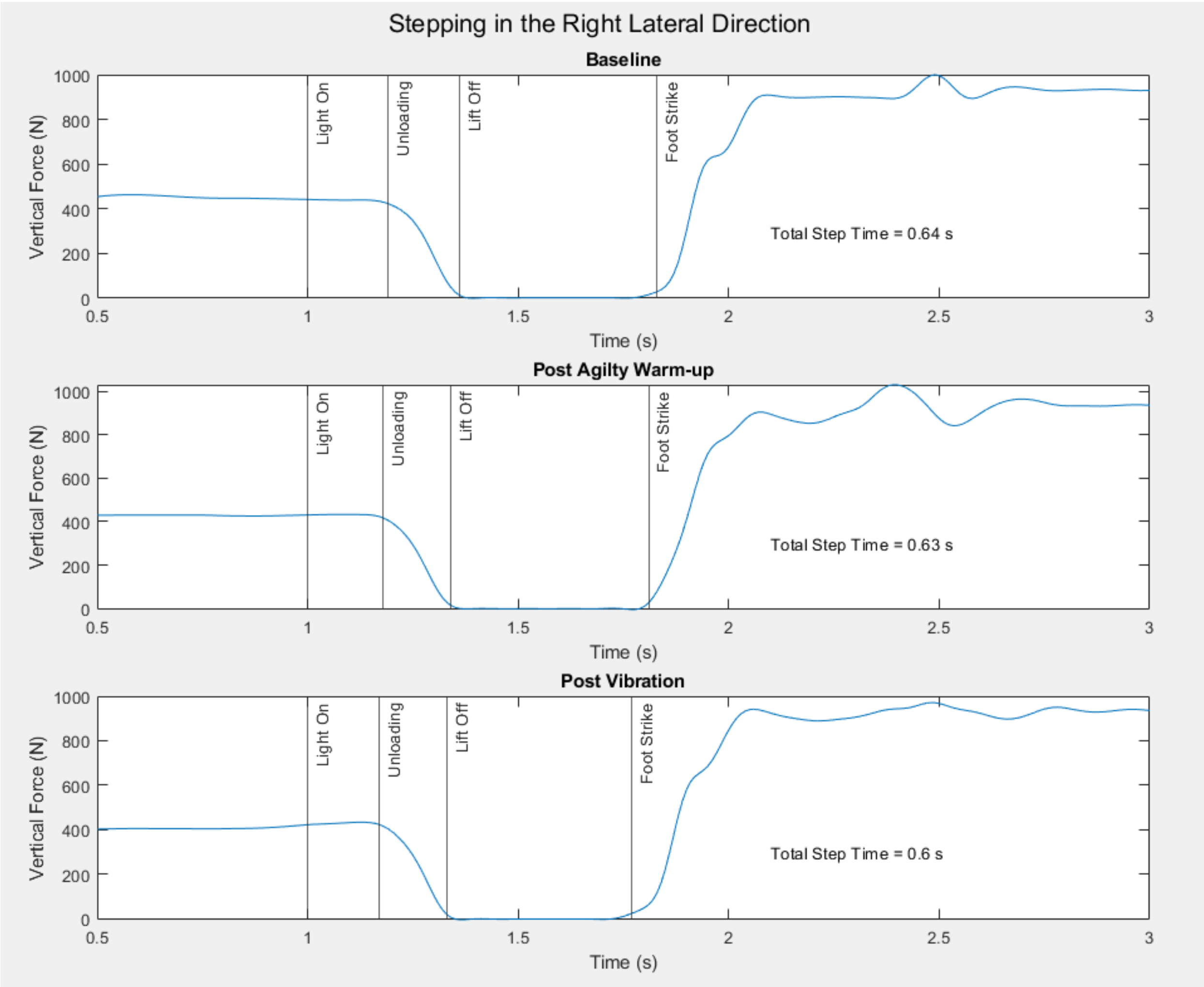

Figure 6. *Example of vertical force data for the right lateral volitional stepping task. Parameter time events are marked with a vertical line and the total step time (from asymmetric unloading to foot strike) is displayed on the graphs.*

For the right lateral stepping direction there was significant difference between the BL vs PW ($p = 0.033$) and BL vs PS ($p = 0.008$) total times in the vibration condition. The average total step time during the BL trial was 0.58 ± 0.06 seconds while the average total step times for the PW and PS trials were both 0.55 ± 0.06 seconds (Table 4). There was a decreasing trend found across these two comparisons, but no significant difference was found between the PW and PS trials for vibration. No significant differences ($p > 0.05$) were found when comparing the BL, PW, and PS asymmetric unloading for the vibration condition. There were also no significant differences ($p > 0.05$) across the placebo and vibration conditions in the BL, PW, and PS trials.

Table 4. *Average temporal data for volitional stepping in the right lateral direction.*

	Asymmetric Unloading			**Total Time**		
	Baseline Mean ± SD (sec)	**Post Warm-up** Mean ± SD (sec)	**Post Stimulation** Mean ± SD (sec)	**Baseline** Mean ± SD (sec)	**Post Warm-up** Mean ± SD (sec)	**Post Stimulation** Mean ± SD (sec)
Placebo	0.26 ± 0.07	0.18 ± 0.04	0.24 ± 0.06	0.55 ± 0.06	0.57 ± 0.06	0.52 ± 0.02
Vibration	0.24 ± 0.09	0.21 ± 0.07	0.24 ± 0.10	0.58 ± 0.06	0.55 ± 0.06	0.55 ± 0.06

The components for average total step time, lift-off and swing time are shown in Figure 7. Because the total time was found to be significantly different for BL vs PW and BL vs PS in the vibration condition, comparison tests for the lift-off and swing times were completed. There was no significant difference ($p > 0.05$) of lift-off times during BL, PW, and PS trials for the vibration condition. However, there was a significant difference for BL vs PW ($p = 0.038$) and BL vs PS ($p = 0.002$) average swing time with a decreasing trend in both comparisons, -0.02 and -0.03 respectively. The average swing time for BL, PW, and PS were 0.43 ± 0.06 seconds, 0.41 ± 0.07, and 0.40 ± 0.06 seconds respectively. There was no significant difference between the PW and PS swing times in the vibration condition.

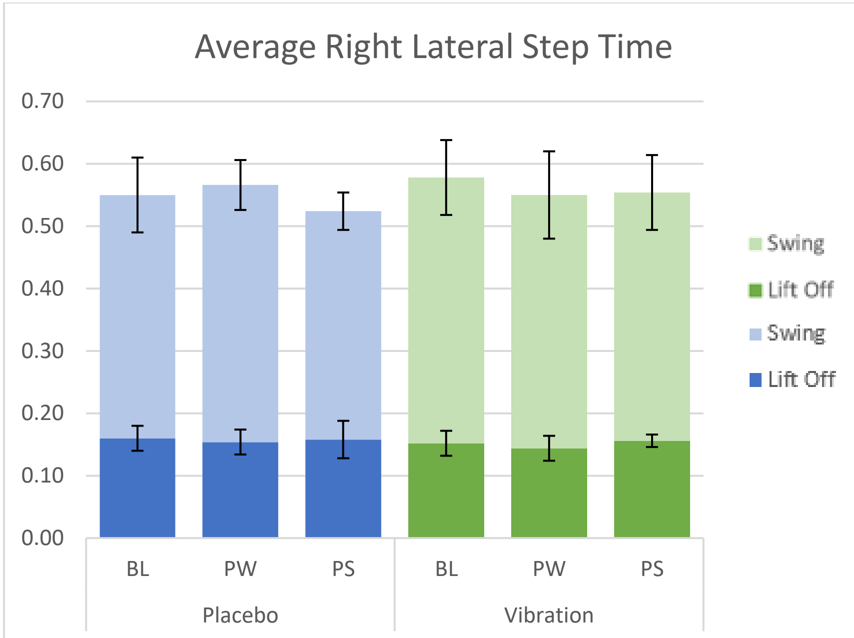

Figure 7. *Average total step time for the right lateral direction broken into the lift-off times and swing times. The lift-off is the bottom section while the swing time is the top portion. Placebo trials are on the left side (blue) and vibration trials are on the right (green). Standard deviations for each variable are also displayed on the bar graph.*

3.5 Discussion

3.5.1 Effects of the 505 Agility Task on Stepping

The first aim of this study was to investigate the effects of an agility warm-up on volitional stepping in response to a visual stimulus. It was hypothesized that after completing an agility-based warm-up task, compared to their performance before the agility task, the subjects would improve their performance by stepping quicker and decreasing their reaction times in the anterior and right lateral stepping tasks. BL and PW data was only compared across the vibration condition. Although the vibration had not yet been introduced, the placebo data was kept separate due to a lack of independence between the BL and PW trails for the placebo and vibration conditions.

This study showed no significant improvement in reaction time in the before versus after agility warm-up comparison in either stepping direction. For both anterior and lateral stepping, a postural adjustment for weight shifting is required before stepping (McIlroy & Maki, 1993; Sparto et al., 2014). It was proposed that the agility warm-up would help to facilitate a faster weight shift reaction, but this was not supported. While this study shows that reaction times were not affected by an agility warm-up in younger persons, this does not rule out the opportunity for improvements in older adults. Reaction times for volitional stepping increase as age increases (Luchies et al., 2002; Sparto et al., 2014). With naturally longer reaction times, there is a wider range for intervention improvement.

There were also no significance differences found in total step time for the anterior direction; however, there was a significant decrease in total time in the right lateral direction from BL to PW. To understand which variable significantly contributes to the decrease in total time, foot lift off duration and swing time were both investigated. On average, there was a significant reduction in swing time from BL to PW of 0.02 seconds which resulted in a 0.03 second average reduction in total time. Subjects improved their right lateral total step time by reducing the time their right foot spent in the air. While this average reduction in total time is statically significant, there may not be physical significance for task completion. However, as mentioned previously there could be physical significance for an aging population.

3.5.2 Stochastic Resonance Effects on Agility

The results of the comparison of the 505-agility task performance before versus after stochastic resonance vibration did not support the hypothesis that stochastic resonance would decrease the time to complete the 505-agility task. There was no difference within or across the vibration and placebo groups. Subjects performed the 505-agility task just as well after receiving vibration as before vibration. The 505-agility task has been seen as the superior agility test due to its dependence on acceleration rather than velocity (Draper & Lancaster, 1985). While it does not matter the speed of the subject, there are still factors such as flexibility, stride length, and limb length that the test depends on (Cochrane et al., 2004). In this study, these dependent factors were not accounted for, and this potential variability could have influenced the outcome.

There is also skepticism on the ability of non-elite level athletes to respond to a vibration stimulus for training purposes. It is proposed that elite athletes have higher level of central nervous system sensitivity which allows them to be more receptive to vibration training (Cochrane et al., 2004; Issurin & Tenenbaum, 1999). While participants in this study were required to have a regular activity intensity level similar to the 505-agility test, they all were well below the intensity of an elite athlete. One study did show that untrained adults improved their agility tests after vibration, but the vibration was whole body, which is very different from the localized, subthreshold vibration used in this study (Wallmann et al., 2019). For healthy non-athletes, it is possible that a higher magnitude of vibration is needed to have influence on a highly athletic agility task. It is also possible that the agility test needs to have a lower athletic threshold to see results with our current vibration methods.

3.5.3 Stochastic Resonance Effects on Volitional Stepping

The last hypothesis of this study was that stochastic resonance vibration would improve performance on a voluntary anterior and right lateral stepping task. Performance was assessed through reaction time and total stepping time. Identical with results found from the effects of agility on stepping, the only significant decrease from BL to PS was seen in the right lateral total time. No improvements were found in any reaction times across or between vibration and placebo conditions. To find the source of the total time difference in the right lateral step, the foot lift off duration and swing times were both assessed. Lift off duration did not see a significant decrease; however, there was a 0.03 second average decrease in swing time that led to the average total time reduction of 0.03 seconds.

It is worth noting that this observation could be a residual effect of the agility warm-up on the PS trials. During one testing session, participants completed the baseline stepping tasks, followed by the agility warm-up and post warm-up trials, before moving on to the stimulation and post stimulation measurements. To avoid any lingering effects of the agility warm-up, several seated breaks were given throughout the protocol. This amounted to a total of 15 minutes of rest between the warm-up and PS stepping task, with 10 of those minutes happening after PW 505-agility trial. Additionally, there was no significance found in any of the stepping tasks completed during placebo trials, further indicating a lack of residual influence of the warm-up.

Based on the definition that agility is the ability to rapidly change direction or speed, the stepping task could be seen as an agility task. The volitional stepping tasks, in both directions, require a quick response that results in a change of speed (static standing to motion) and direction (anterior or right lateral). As postulated previously, it is possible that (1) vibration magnitude needs to be increased or (2) the agility task should have a lower athletic requirement to find substantial changes in agility task performance. Changing the 505-agility task to a volitional stepping task would be one way to lower the athletic intensity requirement. When the athletic threshold was lowered, there were significant differences found between pre and post vibration trials. To further test this theory, subjects without any athletic background could be future participants in the study.

3.5.4 Lateral vs Anterior Stepping

Reasoning for why only the lateral step was affected can be found in the mechanics of stepping in both directions. There are two postural adjustments made while taking a step in the anterior direction. The first creates an increase in vertical force between the ground and the swing leg as weight is transferred to the stance leg, and the second occurs when the swing leg starts the lifting sequence (McIlroy & Maki, 1993). For young people, taking a lateral step only requires one postural adjustment of lifting stepping foot off the ground (Sparto et al., 2014). The higher number of postural adjustments indicates that there is more concern with creating stability before taking a step. For steps taken in the anterior direction, weight shift needs to occur to laterally stabilize over one support limb, but during a lateral step there is no need for perpendicular stabilization because the body weight is already centered in the anteroposterior direction. This creates faster stepping times in the lateral direction with only adjusting posture once rather than twice before stepping. With less concern for creating stability during a step, there is more of an 'automatic' response to the visual cue, as opposed to the complexity that comes with having to stabilize and then move.

More simply, the lateral step could have also been influenced by the agility warm-up and stochastic resonance because it is a less common movement for people in daily life. During the testing session alone, subjects took hundreds of forward steps and maybe ten explicitly lateral steps. Subjects could have already been 'warmed-up' to anterior gait initiation and were at a task plateau, whereas the lateral step could have greater room for improvement.

3.5.5 Limitations

There were several sources of limitations in this study due to the experimental protocol and the total number of participants. Participant recruitment was extremely limited due to the COVID-19 pandemic. The pandemic caused many lifestyle changes that resulted in less people qualifying for participation. Safety measures that were implemented due to the pandemic also limited participation. With smaller sample sizes, complete statistical analysis could not be performed. As previously mentioned, the data was assumed to fit the requirements for t-tests; however, with a limited sample size, it is impossible to say whether the data would truly have equal variance or a normal distribution. There was also a wider range of activity level across subjects than initially desired. While all participants met the study requirements, activity ranged from 30 minutes twice a week to 2 hours 5 times a week. This introduces greater variability to performance outcomes due to the small sample size.

Limitations of the protocol arise from the combination of the agility task and the volitional stepping task. Currently, the vibration mat in the lab has only been tested in studies that took post vibration measurements immediately following stimulation. However, after the stimulus was given, participants completed three anterior steps, three right lateral steps and then the 505-agility task. This succession places both the agility and right lateral task at a slight disadvantage having a larger time gap between stimulus and data collection. Subjects also walked about 20 meters from the stimulus area to the agility task testing area. The vibration mat has not been explored for retention effects and the agility task could have been affected by movement between stimulation and testing.

3.5.6 Future Work

Future studies are needed to gain further knowledge of the complex connection between agility, gait initiation, and stochastic resonance. There should be more investigation into the role that athletic ability has on the efficacy of utilizing stochastic resonance vibration as a method to improve agility. There also can be more examination into stochastic resonance and gait imitation in more directions than the two presented in this study. Finally, modifications of the current protocol should be made to adapt this study for an older population to assess the validity of the hypotheses in these different groups. Through this research better intervention methods can be identified to reduce the risk of falling in older adults.

3.6 Conclusion

In conclusion, this is the first study that we are aware of that investigated the use of agility and stochastic resonance to improve voluntary step performance. This study demonstrated potential benefits of the use of agility training or stochastic resonance as a method to improve step performance. The ability of a session of stochastic resonance vibration to improve performance on an agility task was not supported through this study; however, there is evidence that stochastic resonance vibration could be an effective method of improving step performance. Further work is needed to gain deeper knowledge into the connection between stochastic resonance vibration, volitional stepping, and agility.

Understanding the impact of these connections can help to create cheaper, more accessible, and effective alternative methods of fall intervention for high fall risk older adults.

3.7 References

Brunt, D., Lafferty, M. J., Mckeon, A., Goode, B., Mulhausen, C., & Polk, P. (1991). Invariant Characteristics of Gait Initiation. *American Journal of Physical Medicine and Rehabilitation*, *70*(4), 206–212.

Cochrane, D. J., Legg, S. J., & Hooker, M. J. (2004). the Short-Term Effect of Whole-Body Vibration Training on Vertical Jump,Sprint, and Agility Performance. *Journal of Strength and Conditioning Research*, *18*(4), 828–832. https://doi.org/10.1519/00124278-200411000-00025

Donath, L., van Dieën, J., & Faude, O. (2016). Exercise-Based Fall Prevention in the Elderly: What About Agility? *Sports Medicine*, *46*(2), 143–149. https://doi.org/10.1007/s40279-015-0389-5

Draper, J. A., & Lancaster, M. R. (1985). The 505 Test: A Test for Agility in the Horizontal Plane. *The Australian Journal of Science and Medicine in Sport*, *March* 15–18.

Enderlin, C., Rooker, J., Ball, S., Hippensteel, D., Alderman, J., Fisher, S. J., McLeskey, N., & Jordan, K. (2015). Summary of factors contributing to falls in older adults and nursing implications. *Geriatric Nursing*, *36*(5), 397–406. https://doi.org/10.1016/j.gerinurse.2015.08.006

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical Costs of Fatal and Nonfatal Falls in Older Adults. *Journal of the American Geriatrics Society*, *66*(4), 693–698. https://doi.org/10.1111/jgs.15304

Giraldo, C. (2021). *Design, Validation and Assessment of Vibratory Mat for Stochastic Resonance Applications* (Publication No. 28547245) [Doctoral dissertation, University of Kansas]. ProQuest Dissertations Publishing.

Haddad, Y. K., Bergen, G., & Florence, C. S. (2019). Estimating the Economic Burden Related to Older Adult Falls by State. *Journal of Public Health Management and Practice*, *25*(2), E17–E24. https://doi.org/10.1097/PHH.0000000000000816

Issurin, V. B., & Tenenbaum, G. (1999). Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *Journal of Sports Sciences*, *17*(3), 177–182. https://doi.org/10.1080/026404199366073

Khow, K. S. F., & Visvanathan, R. (2017). Falls in the Aging Population. *Clinics in Geriatric Medicine*, *33*(3), 357–368. https://doi.org/10.1016/j.cger.2017.03.002

Lichtenstein, E., Morat, M., Roth, R., Donath, L., & Faude, O. (2020). Agility-based exercise training compared to traditional strength and balance training in older adults: A pilot randomized trial. *PeerJ*, *2020*(4). https://doi.org/10.7717/peerj.8781

Liu-Ambrose, T., Davis, J. C., Best, J. R., Dian, L., Madden, K., Cook, W., Hsu, C. L., & Khan, K. M. (2019). Effect of a Home-Based Exercise Program on Subsequent Falls among Community-Dwelling High-Risk Older Adults after a Fall: A Randomized Clinical Trial. *JAMA - Journal of the American Medical Association*, *321*(21), 2092–2100. https://doi.org/10.1001/jama.2019.5795

Liu-Ambrose, T., Khan, K. M., Eng, J. J., Janssen, P. A., Lord, S. R., & McKay, H. A. (2004). Resistance and Agility Training Reduce Fall Risk in Women Aged 75 to 85 with Low Bone Mass: A 6-Month Randomized, Controlled Trial. *Journal of the American Geriatrics Society*, *52*(5), 657–665. https://doi.org/10.1111/j.1532-5415.2004.52200.x

Luchies, C. W., Schiffman, J., Richards, L. G., Thompson, M. R., Bazuin, D., & DeYoung, A. J. (2002). Effects of age, step direction, and reaction condition on the ability to step quickly. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *57*(4), M246–M249. https://doi.org/10.1093/gerona/57.4.M246

McIlroy, W. E., & Maki, B. E. (1993). Changes in early “automatic” postural responses associated with the prior-planning and execution of a compensatory step. *Brain Research*, *631*(2), 203–211. https://doi.org/10.1016/0006-8993(93)91536-2

McIlroy, W. E., & Maki, B. E. (1997). Preferred placement of the feet during quiet stance: Development of a standardized foot placement for balance testing. *Clinical Biomechanics*, *12*(1), 66–70. https://doi.org/10.1016/S0268-0033(96)00040-X

Miranda, D. L., Hsu, W. H., Gravelle, D. C., Petersen, K., Ryzman, R., Niemi, J., & Lesniewski-Laas, N. (2016). Sensory enhancing insoles improve athletic performance during a hexagonal agility task. *Journal of Biomechanics*, *49*(7), 1058–1063. https://doi.org/10.1016/j.jbiomech.2016.02.022

Okubo, Y., Schoene, D., & Lord, S. R. (2017). Step training improves reaction time, gait and balance and reduces falls in older people: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *51*(7), 586–593. https://doi.org/10.1136/bjsports-2015-095452

Priplata, A. A., Niemi, J. B., Harry, J. D., Lipsitz, L. A., & Collins, J. J. (2003). Vibrating insoles and balance control in elderly people. *Lancet*, *362*(9390), 1123–1124. https://doi.org/10.1016/S0140-6736(03)14470-4

Sierra-Guzman, R., Jimenez-Diaz, F., Ramirez, C., Esteban, P., & Abian-Vicen, J. (2018). Whole-Body-Vibration Training and Balance in Recreational Athletes With Chronic Ankle Instability. *Journal of Athletic Training*, *53*(4), 355–363.

Sparto, P. J., Jennings, J. R., Furman, J. M., & Redfern, M. S. (2014). Lateral step initiation behavior in older adults. *Gait and Posture*, *39*(2), 799–803. https://doi.org/10.1016/j.gaitpost.2013.10.021

Van Vost Moncada, L., & Mire, L. G. (2017). Preventing Falls in Older Patients. *Amerian Family Physician*, *96*(4), 240–247.

Wallmann, H. W., Bell, D. L., Evans, B. L., Hyman, A. A., Goss, G. K., & Paicely, A. M. (2019). the Effects of Whole Body Vibration on Vertical Jump, Power, Balance, and Agility in Untrained Adults. *International Journal of Sports Physical Therapy*, *14*(1), 55–64. https://doi.org/10.26603/ijspt20190055

White, O., Babic, J., Trenado, C., Johannsen, L., & Goswami, N. (2019). The promise of stochastic resonance in falls prevention. *Frontiers in Physiology*, *10*(JAN), 1–12. https://doi.org/10.3389/fphys.2018.01865

Whorley, B. (2020). *A Physiology-Based Approach for Detecting Vibration Perception Threshold in the Plantar Foot* (Publication No. 28029429) [Master's Thesis, University of Kansas]. ProQuest Dissertations Publishing.

Zhao, G., Grimmer, M., & Seyfarth, A. (2021). The mechanisms and mechanical energy of human gait initiation from the lower-limb joint level perspective. *Scientific Reports*, *11*(1), 1–12. https://doi.org/10.1038/s41598-021-01694-5

Chapter 4: Conclusion

4.1 Study Summary

The objective of this study was to assess the relationship of agility, stochastic resonance vibration, and multidirectional volitional stepping. To investigate these relationships time series data was collected through timing gates during a 505-agility task and through force plates during an anterior and right lateral volitional stepping task before and after of vibration stimulation.

The hypotheses of the study were (1) an agiilty warm-up will decrease reaction and completion time for multidirectional voltional stepping , (2) stochastic resonance stimulation will decrease the completion time of the 505-agility task and (3) stochastic resonance will decrease reaction and completion time for multidirectional voltional stepping. The results of this study do not support the hypothesis that stochastic resonance will improve the performance on the 505-agiltiy task, however there are some factors such as age and variability in athletic ability of participants that could have affected the results. In the right lateral stepping task, there was evidence that to support the hypothesis that stochastic resonance and an agility warm-up both decrease the total step time.

Based on the results, further investigation of the influence of stochastic resonance and agility on volitional stepping is recommended. This study has demonstrated potential benefits of the use of agility training or stochastic resonance as a method to improve step performance. Understanding the impact of these connections can help to create cheaper, more accessible, and effective alternative methods of fall intervention for high fall risk older adults.

4.2 Future Works

Further investigation on the effects of stochastic resonance and agility on volitional stepping is needed. Future studies could include the following:

- Using suprathreshold vibration rather than subthreshold and exploring its effects on stepping and agility in active young adults. This would test whether a stronger vibration could produce significant results from the agility test in active healthy young participants (Cochrane et al., 2004).
- Removing the highly athletic 505-agilty task and further investigate the effects of subthreshold vibration on multidirectional volitional stepping in more than 2 directions. Removal of the agility task would better isolate the relationship between vibration and stepping without possible residual effects from an agility warm-up.
- Comparing the effects of stochastic resonance on volitional stepping between healthy young and healthy old persons. As mentioned previously aging results in slower reaction and weight shift times for volitional stepping which gives healthy older adults a long step time that has a greater possibility of showing improvement compared to healthy young adults (Luchies et al., 2002; Sparto et al., 2014).
- Creating a longer agility routine to investigate long term effects of agility training on volitional stepping. The study outlined in this chapter had a short agility warm-up, however agility could still have long term affects an agility exercise was implemented into participants routines (Lichtenstein et al., 2020; Liu-Ambrose et al., 2004).

Although these suggestions do not cover the full extent of possible future studies, they may provide a better understanding the relationships between agility, stochastic resonance, and volitional stepping.

4.3 References

Cochrane, D. J., Legg, S. J., & Hooker, M. J. (2004). the Short-Term Effect of Whole-Body Vibration Training on Vertical Jump,Sprint, and Agility Performance. *Journal of Strength and Conditioning Research*, *18*(4), 828–832. https://doi.org/10.1519/00124278-200411000-00025

Luchies, C. W., Schiffman, J., Richards, L. G., Thompson, M. R., Bazuin, D., & DeYoung, A. J. (2002). Effects of age, step direction, and reaction condition on the ability to step quickly. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *57*(4), M246–M249. https://doi.org/10.1093/gerona/57.4.M246

Sparto, P. J., Jennings, J. R., Furman, J. M., & Redfern, M. S. (2014). Lateral step initiation behavior in older adults. *Gait and Posture*, *39*(2), 799–803. https://doi.org/10.1016/j.gaitpost.2013.10.021

Liu-Ambrose, T., Khan, K. M., Eng, J. J., Janssen, P. A., Lord, S. R., & McKay, H. A. (2004). Resistance and Agility Training Reduce Fall Risk in Women Aged 75 to 85 with Low Bone Mass: A 6-Month Randomized, Controlled Trial. *Journal of the American Geriatrics Society*, *52*(5), 657–665. https://doi.org/10.1111/j.1532-5415.2004.52200.x

Lichtenstein, E., Morat, M., Roth, R., Donath, L., & Faude, O. (2020). Agility-based exercise training compared to traditional strength and balance training in older adults: A pilot randomized trial. *PeerJ*, *2020*(4). https://doi.org/10.7717/peerj.8781

Appendix A: Power Analysis and P-values

Table 5: Required number of subjects to achieve significance ($p < 0.05$) and 80% power for two-sample one-sided t-tests with asymmetric loading and total time variables.

	Asymmetric Loading			Total Time		
	BL vs PT	**BL vs PS**	**PT vs PS**	**BL vs PT**	**BL vs PS**	**PT vs PS**
Anterior	221	33	43	82	77	4014
Right Lateral	87	27433	92	63	79	2925

Table 6: Required number of subjects to achieve significance ($p < 0.05$) and 80% power for two-sample one-sided t-tests with lift off duration and swing time variables.

	Lift Off Duration		Swing Time	
	BL vs PT	**BL vs PS**	**BL vs PT**	**BL vs PS**
Right Lateral	60	172	121	60

Table 7: P-value results of two-sample one-sided t-tests for asymmetric loading and total time. Significant p-values ($p < 0.05$) are highlighted

	Asymmetric Loading			Total Time		
	BL vs PT	**BL vs PS**	**PT vs PS**	**BL vs PT**	**BL vs PS**	**PT vs PS**
Anterior	0.342	0.141	0.085	0.118	0.29	0.533
Right Lateral	0.137	0.532	0.937	0.033	0.008	0.392

Table 8: P-value results of two-sample one-sided t-tests for lift off duration and swing time. Significant p-values ($p < 0.05$) are highlighted.

	Lift Off Duration		Swing Time	
	BL vs PT	**BL vs PS**	**BL vs PT**	**BL vs PS**
Right Lateral	0.187	0.762	0.038	0.002

Appendix B: MATLAB Codes

Appendix B.1: Main Body

```
%Jessica Kirchner
%Agility Study
%Modified by Kirchner 4/21/2022

clear; clc; close all;

%FP 3364 is the right force plate
%FP 3477 is the left force plate

%Forward step, feet pointed in the +x direction, R foot on FPs
%   Right foot on 3477 left foot shoulder width away then right foot took
%   step forward to 3364 and left foot brought up to match (off FP)
%Side step, feet pointed in the -y direction
%   both feet started on 3477 and right foot moved to 3364 and left foot
%   brought over to match

%% Define Parameters

%Asking for Subject Number and color to analyze
prompt = 'Subject Number: ';
subject_num = inputdlg(prompt);
subject_num = str2double(subject_num);
prompt = 'Color: ';
color = inputdlg(prompt);


%establish the path to the data
datapath_raw = ['C:\Users\jessk\OneDrive - University of Kansas\Agility Study\01 Raw
Data\s' num2str(subject_num) '\'];
datapath_pros = 'C:\Users\jessk\OneDrive - University of Kansas\Agility Study\02
Processed Data\';
datapath_filt='C:\Users\jessk\OneDrive - University of Kansas\Agility Study\03
Filtered Data\';
datapath_final='C:\Users\jessk\OneDrive - University of Kansas\Agility Study\04 Final
Data\';

%Sway 1-3, Forward 4-12, Side 13-21
files = {'_BLSWAY' 'BL Sway';
         '_PTSWAY' 'Post Train Sway';
         '_SWAY' 'Post Stim Sway';
         '_BLF_1' 'BL Forward Step 1';
         '_BLF_2' 'BL Forward Step 2';
         '_BLF_3' 'BL Forward Step 3';
         '_PTF_1' 'Post Train Forward Step 1';
         '_PTF_2' 'Post Train Forward Step 2';
         '_PTF_3' 'Post Train Forward Step 3';
         '_FOR_1' 'Post Stim Forward Step 1';
         '_FOR_2' 'Post Stim Forward Step 2';
         '_FOR_3' 'Post Stim Forward Step 3';
```

```
         '_BLSS_1' 'BL Side Step 1';
         '_BLSS_2' 'BL Side Step 2';
         '_BLSS_3' 'BL Side Step 3';
         '_PTSS_1' 'Post Train Side Step 1';
         '_PTSS_2' 'Post Train Side Step 2';
         '_PTSS_3' 'Post Train Side Step 3';
         '_SIDE_1' 'Post Stim Side Step 1';
         '_SIDE_2' 'Post Stim Side Step 2';
         '_SIDE_3' 'Post Stim Side Step 3'};

%Force Plate Gain
fp_gain = 1000;

%Distance Below FP surface to axis origin
dz_3364 = .038; %[m] Right FP
dz_3477 = .037; %[m] Left FP
dz_mean = mean([dz_3364,dz_3477]);

%Sampling Rate
fsample = 100; %[Hz]

%Step Size
dt = 1/fsample; %[s]

%% Zeros Data

isub = subject_num;

zeros_temp = load([datapath_filt 's' num2str(isub) '_' color{1} '_zeros_filt.mat']);
zeros_temp = struct2table(zeros_temp); zeros_temp = table2array(zeros_temp);

    zeros_data = zeros_temp(:,2:19);
    mean_zeros = mean(zeros_data);
    mean_zeros_3364 = mean_zeros(1:6);
    mean_zeros_3477 = mean_zeros(7:12);
    mean_zeros_4033 = mean_zeros(13:18);

%% Sway Trial
    %BLSWAY PTSWAY SWAY

isub = subject_num;
for ii = 1:3

    data = load([datapath_filt 's' num2str(isub) '_' color{1} files{ii,1}
'_filt.mat']);
    data = struct2table(data); data = table2array(data);
    data = data(2:end,:);

    sway_3364 = V2f_fp3364(data(:,2:7), mean_zeros_3364, fp_gain);
    sway_3477 = V2f_fp3477(data(:,8:13), mean_zeros_3477, fp_gain);
    %Data Columns 1:6, Fx Fy Fz Mx My Mz

    %Combining data
    FP = Comb_fp3477_fp3364(sway_3477,sway_3364);
```

```
    %Rotating data around z-axis -90 degrees
    %(X to A/P and Y to M/L) was (X M/L and Y -A/P)
    sway=[data(:,1) ...                                                     %Time
    -sway_3364(:,2) sway_3364(:,1) sway_3364(:,3) -sway_3364(:,5) sway_3364(:,4)
sway_3364(:,6) ...   %Right 3364
    -sway_3477(:,2) sway_3477(:,1) sway_3477(:,3) -sway_3477(:,5) sway_3477(:,4)
sway_3477(:,6)]; %Left 3477

    %Combining Data
    sway_comb = Comb_fp3477_fp3364(sway(:,8:13),sway(:,2:7));

    %Body Weight
    body_weight(ii) = mean(FP(:,3));

    %Center of Pressure
    COPx = -(sway_comb(:,5)+sway_comb(:,1)*dz_mean)./sway_comb(:,3); %AP, +facing
forward
    COPy = (sway_comb(:,4)-sway_comb(:,2)*dz_mean)./sway_comb(:,3); %ML, +right hand

    COPx_sway = mean(COPx);
    COPy_sway = mean(COPy);

    %Width and Length
    Width = max(COPy)- min(COPy);
    Length = max(COPx)- min(COPx);

    %Distance Traveled
    for i = 1:length(COPx)-1
        delta_x = COPx(i+1)-COPx(i);
        delta_y = COPy(i+1)-COPy(i);
        d(i) = sqrt(delta_x^2 + delta_y^2);
    end

    distance = sum(d);

    %Radius
    Xm = mean(COPx);
    Ym = mean(COPy);
    r = sqrt((COPx-Xm).^2+(COPy-Ym).^2);
    radius = max(r);

    %Differentiate COPs for Peak Velocity Magnitude
    [COPVx, COPAx] = derivative(COPx,1,dt); %[velocity, acceleration]
    [COPVy, COPAy] = derivative(COPy,1,dt);

    vel_mag = sqrt(COPVx.^2+COPVy.^2);
    vel_mag_max = max(vel_mag);

end

%Average Body wieght over three trials
BW = mean(body_weight);
%% FORWARD STEP TRIALS
    %BLF, PTF, FOR
isub = subject_num;
```

```
for n = [0 3 6]
    for itrial = 4+n:6+n
        if itrial == 4+n
            rootname = files{4+n,1}; %_BLF_1/_PT_1/_FOR_1
            row = 1;
        elseif itrial == 5+n
            rootname = files{5+n,1}; %_BLF_2/_PT_2/_FOR_2
            row = 2;
        else
            rootname = files{6+n,1}; %_BLF_3/_PT_3/_FOR_3
            row = 3;
        end

        data = load([datapath_filt 's' num2str(isub) '_' color{1} files{itrial,1}
'_filt.mat']);
        data = struct2table(data); data = table2array(data);
        data = data(2:end,:);

        fs_3364 = V2f_fp3364(data(:,2:7), mean_zeros_3364, fp_gain);
        fs_3477 = V2f_fp3477(data(:,8:13), mean_zeros_3477, fp_gain);
        %Data Columns 1:6, Fx Fy Fz Mx My Mz
        % +X in forward facing direction, +Y is to the right
        %RF starting on 3477, step to 3364 w/ RF

        %Combining data
        FP = Comb_fp3477_fp3364(fs_3477,fs_3364);

        %Plotting full data
        figure(2+n); sgtitle(['Forward Step 3477 and 3364 ' color{1}])
        subplot(3,1,itrial-(3+n)); plot(FP(:,3));
        xlabel('Time'); ylabel('Force [N]')
        if itrial == 4+n
            title(files{4+n,2});
        elseif itrial == 5+n
            title(files{5+n,2});
        else
            title(files{6+n,2});
        end


        %Cut data after Lift Off
        stand_avg_3477 = mean(FP(80:110,3));
        i_3477 = find(FP(:,3) <= 0.05*stand_avg_3477);
        fs_3477 = FP(1:i_3477(1),:);

        %Determine Asymmetric Loading Time
            %Graph of s1003_WH_FOR_2 has no weight shift
        difference = diff(FP(:,3));
        ishift = find(difference(100:end)>0.01*stand_avg_3477);
        ishift = ishift+100;

        %Determine when Reaction and Lift Off Occur
        reaction_t(itrial - 3) = (ishift(1)-100)/100;
            %reaction time is being selected as the first asymmetric loading
```

```
            %the light goes off at 1 sec heance the -100
        liftoff_t(itrial-3) = (length(fs_3477)-100)/100;

        %Plotting events on full data plot
        figure(2+n); subplot(3,1,itrial-(3+n))
        xline([100, ishift(1), length(fs_3477),],'-',{'Light on', 'Reaction', 'End
liftoff'})

        %Start 3364 after end of lift off
        fs_3364 = FP(length(fs_3477)+1:end,:);
            %to get time from zero add length of 3477 to fs_3364

        %Determine Heel Strike Time (3364)
            %s1001_WH has bad BLF_2 data (moved after taking step)
            %this if statement uses the stand avg from BLF_1 for s1001_WH
            if subject_num == 1001 && strcmp(color{1}, 'WH')&& itrial == 5
                %stand avg for s1001_WH_BLF_1
            else
                stand_avg_3364 = mean(fs_3364(end-200:end,3));
            end

        iheel_hit = find(fs_3364(:,3) >= 0.05*stand_avg_3364);

        %Plotting events on full data plot
        figure(2+n); subplot(3,1,itrial-(3+n))
        xline(length(fs_3477)+iheel_hit(1),'-',{'Heel Strike'})

        %Step Duration (time RF is in the air)
        air_t(itrial-3) = iheel_hit(1)/100;

        %TOTAL STEP TIME (Asymmetric loading to heel strike)
        total_step_t(itrial - 3) = (length(fs_3477)+iheel_hit(1) - ishift(1))/100;

        %Asymmetric Load to Lift Off (How long did it take for foot to lift off after
'reaction')
        Load_to_Liftoff(itrial - 3) = liftoff_t(itrial - 3) - reaction_t(itrial - 3);

    end
end


%% Create Tables Forward Step
    % datapoint = [BLF_3;
    %               PTF_3);
    %               FOR_3)];
if subject_num == 1003 && strcmp(color{1}, 'PB')
    %s1003 on PB Post Training pre-loaded in the beginning so I will
    %compare the second step got this color (no asymmetric loading occurs)
    Data = ["Reaction";"Lift Off";"Swing";"Total"];
    Baseline = [reaction_t(2);Load_to_Liftoff(2); air_t(2); total_step_t(2)];
    Post_Training = [reaction_t(5);Load_to_Liftoff(5); air_t(5); total_step_t(5)];
    Post_Vibration = [reaction_t(8);Load_to_Liftoff(8); air_t(8); total_step_t(8)];


    forward_steps = table(Data, Baseline, Post_Training, Post_Vibration);
```

```
elseif subject_num == 1005 && strcmp(color{1}, 'WH')
    %s1005 on WH Baseline Stumbled in the beginning so I will
    %compare the second step got this color (no asymmetric loading occurs)
    Data = ["Reaction";"Lift Off";"Swing";"Total"];
    Baseline = [reaction_t(2);Load_to_Liftoff(2); air_t(2); total_step_t(2)];
    Post_Training = [reaction_t(5);Load_to_Liftoff(5); air_t(5); total_step_t(5)];
    Post_Vibration = [reaction_t(8);Load_to_Liftoff(8); air_t(8); total_step_t(8)];


    forward_steps = table(Data, Baseline, Post_Training, Post_Vibration);
else
%Creating table for third trial
    Data = ["Reaction";"L2L";"Swing";"Total"];
    Baseline = [reaction_t(3);Load_to_Liftoff(3); air_t(3); total_step_t(3)];
    Post_Training = [reaction_t(6);Load_to_Liftoff(6); air_t(6); total_step_t(6)];
    Post_Vibration = [reaction_t(9);Load_to_Liftoff(9); air_t(9); total_step_t(9)];


    forward_steps = table(Data, Baseline, Post_Training, Post_Vibration);
end

%% SIDE STEP TRIALS
    %BLSS, PTS, SIDE
for n = [0 3 6]
    for itrial = 13+n:15+n
        if itrial == 13+n
            rootname = files{13+n,1}; %_BLF_1
            row = 1;
        elseif itrial == 14+n
            rootname = files{14+n,1}; %_BLF_2
            row = 2;
        else
            rootname = files{15+n,1}; %_BLF_3
            row = 3;
        end

    data = load([datapath_filt 's' num2str(isub) '_' color{1} files{itrial,1}
'_filt.mat']);
    data = struct2table(data); data = table2array(data);
    data = data(2:end,:);

    ss_3364 = V2f_fp3364(data(:,2:7), mean_zeros_3364, fp_gain);
    ss_3477 = V2f_fp3477(data(:,8:13), mean_zeros_3477, fp_gain);

    %Combining data
    FPs = Comb_fp3477_fp3364(ss_3477,ss_3364);

    %Plotting events on full data plot (Combined FP)
    figure(11+n); subplot(3,1,itrial-(12+n))
    plot(FPs(:,3))
        if itrial == 13+n
            title(files{13+n,2});
        elseif itrial == 14+n
            title(files{14+n,2});
```

```
        else
            title(files{15+n,2});
        end

        %Determine Stand Average Beginning
        stand_avg_3477 = mean(FPs(80:110,3));

        %Cut data after Lift Off
        i_3477 = find(FPs(:,3) <= 0.05*stand_avg_3477);
        ss_3477 = FPs(1:i_3477(1),:);

        %Find difference in Z-Force
        diff_ss3477 = diff(ss_3477(:,3));
        i_diff = find((diff_ss3477(100:end)) <= -5);

        %Start Lift Off set for difference of 5
        start_LO_t(itrial - 12) = i_diff(1);

        %End Lift Off
        end_LO_t(itrial - 12) = length(ss_3477(:,3)) - 100;

        %Lift Off Duration
        ss_liftoff_duration(itrial - 12) = end_LO_t(itrial - 12) - start_LO_t(itrial
- 12);

        %Plotting Lift Off events on full data plot
        figure(11+n); subplot(3,1,itrial-(12+n))
        xline([start_LO_t(itrial - 12)+100, end_LO_t(itrial-12)+100],'-',{'Start
LO','End LO'})

        %Foot Strike
        ss_3364 = FPs(length(ss_3477)+1:end,:);
        ifoot_hit = find(ss_3364(:,3) >= 0.05*stand_avg_3477);
        foot_hit_t(itrial - 12) = ifoot_hit(1)+length(ss_3477)-100;

        %Air Time
        ss_air_t(itrial - 12) = foot_hit_t(itrial - 12) - end_LO_t(itrial - 12);

        %Plotting Lift Off events on full data plot
        figure(11+n); subplot(3,1,itrial-(12+n))
        xline(foot_hit_t(itrial - 12)+100,'-',{'Foot Strike'})
        xline(100,'-',{'Light On'})

        %TOTAL STEP TIME
        ss_total_step_t(itrial - 12) = (foot_hit_t(itrial - 12) - start_LO_t(itrial -
12))/100;

    end
end
%% Create Tables Side Step
%Creating table for third trial
    Data = ["Start LO";"LO Duration";"Swing";"Total"];
    Baseline = [start_LO_t(3)/100;ss_liftoff_duration(3)/100; ss_air_t(3)/100;
ss_total_step_t(3)];
```

```
    Post_Training = [start_LO_t(6)/100;ss_liftoff_duration(6)/100; ss_air_t(6)/100;
ss_total_step_t(6)];
    Post_Vibration = [start_LO_t(9)/100;ss_liftoff_duration(9)/100; ss_air_t(9)/100;
ss_total_step_t(9)];


    side_steps = table(Data, Baseline, Post_Training, Post_Vibration);

%% Creating Graphs to Save (Third Step for Forward and Side)
%NEED TO ACCOUNT FOR s1003 and s1005 USING SECOND STEP NOT THIRD

graph_files = {'_BLF_3' 'BL Forward Step 3';
               '_PTF_3' 'Post Train Forward Step 3';
               '_FOR_3' 'Post Stim Forward Step 3';
               '_BLSS_3' 'BL Side Step 3';
               '_PTSS_3' 'Post Train Side Step 3';
               '_SIDE_3' 'Post Stim Side Step 3'};

%Forward Step Graphs
for itrial = 1:3
    data = load([datapath_filt 's' num2str(isub) '_' color{1} graph_files{itrial,1}
'_filt.mat']);
    data = struct2table(data); data = table2array(data);
    data = data(2:end,:);

    fs_3364 = V2f_fp3364(data(:,2:7), mean_zeros_3364, fp_gain);
    fs_3477 = V2f_fp3477(data(:,8:13), mean_zeros_3477, fp_gain);

    %Combining data
    FP = Comb_fp3477_fp3364(fs_3477,fs_3364);

    x_scale = 0.50:0.01:3;

    %Plotting events on full data plot (Combined FP)
    for_fig = figure(40); subplot(3,1,itrial); plot(x_scale,FP(50:300,3));
    xline([1, forward_steps{1,itrial+1}+1],'-',{'Light On','Asymmetric Loading'})
    xline(forward_steps{2,itrial+1}+ 1 + forward_steps{1,itrial+1}, '-', 'Lift Off');
    xline(forward_steps{4,itrial+1}+ 1 + forward_steps{1,itrial+1}, '-', 'Heel
Strike');
    sgtitle('Stepping in the Anterior Direction')
    xlabel('Time (s)'); ylabel('Vertical Force (N)')
    text(2.25,300,['Total Step Time = ' num2str(forward_steps{4,itrial+1}) ' s'])
    if itrial == 1
        title('Baseline')
    elseif itrial == 2
        title('Post Agilty Warm-up')
    else
        title('Post Vibration')
    end

end

%Side Step Graphs
for itrial = 4:6
```

```
    data = load([datapath_filt 's' num2str(isub) '_' color{1} graph_files{itrial,1}
'_filt.mat']);
    data = struct2table(data); data = table2array(data);
    data = data(2:end,:);

    ss_3364 = V2f_fp3364(data(:,2:7), mean_zeros_3364, fp_gain);
    ss_3477 = V2f_fp3477(data(:,8:13), mean_zeros_3477, fp_gain);

    %Combining data
    FP = Comb_fp3477_fp3364(ss_3477,ss_3364);

    x_scale = 0.50:0.01:3;

    %Plotting events on full data plot (Combined FP)
    side_fig = figure(41); subplot(3,1,itrial-3); plot(x_scale,FP(50:300,3));
    xline([1, side_steps{1,itrial-2}+1],'-',{'Light On','Unloading'})
    xline(side_steps{2,itrial-2}+ 1 + side_steps{1,itrial-2}, '-', 'Lift Off');
    xline(side_steps{4,itrial-2}+ 1 + side_steps{1,itrial-2}, '-', 'Foot Strike');
    sgtitle('Stepping in the Right Lateral Direction')
    xlabel('Time (s)'); ylabel('Vertical Force (N)')
    text(2.1,300,['Total Step Time = ' num2str(side_steps{4,itrial-2}) ' s'])
    if itrial == 4
        title('Baseline')
    elseif itrial == 5
        title('Post Agilty Warm-up')
    else
        title('Post Vibration')
    end
end
```

Appendix B.2: Raw Data Check

```
%DATA CHECK
%Agility Study
%Modified by Kirchner 04-21-22

%Full Protocol Run Through
clear; clc; close all;

%FP 3364 is the right force plate
%FP 3477 is the left force plate

%Forward step, feet pointed in the +x direction, R foot on FPs
%   Right foot on 3477 left foot shoulder width away then right foot took
%   step forward to 3364 and left foot brought up to match (off FP)
%Side step, feet pointed in the -y direction
%   right feet started on 3477 (left foot off FP shoulder width away)
%   right foot moved to 3364 and left foot brought over to match

prompt = 'Subject Number: ';
subject_num = inputdlg(prompt);
subject_num = str2double(subject_num);

%establish the path to the data
datapath_raw = ['C:\Users\jessk\OneDrive - University of Kansas\Agility Study\01 Raw
Data\s' num2str(subject_num) '\'];
datapath_pros = 'C:\Users\jessk\OneDrive - University of Kansas\Agility Study\02
Processed Data\';
datapath_filt = 'C:\Users\jessk\OneDrive - University of Kansas\Agility Study\03
Filtered Data\';

    % BLSWAY PTSWAY SWAY
    % BLF_1  BLF_2  BLF_3
    % PTF_1 PTF_2  PTF_3
    % FOR_1  FOR_2  FOR_3
    % BLSS_1  BLSS_2  BLSS_3
    % PTSS_1  PTSS_2  PTSS_3
    % SIDE_1  SIDE_2  SIDE_3

files = {'_BLSWAY' 'BL Sway';
         '_PTSWAY' 'Post Train Sway';
         '_SWAY' 'Post Stim Sway';
         '_BLF_1' 'BL Forward Step 1';
         '_BLF_2' 'BL Forward Step 2';
         '_BLF_3' 'BL Forward Step 3';
         '_PTF_1' 'Post Train Forward Step 1';
         '_PTF_2' 'Post Train Forward Step 2';
         '_PTF_3' 'Post Train Forward Step 3';
         '_FOR_1' 'Post Stim Forward Step 1';
         '_FOR_2' 'Post Stim Forward Step 2';
         '_FOR_3' 'Post Stim Forward Step 3';
         '_BLSS_1' 'BL Side Step 1';
         '_BLSS_2' 'BL Side Step 2';
         '_BLSS_3' 'BL Side Step 3';
         '_PTSS_1' 'Post Train Side Step 1';
```

```
         '_PTSS_2' 'Post Train Side Step 2';
         '_PTSS_3' 'Post Train Side Step 3';
         '_SIDE_1' 'Post Stim Side Step 1';
         '_SIDE_2' 'Post Stim Side Step 2';
         '_SIDE_3' 'Post Stim Side Step 3'};

color = {'_PB'; '_WH'};
subject = 1001:1010;

%Column 1-6: 3364: Fx, Fy, Fz, Mx, My, Mz
%Column 7-12: 3477: '   '

%% Zeros
%isub = subject(2);
isub = subject_num;
for icolor = 1:2
    figure(9+icolor)

    data_time = readmatrix([datapath_raw 's' num2str(isub) color{icolor}
'_zeros.txt']);
    data_time(isnan(data_time)) = 0;

    t = data_time(:,1);
    data = data_time(:,2:end);

    %Plotting
    plot(data)

    if icolor == 1
       title('PB zeros');
    else
       title('WH zeros');
    end

    %Saving prcessed data
    data_pros = data_time;
    save([datapath_pros 's' num2str(isub) color{icolor}
'_zeros_pros.mat'],'data_pros')
end

%% Sway Figure
%isub = subject(2);
isub = subject_num;
for icolor = 1:2
    for ii = 1:3
        figure(icolor)

        data_time=readmatrix([datapath_raw 's' num2str(isub) color{icolor}
files{ii,1} '.txt']);
        data_time(isnan(data_time))=0;

        t = data_time(:,1);
        data = data_time(:,2:end);

        %Plotting
```

```
        subplot(1,3,ii); plot(data);

        if icolor == 1
           title([files{ii,2} ' PB']);
        else
           title([files{ii,2} ' WH']);
        end

        %Saving prcessed data
        data_pros = data_time;
        save([datapath_pros 's' num2str(isub) color{icolor} files{ii,1}
'_pros.mat'],'data_pros')
    end
end
%% Forward and Side Steps

%isub = subject(2);
isub = subject_num;

for icolor = 1:2
    icounter = 0;

    for itask = 4:21

        if itask <= 12
            figure(2+icolor)
        elseif itask == 13
            icounter = 0;
            figure(4+icolor)
        end

        icounter=icounter+1;
        data_time=readmatrix([datapath_raw 's' num2str(isub) color{icolor}
files{itask,1} '.txt']);

        %Replace NaN with 0...data collected for 6 seconds
        data_time(isnan(data_time))=0;
        data_time = data_time(1:601,:);

        t = data_time(:,1);
        data = data_time(:,2:end);

        %Plotting
        subplot(3,3,icounter), plot(data)
        title(files{itask,2})

        if icolor == 1
           sgtitle('Placebo');
        else
           sgtitle('White');
        end

        %Saving prcessed data
        data_pros = data_time;
```

```
        save([datapath_pros 's' num2str(isub) color{icolor} files{itask,1}
'_pros.mat'],'data_pros')

    end
end
```

Appendix B.3: Data Filtering

```
%Jessica Kirchner
%Agility Study
%Modified by Kirchner 04-21-22

clear; clc; close all;

%FP 3364 is the right force plate
%FP 3477 is the left force plate

%Forward step, feet pointed in the +x direction, R foot on FPs
%   Right foot on 3477 left foot shoulder width away then right foot took
%   step forward to 3364 and left foot brought up to match (off FP)
%Side step, feet pointed in the -y direction
%   both feet started on 3477 and right foot moved to 3364 and left foot
%   brought over to match
%% Define Parameters

prompt = 'Subject Number: ';
subject_num = inputdlg(prompt);
subject_num = str2double(subject_num);

%establish the path to the data
datapath_raw = ['C:\Users\jessk\OneDrive - University of Kansas\Agility Study\01 Raw
Data\s' num2str(subject_num) '\'];
datapath_pros = 'C:\Users\jessk\OneDrive - University of Kansas\Agility Study\02
Processed Data\';
datapath_filt='C:\Users\jessk\OneDrive - University of Kansas\Agility Study\03
Filtered Data\';

%Sway 1-3, Forward 4-12, Side 13-21
files = {'_BLSWAY' 'BL Sway';
         '_PTSWAY' 'Post Train Sway';
         '_SWAY' 'Post Stim Sway';
         '_BLF_1' 'BL Forward Step 1';
         '_BLF_2' 'BL Forward Step 2';
         '_BLF_3' 'BL Forward Step 3';
         '_PTF_1' 'Post Train Forward Step 1';
         '_PTF_2' 'Post Train Forward Step 2';
         '_PTF_3' 'Post Train Forward Step 3';
         '_FOR_1' 'Post Stim Forward Step 1';
         '_FOR_2' 'Post Stim Forward Step 2';
         '_FOR_3' 'Post Stim Forward Step 3';
         '_BLSS_1' 'BL Side Step 1';
         '_BLSS_2' 'BL Side Step 2';
         '_BLSS_3' 'BL Side Step 3';
         '_PTSS_1' 'Post Train Side Step 1';
         '_PTSS_2' 'Post Train Side Step 2';
         '_PTSS_3' 'Post Train Side Step 3';
         '_SIDE_1' 'Post Stim Side Step 1';
         '_SIDE_2' 'Post Stim Side Step 2';
         '_SIDE_3' 'Post Stim Side Step 3'};

color = {'_PB'; '_WH'};
```

```
subject = 1001:1010;

%% Filtering Parameters

%Force Plate Gain
fp_gain = 1000;

%Distance Below FP surface to axis origin
dz_3364 = .038; %[m] Right FP
dz_3477 = .037; %[m] Left FP
dz_mean = mean([dz_3364,dz_3477]);

%Sampling Rate
fsample = 100; %[Hz]

%Step Size
dt = 1/fsample; %[s]

%Low Pass Butterworth Filter
order = 4;
nyquist_frequency = fsample/2;
cutoff_LP = 10;
normalized_cutoff = cutoff_LP/nyquist_frequency;

[b,a] = butter(order, normalized_cutoff , 'low');
%% Filtering Data and Storing
%isub = subject(2);
isub = subject_num;
for icolor = 1:2
    for ii = 1:21

        y = load([datapath_pros 's' num2str(isub) color{icolor} files{ii,1}
'_pros.mat']);
        y = struct2table(y); y = table2array(y);
        y_filt = filtfilt(b,a,y);
        save([datapath_filt 's' num2str(isub) color{icolor} files{ii,1}
'_filt.mat'],'y_filt');
    end

    y = load([datapath_pros 's' num2str(isub) color{icolor} '_zeros_pros.mat']);
    y = struct2table(y); y = table2array(y);
    y_filt = filtfilt(b,a,y);
    save([datapath_filt 's' num2str(isub) color{icolor} '_zeros_filt.mat'],'y_filt');

end
```

Appendix B.4: Functions

```
function FP = Comb_fp3477_fp3364(fp_3477,fp_3364)
%% FP = comb_FPs(fp_left, fp_right)
%Combination of Force Plates into One Force Plate
%Camilo Giraldo (c318g339@ku.edu)
%The University of Kansas - Biodynamics Lab
%Last Update: March 25, 2020
%
%Purpose: this function combines the analog data (already converted to N and N-m
%units) of two force plates: 3477 (Left) and 3364 (Right). It is assumed
%that the coordinate systems of both force plates are: +x is to the
%facing forward direction, +y is to the right hand of the subject, and +z is
%towards the ground.
%
%Inputs:
%   fp_3477: calibrated analog data of 3477 (Fx,Fy,Fz,Mx,My,Mz) --- Left
%   fp_3364: calibrated analog data of 3364 (Fx,Fy,Fz,Mx,My,Mz) --- Right
%
%Outputs:
%   FP: Combined force plate data (Fx,Fy,Fz,Mx,My,Mz)

%% Beginning of function
%Distance from center of force plates to middle of force plates
d = 231.5/1000;         %[m]

%Combined force plate components
    %Fx component [N]
    FP(:,1)=fp_3477(:,1)+fp_3364(:,1);

    %Fy component [N]
    FP(:,2)=fp_3477(:,2)+fp_3364(:,2);

    %Fz component [N]
    FP(:,3)=fp_3477(:,3)+fp_3364(:,3);

    %Mx component [N-m]
    FP(:,4)=fp_3477(:,4)+fp_3364(:,4)-d*fp_3477(:,3)+d*fp_3364(:,3);

    %My component [N-m]
    FP(:,5)=fp_3477(:,5)+fp_3364(:,5);

    %Mz component [N-m]
    FP(:,6)=fp_3477(:,6)+fp_3364(:,6)+d*fp_3477(:,1)-d*fp_3364(:,1);

%New coordinate system
%             x
%             ^
%             |
%             |
%             |
%             |
%             X- - - - - - > y

end
```

```
function [fm_3477, dz]=V2f_fp3477(volt,zeross,gain_fp)
%% [fm_3477, dz]=V2f_fp3477(volt,zeross,gain_fp)
%Force Plate 3477 Volts to Force and Moments
%Camilo Giraldo (c318g339@ku.edu)
%The University of Kansas - Biodynamics Lab
%Last Update: 06/12/2017
%
%Purpose: This function turns the voltage data of 3477 into N and N-m
%
%Inputs:
%   volt:   Force plate 3477 data in volts
%   zeross: 1x6 vector with the mean volts for no load on force plate
%   gain_fp: gain (Amps) of the force plate for the experiment
%
%Outputs:
%   fm_3477: force and moments columns in a matrix (Fx,Fy,Fz,Mx,My,Mz)
%   dz:      calibration offset from ground to force plate

%% Beginning of function
%KU Biomechanics Lab Force Plate 3364 Calibration Matrix
SIcalmat_3477=[1.498 -0.002  0.004  0.003 -0.006  0.011;
                0.006  1.500  0.001 -0.014  0.003  0.015;
               -0.002  0.016  5.930 -0.001  0.003  0.000;
                0.001 -0.001  0.0    0.740 -0.003 -0.001;
               -0.001  0.0    0.0    0.002  0.740  0.001;
                0.0    0.003 -0.002  0.0    0.001  0.383];

%Substract zeros from force plate volts data
[volt_rows,~]=size(volt);                    %Number of rows in data
zero_offset=(zeross'*ones(1,volt_rows))';   %Zero offset in matrix volt_rowsx6
[Volts]
volt=volt-zero_offset;                       %Volt data minus the zero values

%Converting volt data of FP 3364 to N and N-m
GF=(1.e6)/(gain_fp*10);                      %Equation given by AMTI
fm_3477=GF*volt*SIcalmat_3477';              %FP 3477 data in N and N-m

%Calibration dz [m]
dz=0.037;

end
```

```
function [fm_3364, dz]=V2f_fp3364(volt,zeross,gain_fp)
%% [fm_3364, dz]=V2f_fp3364(volt,zeross,gain_fp)
%Force Plate 3364 Volts to Force and Moments
%Camilo Giraldo (c318g339@ku.edu)
%The University of Kansas - Biodynamics Lab
%Last Update: 06/12/2017
%
%Purpose: This function turns the voltage data of 3364 into N and N-m
%
%Inputs:
```

```
%   volt:    Force plate 3364 data in volts
%   zeross:  1x6 vector with the mean volts for no load on force plate
%   gain_fp: gain (Amps) of the force plate for the experiment
%
%Outputs:
%   fm_3364: force and moments columns in a matrix (Fx,Fy,Fz,Mx,My,Mz)
%   dz:      calibration offset from ground to force plate

%% Beginning of function
%KU Biomechanics Lab Force Plate 3364 Calibration Matrix
SIcalmat_3364=[1.506 0.003  0.01  -0.003 -0.013  0.006;
              -0.012 1.513 -0.01   0.01   0.001  0.009;
               0.001 0.002  5.895 -0.002  0.008  0.017;
              -0.001 0.0    0.0    0.732 -0.002 -0.001;
               0.0   0.0    0.0    0.001  0.732  0.003;
               0.001 0.004 -0.02  -0.001 -0.001  0.385];

%Substract zeros from force plate volts data
[volt_rows,~]=size(volt);                   %Number of rows in data
zero_offset=(zeross'*ones(1,volt_rows))';   %Zero offset in matrix volt_rowsx6
[Volts]
volt=volt-zero_offset;                      %Volt data minus the zero values

%Converting volt data of FP 3364 to N and N-m
GF=(1.e6)/(gain_fp*10);                     %Equation given by AMTI
fm_3364=GF*volt*SIcalmat_3364';             %FP 3364 data in N and N-m

%Calibration dz [m]
dz=0.038;

end
```