

## **CURRICULUM VITAE**

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### **Education**

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2015-2018 Graduate Teaching Assistant, Department of Physiology, JUST

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2014-2015 Physical Therapist, Northern Academy for Training and Rehabilitation,  
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2018-2019 Research Assistant, Department of Physical Therapy, Rehabilitation  
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### **Honors and Awards**

- 2012-2013 Dean's List, JUST, awarded to the top 10 students in their respective departments each semester
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**Clinical Activities**

- 2014-2015 Physical Therapist, Northern Academy for Training and Rehabilitation (private rehabilitation clinic), Jordan

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- 2021-2022 American Society for Neurorehabilitation
- 2022-2023 American College of Sports Medicine
- 2022-2023 Society for Neuroscience
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- 2023-2024 American Congress of Rehabilitation Medicine

**Administrative Service**

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UMB

- 2021 Member, Graduate Program in Life Sciences Award Committee
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- 2021-2023 Member, Student Advisory Committee
- 2021-2023 Member, UMB URS PhD Review Task Force
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**Teaching Service**

Undergraduate Student Teaching

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### Research Activities

- 2016-2018 “Understanding the association between pain, pain biomarkers, and physical activity in Parkinson's Disease”, JUST
- 2018 “Task-Evoked Pupillary Response: Cognitive Effort for Breast Cancer Survivors”, KUMC
- 2019 “Eye-Catching Measures of Daytime Sleepiness and Cognitive Fatigability in Multiple Sclerosis”, KUMC
- 2019-2020 “Influence of an Anxiety-Provoking Mental Stress Task on Reach to Grasp Balance Responses in Older Adults”, UMB  
“Age-Related Changes in Upper Limb and Trunk Responses to First and Repeated Exposure to Laterally Induced Imbalances”, UMB
- 2021-2022 “Efficacy of an Interactive Web-Based Home Therapy Program in the Recovery of Arm and Hand function following Stroke: A Randomized Trial”, UMB  
“Exploring the Neural Basis of Fear of Falling in Relation to Balance Perturbations in Older Adults”, UMB
- 2022-2024 “Protective Arm Balance Response Training in Older Adults”, UMB  
“Motor Learning of Reactive Balance Responses in People with Parkinson's Disease”, UMB
- 2024 “Postural Responses During Virtual Reality Induced Fear of Falling”, UMB

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- 2020-2022 Total: \$7,000  
 Gladys E. Wadsworth Physical Therapy Endowment Fund  
 “Proactive and reactive balance control during trip perturbations in individuals with peripheral neuropathy”  
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- 2023 University of Maryland School of Medicine, PTRS PhD Endowment Fund  
 “Physical and psychological factors affecting postural control in individuals with diabetic peripheral neuropathy”  
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## **Publications**

### Peer-Reviewed Journal Articles

1. Devos, H., Akinwuntan, A. E., **Alissa, N.**, Morohunfola, B., & Lynch, S. (2020). Cognitive performance and cognitive workload in multiple sclerosis: Two different constructs of cognitive functioning? *Multiple sclerosis and related disorders*, 38, 101505. <https://doi.org/10.1016/j.msard.2019.101505>
2. Myers, J. S., **Alissa, N.**, Mitchell, M., Dai, J., He, J., Moon, S., O'Dea, A., Klemp, J., Kurylo, M., Akinwuntan, A., & Devos, H. (2020). Pilot Feasibility Study Examining Pupillary Response During Driving Simulation as a Measure of Cognitive Load in Breast Cancer Survivors. *Oncology nursing forum*, 47(2), 203–212. <https://doi.org/10.1188/20.ONF.203-212>
3. Akinlosotu, R. Y., **Alissa, N.**, Sorkin, J. D., Wittenberg, G. F., & Westlake, K. P. (2020). Age-Related Differences in Arm and Trunk Responses to First and Repeated Exposure to Laterally Induced Imbalances. *Brain sciences*, 10(9), 574. <https://doi.org/10.3390/brainsci10090574>
4. Devos, H., **Alissa, N.**, Lynch, S., Sadeghi, M., Akinwuntan, A. E., & Siengsukon, C. (2021). Real-time assessment of daytime sleepiness in drivers with multiple sclerosis. *Multiple sclerosis and related disorders*, 47, 102607. <https://doi.org/10.1016/j.msard.2020.102607>
5. **Alissa, N.**, Akinlosotu, R. Y., Shipper, A. G., Wheeler, L. A., & Westlake, K. P. (2020). A systematic review of upper extremity responses during reactive balance perturbations in aging. *Gait & posture*, 82, 138–146. <https://doi.org/10.1016/j.gaitpost.2020.08.134>
6. Khalil, H., **Alissa, N.**, Al-Sharman, A., E'leimat, I., Majdi Al Qawasmeh, & El-Salem, K. (2021). Understanding the influence of pain and fatigue on physical performance, fear of falling and falls in people with Parkinson's disease: a pilot study. *Neurodegenerative disease management*, 11(2), 113–124. <https://doi.org/10.2217/nmt-2020-0053>
7. Akinlosotu, R. Y., **Alissa, N.**, Waldstein, S. R., Creath, R. A., Wittenberg, G. F., & Westlake, K. P. (2021). Examining the influence of mental stress on balance perturbation responses in older adults. *Experimental gerontology*, 153, 111495. <https://doi.org/10.1016/j.exger.2021.111495>

8. Jeon, W., Whittall, J., **Alissa, N.**, & Westlake, K. (2022). Age-related differences in stepping stability following a sudden gait perturbation are associated with lower limb eccentric control of the perturbed limb. *Experimental gerontology*, 167, 111917. <https://doi.org/10.1016/j.exger.2022.111917>
9. **Alissa, N.**, Khalil, H., Kanaan, S., Aldughmi, M., Al-Sharman, A., Morris, L., Latrous, M. S., & El-Salem, K. (2023). Translation, cultural adaptation and validation of the Arabic version of the king's Parkinson's disease pain scale. *Disability and rehabilitation*, 1–6. <https://doi.org/10.1080/09638288.2023.2202416>
10. **Alissa, N.**, Rehan, R., Al-Sharman, A., Latrous, M., Aburub, A. S., El-Salem, K., Morris, L., & Khalil, H. (2023). Cognitive status and sleep quality can explain the fear of falling and fall history in people with Parkinson's disease. *International journal of rehabilitation research*, 10.1097/MRR.0000000000000596. <https://doi.org/10.1097/MRR.0000000000000596>
11. Jeon, W., Ramadan, A., Whittall, J., **Alissa, N.**, Westlake, K. (2023). Age-Related Differences in Kinematics, Kinetics, and Muscle Synergy Patterns Following a Sudden Gait Perturbation: Changes in Movement Strategies and Implications for Fall Prevention Rehabilitation. *Applied Sciences* 13, no. 15: 9035. <https://doi.org/10.3390/app13159035>
12. Jeon, W., Ramadan, A., Whittall, J., **Alissa, N.**, Westlake, K. (2023). Age-related differences in lower limb muscle activation patterns and balance control strategies while walking over a compliant surface. *Sci Rep* 13, 16555. <https://doi.org/10.1038/s41598-023-43728-0>
13. **Alissa, N.**, Shipper, A. G., Zilliox, L., & Westlake, K. P. (2024). A Systematic Review of the Effect of Physical Rehabilitation on Balance in People with Diabetic Peripheral Neuropathy Who are at Risk of Falling. *Clinical interventions in aging*, 19, 1325–1339. <https://doi.org/10.2147/CIA.S459492>

## **Presentations**

### **Oral Presentations**

1. **Alissa N.** Age-Related Differences in Upper Limb Responses to Laterally Induced Imbalances. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. November 2019.
2. **Alissa N.** Reactive Balance Responses of the Arms and Trunk in Relation to Stepping Strategies and Fear of Falling in Aging. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. April 2020.
3. **Alissa N.** Gait Changes in Individuals with Peripheral Neuropathy and Potential Influence on Reactive Balance Control. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. November 2020.
4. **Alissa N.** The Effectiveness of Active Rehabilitation Interventions for Diabetic Peripheral Neuropathy for Reduction of Fall Risk and Fall Rate. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. April 2021.
5. **Alissa N.** Interventions for Diabetic Peripheral Neuropathy: Do They Reduce Fall Risk? A Systematic Review. Oral presentation presented at: Annual Meeting of the Peripheral Nerve Society. Virtual. June 2021.

6. **Alissa N.** Anticipatory and Compensatory Postural Adjustments in Individuals with Diabetic Peripheral Neuropathy. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. November 2021.
7. **Alissa N.** A Comparison of Balance Responses While Walking Over Foam Between Young and Older Adults. Oral presentation at: UMB, Graduate Research Conference. Baltimore, MD. March 2022.
8. **Alissa N.** Using Psychophysiological Outcomes to Measure Fear of Falling in Older Adults. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. October 2022.
9. **Alissa N.** Age-Related Changes in the Reach to Grasp Balance Response During Attentional Demands. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. October 2022.
10. **Alissa N.** Pupillary Response During Driving Simulation as a Measure of Cognitive Load in Breast Cancer Survivors. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. April 2023.
11. **Alissa N.** Measurement of Physiological Responses to Emotion: Electrodermal Activity & Pulse Rate Variability. Oral seminar presented at: UMB, PTRS, Research Seminar. Baltimore, MD. November 2023.
12. **Alissa N.** Falls Prevention and Balance Training for Older Adults. Oral presentation at: The Waxter Center for Senior Citizens. Baltimore, MD. November 2023.
13. **Alissa N.** Comparing Responders and Non-Responders to Dual-Task Cognitive and Reach-to-Grasp Balance Perturbation Training in Older Adults. Oral presentation at: UMB Graduate Research Conference. Baltimore, MD. April 2024.
14. Hannes Devos, Sodiq Fakorede, **Alissa N.** The Effect of Perturbations on Postural Control in Older Adults with Cognitive Impairment. Oral symposium presentation at: American Congress of Rehabilitation Medicine Annual Fall Conference, Dallas, TX. November 2024.

#### Poster Presentations

1. **Alissa N,** Westlake K. The Role of Anxiety as a Fall Risk Factor in Community Dwelling Older Adults. Poster presented at: UMB, PTRS, Research Day. Baltimore, MD. May 2020.
2. **Alissa N,** Zilliox L, Westlake K. Current Interventions for Diabetic Peripheral Neuropathy: Do They Reduce Fall Risk? A Systematic Review. Poster presented at: UMB, PTRS, Research Day. Baltimore, MD. May 2021.
3. **Alissa N,** Akinlosotu R, Westlake K. Upper Limb and Trunk Responses to Repeated Lateral Perturbations in Aging. Poster presented at: the Annual Meeting of the American Society for Neurorehabilitation. Virtual. April 2021.
4. **Alissa N,** Zilliox L, Westlake K. Active Rehabilitation Interventions for Diabetic Peripheral Neuropathy: Do They Reduce Fall Risk? Poster presented at: UMB, Graduate Research Conference. Baltimore, MD. March 2021.
5. **Alissa N,** Jeon W, Westlake K. Age-Related Changes in Kinematic Responses While Walking Over a Compliant Surface. Poster presented at: the Annual

- Meeting of the American Society of Neurorehabilitation. St. Louis, MO. March 2022.
6. **Alissa N**, Jeon W, Westlake K. Age-Related Differences in Limb and Trunk Kinematics While Walking Over Foam. Poster presented at: UMB, PTRS, Research Day. Baltimore, MD. May 2022.
  7. **Alissa N**, Westlake K. Objective Measures of Fear of Falling in Older Adults. Poster presented at: the Combined Sections Meeting of the American Physical Therapy Association. San Diego, CA. February 2023.
  8. **Alissa N**, Westlake K. Feasibility of Dual Task Cognitive and Balance Perturbation Training in Older Adults. Poster presented at: UMB, PTRS, Research Day. Baltimore, MD. May 2023.
  9. **Alissa N**, Westlake K. Balance Perturbation Training with a Simultaneous Cognitive Task in Older Adults: A pilot study. Poster presented at: Neuroscience, the Annual Meeting of the Society for Neuroscience. Washington, DC. November 2023.
  10. **Alissa N**, Westlake K. Reach to Grasp Reactive Balance Training During Concurrent Cognitive Task in Older Adults. Poster presented at: the Combined Sections Meeting of the American Physical Therapy Association. Boston, MA. February 2023.

## ABSTRACT

**Dissertation Title:** The Effects of a Reach To Grasp Training Intervention on Balance Responses and Fall-Related State Anxiety

**Nesreen Alissa, PT, MS, Doctor of Philosophy, 2024**

**Dissertation Research Directed by:** Kelly Westlake, PhD, MSc, MSc, PT, Associate Professor, Department of Physical Therapy and Rehabilitation Science, Director of the Physical Rehabilitation Science PhD Program.

The objective of this dissertation was to investigate the relationship of falls efficacy and balance confidence with fall-related state anxiety, and the effectiveness of a dual-task reach-to-grasp balance perturbation intervention and the relationship between balance confidence and intervention responsiveness in older adults. First, the relationship between the falls efficacy scale-international (FES-I) and activities-specific balance confidence (ABC) scale with psychophysiological state anxiety, measured through skin conductance levels (SCLs)) during trip perturbations. Subjective fall-related state anxiety was assessed using the Subjective Units of Distress Scale (SUDS)), comparing participants with high (FES-I>23) and low (FES-I<23) fall concerns. Results indicated a positive correlation between changes in SCL from pre- to post-perturbation with FES-I and a negative correlation with ABC. SUDS scores differed between groups based on FES-I classifications. Next, the effects of a dual-task reach-to-grasp intervention on grasp responses to balance perturbations were investigated. The training involved 30 randomized walking perturbations with a handrail positioned laterally beside the dominant (trained) arm. Pre-training assessment included three unpredictable slip

perturbations - two accompanied by a cognitive task and one without - with a handrail positioned for the trained reach to grasp response. Post-training assessments replicated pretest conditions and introduced two additional perturbations to evaluate the transfer and generalization of training effects (with the handrail on the non-dominant (untrained) side and without the handrail). Analyses focused on grasp accuracy (frequency of grasp errors) and grasp time (time from perturbation onset to handrail contact) for both the trained and untrained (transfer) arms. To assess generalizability, stability (i.e., distance from the center of mass to base of support at first foot touchdown) was calculated during a perturbation without a handrail. Findings showed improvements in grasp time and accuracy in the trained arm, with only grasp accuracy improvements transferring to the untrained arm. No changes were observed in stability during the no-handrail condition. Overall, results suggest that FES-I and ABC are indicative of fall-related state anxiety during balance perturbations, and that dual task reach-to-grasp training enhances performance in the trained arm, with some transfer to the untrained arm, but no generalization to stepping responses when a handrail is not present.

The Effects of a Reach To Grasp Training Intervention on Balance Responses and Fall-Related State Anxiety

by

Nesreen Alissa

Dissertation submitted to the Faculty of the Graduate School of the  
University of Maryland, Baltimore in partial fulfillment  
of the requirements for the degree of  
Doctor of Philosophy

2024

## **DEDICATION**

To my husband and parents for believing in me and supporting me through this long and challenging process with all its many twists and turns.

## ACKNOWLEDGEMENTS

To my advisor Dr. Kelly Westlake for your support and mentorship throughout this journey. Your passion for research and rehabilitation is something I have always admired and which I hope to carry with me moving forward.

To my committee members: Dr. Vicki Gray for taking the time to listen to my questions and for challenging me to become a better scientist.; Dr. Li-Qun Zhang for your invaluable instruction in biomechanics and your thoughtful feedback on my dissertation; Dr. Joseph “Jay” Barton for showing me how fun science can be and for your encouragement and support; and Dr. Lindsay Zilliox for guiding me through the maze of peripheral neuropathy – it did not work out this time, but I hope to come back to it in the future.

To my fellow PRS PhD students who have been a constant source of support through this crazy roller coaster of a process. A special thank you to my fellow mad scientist, Shabnam Lateef.

Thank you to all the faculty and staff at PTRS, especially Angel Chavez, Director of Instructional Technology, and Surekha Vishwasrao, Director of Finance.

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## **List of Abbreviations**

FOF: Fear of falling

FES-I: Falls efficacy scale – international

ABC: Activities-specific balance scale

SUDS: Subjective units of distress scale

COM: Center of mass

BOS: Base of support

S<sub>ML</sub>: Stability in the mediolateral direction

S<sub>AP</sub>: Stability in the anteroposterior direction

FFTD: First foot touchdown

HRV: Heart rate variability

SCL: Skin conductance level

SCR: Skin conductance response

PPG: Photoplethysmography

PRV: Pulse rate variability

HF: High frequency

LF: Low frequency

FSST: Four square step test

mFFABQ: modified fear of falling avoidance behavior questionnaire

BAI: Beck anxiety inventory

PASE: Physical activity scale for the elderly

TUG<sub>COG</sub>: Cognitive timed up and go test

% BW: percent body weight

OA: Older adults

YA: Young adults

AXIS: Appraisal tool for cross-sectional studies

EMG: Electromyography

CINAHL: Cumulative index to nursing and allied health literature

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PFC: Prefrontal Cortex

## **CHAPTER ONE: INTRODUCTION**

### **INTRODUCTION TO THE RESEARCH FOCUS**

Falls are the leading cause of fatal injuries (>180,000 deaths in the past 5 years) in older adults over the age of 65 in the United States.<sup>1</sup> Falls prevalence increases among older adults in the presence of fear of falling (FOF),<sup>2,3</sup> which occurs in 20-85% of older adults.<sup>3</sup> FOF is commonly defined as “A lasting concern about falling that leads an individual to avoid activities that he/she remains capable of performing”.<sup>4</sup> Both injurious and non-injurious falls among older adults commonly occur while walking in the community (slips, trips, going up and down stairs), and in their own homes (slips, trips, going up and down stairs) in the bedroom, kitchen, and bathroom.<sup>5-7</sup> Falls under these circumstances are sudden and unexpected, requiring quick and efficient reactive balance responses to maintain balance and prevent falls.

Reactive balance is a feedback neuromuscular control process that occurs in response to expected and unexpected perturbations with the goal of restoring balance after a perturbation. There are two main reactive balance control strategies used to restore balance after a sudden perturbation: 1) fixed support strategies which include the ankle and hip strategies, and 2) change in support strategies which include the stepping and reaching strategies.<sup>8</sup> Fixed support strategies are elicited when the balance perturbation induces relatively small movements of the center of mass (COM) that do not exceed the boundaries of the base of support (BOS). In these strategies, equilibrium is restored using torque forces generated around the ankle and hip joints. Change in support strategies are elicited when the balance perturbation induces relatively large movements of the COM that exceed the boundaries of the BOS. In these strategies, equilibrium is restored by

taking a step and/ or reaching out and grasping an object. These largely lower limb responses are often accompanied by simultaneous upper limb responses including a counterbalancing, protective, or reach to grasp strategy of the arms to regain equilibrium.<sup>9</sup> This dissertation will focus on upper limb reactive balance strategies, specifically the reach to grasp strategy and how FOF interferes with this strategy in older adults.

Compared to young adults, older adults are more likely to reach for a handrail when stepping responses are inhibited during external perturbations, however, older adults also exhibit a reduced efficiency in the execution of the reach to grasp.<sup>9</sup> Older adults have a greater frequency of grasping errors, delayed reaction time, and decreased movement time.<sup>9-11</sup> These impairments in the reach to grasp balance response in older adults may be explained by increased cognitive-motor interference with age.<sup>12-14</sup> The reach to grasp reactive response depends on the ability to quickly and accurately process the available visuospatial information to determine the trajectory of the grasp.<sup>15-17</sup> Therefore, older adults may experience age-related increases in cognitive interference from ongoing spatial or non-spatial working memory tasks immediately prior to a balance perturbation.<sup>12-14</sup>

Impairments in the reach to grasp response exhibited by older adults may also be due to psychological interference such as the presence of fear or anxiety. Studies have shown differences in balance control strategies between fearful and non-fearful individuals,<sup>18-20</sup> including changes in eye and head movements,<sup>20</sup> which may limit available visuospatial information. FOF may also interfere with reactive arm responses through the effects of anxiety on attention and working memory. Anxiety is associated with changes in the

functional connectivity of specific brain regions responsible for emotional regulation, the central response to internal and external stimuli, and attentional control (particularly the salience network, affective network, default mode network, and executive control network).<sup>21,22</sup> The effects of anxiety on attentional control are especially concerning, given the importance of attentional control and attentional switching during dual motor and cognitive tasks. The aforementioned centrally-mediated changes in anxiety levels are also associated with hyperactive fear responses and heightened threat responsivity.<sup>21</sup> Previous data from our lab showed that the presence of FOF interferes with upper limb reactive balance responses. During repeated lateral perturbations, FOF in older adults directly correlated with shoulder abduction.<sup>23</sup> The impaired attentional control associated with anxiety also interferes with motor learning ability, especially with motor tasks requiring attention to visuospatial details such as the location of a handrail. Therefore, older adults with higher levels of anxiety may exhibit reduced responsiveness to a reach to grasp training intervention compared to those with lower levels of anxiety. This indicates that FOF may not only have a detrimental effect on the reach to grasp response itself, but it may also interfere with the ability to train this response.

Current methods of measuring FOF include the use of questionnaires such as the falls efficacy scale-international (FES-I) and the activities-specific balance confidence (ABC) scale, which while commonly used to measure FOF, have not been specifically validated for the measurement of fear. Rather, these were developed and validated to measure other fall-related psychological constructs. The FES-I measures self-efficacy related to falls which refers to an individual's belief in their ability to perform daily activities without falling,<sup>24</sup> while the ABC measures balance confidence which refers to an individual's

confidence in their ability to maintain stability and avoid falling during specific activities.<sup>25</sup> More specifically, it is unclear whether these measures reflect fall-related state (during a balance perturbation) or trait (general) anxiety. The few available measures of fall-related state anxiety include the question “Are you afraid of falling?” and Likert scales of emotional distress such as the Subjective Units of Distress Scale (SUDS).<sup>26</sup> However, these measures are not as widely known or used among clinicians compared to the FES-I and ABC. Measures of fall-related psychological constructs such as falls efficacy and balance confidence are effective in identifying secondary consequences of FOF such as activity avoidance and deconditioning,<sup>27,28</sup> but they fail to capture the direct effects of FOF on reactive balance responses. Validating the use of the FES-I and ABC to identify older adults who are more likely to exhibit FOF or fall-related state anxiety during reactive balance responses would help to better determine the direct effects of fear on reactive balance responses. To this end, skin conductance, a measure of the skin’s ability to conduct electrical signals, was used to measure psychophysiological stress and anxiety.<sup>29</sup> Skin conductance can be used to measure general physiological arousal, sympathetic activity,<sup>30</sup> and anxiety and its link to fear learning.<sup>31</sup>

This dissertation will address multiple gaps in our knowledge regarding the reach to grasp reactive balance response. We address 1) the need for validated measures of fall-related state anxiety during reactive balance responses in older adults, and 2) the need to investigate whether a 3-week (2 sessions/ week) reach to grasp training intervention can improve the efficiency of the reach to grasp response and how fall-related anxiety may influence responsiveness to this intervention in older adults.

## **SPECIFIC AIMS**

Overall Objective: To investigate the relationship between falls efficacy, balance confidence, and fall-related state anxiety during balance perturbations in older adults, and to investigate the effects of a dual task reach to grasp training intervention on the reach to grasp response and fall-related anxiety in older adults.

**Specific Aim 1: To investigate the construct validity of the Falls Efficacy Scale-International (FES-I) and the Activities-Specific Balance (ABC) scale for the measurement of fall-related state anxiety during a balance perturbation in older adults.**

*Hypothesis 1:* The FES-I and ABC will significantly correlate with a validated measure of physiological fall-related state anxiety (skin conductance levels) during unpredictable balance perturbations in older adults.

**Specific Aim 2: To investigate the effects of a 3-week, 6-session unpredictable reach to grasp balance perturbation intervention in improving the reach to grasp response in older adults.**

*Hypothesis 2a:* Following training, the reach to grasp accuracy will increase and grasp time will decrease in the trained (task-specificity) and untrained arm (transfer).

*Hypothesis 2b:* Following training, stability at first foot touchdown will decrease in the absence of a handrail (generalization).

*Hypothesis 2c:* Pre-training balance confidence (assessed by the ABC scale) will positively correlate with the change in reach to grasp time from pre- to post-training.

## **ORGANIZATION OF DISSERTATION**

This dissertation includes seven chapters beginning with the current chapter, which summarizes the research problem and provides an overview of the aims. The second chapter consists of a systematic review of the literature regarding upper limb response strategies during reactive balance responses. Chapter three addresses specific aim 1, which involves an investigation of the relationship between FES-I and ABC with a validated measure of fall-related state anxiety during reactive balance responses (SCL). Chapter four addresses specific aim 2, which involves an investigation of the effects of a dual task reach to grasp training intervention on the efficiency and stability of the reach to grasp response, interlimb transfer, and generalization to the stepping response, as well as the relationship between balance confidence and responsiveness to the reach to grasp intervention. Chapter five summarizes the findings of the specific aims of this dissertation and ties them together. Chapter six presents potential future directions for the results of this dissertation, including the need to clarify the role of fall-related anxiety and balance confidence on training responsiveness.

## CHAPTER TWO: A SYSTEMATIC REVIEW OF UPPER EXTREMITY

### RESPONSES DURING REACTIVE BALANCE PERTURBATIONS IN AGING<sup>1</sup>

#### ABSTRACT

**Background:** Balance responses to perturbations often involve the arms in an attempt to either restore balance or protect against impact. Although a majority of research has been dedicated to understanding age-related changes in lower limb balance responses, there is a growing body of evidence supporting age-related changes in arm responses. This systematic review aimed to summarize differences in arm responses between older and younger adults under conditions requiring counterbalancing, reaching to grasping, and protection against impact.

**Methods:** Following a systematic review and critical appraisal of the literature, data regarding the arm response in studies comparing young and older adults was extracted. The resulting articles were also assessed for quality to determine risk of bias.

**Results:** Fifteen high quality studies were identified. The majority of these studies reported delayed onsets in muscle activation, differences in arm movement strategies, delayed movement timing, increased impact forces, and greater grasp errors in older compared to young adults. These differences were also identified under varied visual and cognitive conditions.

**Conclusions:** The studies included in this review demonstrate age-related differences in arm responses regardless of the direction and nature of the perturbation. These

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<sup>1</sup> Alissa N, Akinlosotu RY, Shipper AG, Wheeler LA, Westlake KP. A systematic review of upper extremity responses during reactive balance perturbations in aging. *Gait Posture*. 2020;82:138-146. doi:10.1016/j.gaitpost.2020.08.134

differences could provide insight into developing more targeted rehabilitation and fall prevention strategies. More research is needed to assess whether the identified age-related differences are a necessary compensation or a contributory factor to balance impairments and fall risk in older adults.

## **INTRODUCTION**

Falls are the leading cause of accidental death among adults over age 65, while nonfatal falls frequently lead to fractures, traumatic brain injury, reduced levels of activity, fear of falling, and reduced quality of life.<sup>32</sup> Imbalances resulting in falls are due to both intrinsic (e.g. dizziness, fatigue, or postural hypotension<sup>33-35</sup>) and extrinsic (e.g. surface contamination, footwear, uneven and/or challenging surfaces<sup>7,36</sup>) factors. The reactive balance responses to unexpected perturbations introduce time critical challenges that are dependent upon intact sensorimotor and biomechanical control mechanisms to either restore balance or protect against impact. Although a considerable amount of research has been focused on understanding lower extremity responses to balance perturbations,<sup>37,38</sup> the upper extremities also play a key role in whole body fall prevention.<sup>39</sup>

With an intact postural control system, including appropriate upper extremity responses, falls in young, healthy adults from a standing height rarely involve serious trauma.<sup>40,41</sup> In fact, wrist fractures are much more likely to occur in young adults compared to a higher incidence of head trauma in older adults, suggesting age-related differences in protective arm use.<sup>42</sup> An observational study in a nursing home setting reported that over a third of older adults sustained head impact due to a fall, and an alarming 75 % of this group was unsuccessful in the attempt to use the arm to prevent

impact.<sup>43</sup> Among community dwelling older adults, those who fell and sustained a hip fracture were also less likely to grab a stable object to break the fall,<sup>41</sup> again suggesting the critical nature of this response when intact.

Rapid arm movements after balance and gait perturbations have been shown to act simultaneously and in a coordinated manner with lower extremity reactions.<sup>44,45</sup> These responses have been characterized as counterbalancing, protective, or reach to grasp during perturbations from both static standing positions and while walking.<sup>45-47</sup> In a counterbalancing role, the arms can prevent a fall occurrence by halting or reversing fall direction. For example, following a trip, arm movements are generated in the forward and upward direction, serving to reduce the center of mass (COM) angular momentum in the trip direction.<sup>48</sup> Similarly, arm elevation strategies following a slip help to shift the COM forward to restore an upright position.<sup>46</sup> In a protective role, the arms serve to arrest a fall and ultimately dampen or prevent impact at the head or other joints. In these situations, the arms must not only generate enough force to prevent collapse, they must also be able to move quickly with precise spatial accuracy and appropriate joint positions and velocity.<sup>49-52</sup> Reach to grasp responses to a nearby handrail or support surface, such as may occur in confined bathroom spaces or on stairs, provide a further means to prevent falls and related injuries.<sup>14,53</sup> Age related differences in the use of these three different strategies have been reported. Whereas young adults tend to demonstrate a counterbalancing motion in response to a perturbation, older adults tend to move the arms in a protective direction.<sup>39</sup> In addition, older adults tend to rely on a reach to grasp response more frequently than young adults when a handrail is present.<sup>54</sup>

The above-mentioned studies, as well as others, point to the importance of the upper extremities in the generation of whole-body or grasping responses to restore balance or as the last line of defense against fall-related injuries. As a result, any age-related limitations in upper extremity responses to unanticipated perturbations may limit the effectiveness of balance control and should be appropriately assessed and incorporated into balance rehabilitation and fall prevention interventions. Therefore, in order to better understand age-related differences in upper extremity responses to reactive balance perturbations, we aimed to review and discuss similarities and discrepancies in currently available literature.

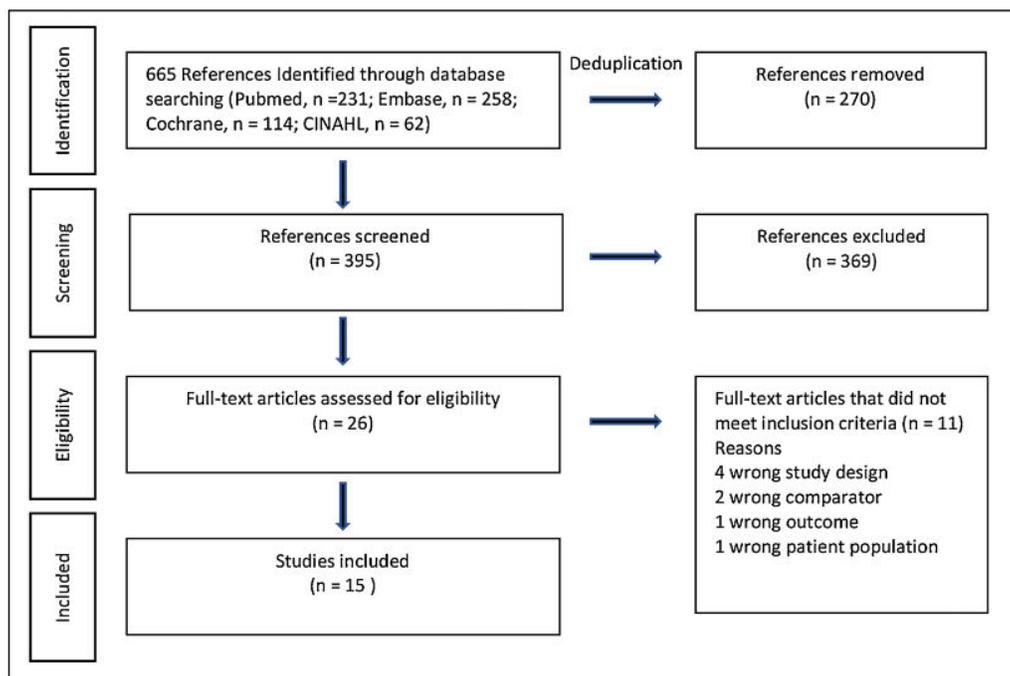
## **METHODS**

### **Search Strategies**

PubMed, Embase (Excerpta Medica Database), Cochrane Library, CINAHL (Cumulative Index to Nursing and Allied Health Literature) and google were searched between March 1, 2019 and March 27, 2019. All searches were performed in English. Keywords included “arm” or "upper extremity" or "upper limb" AND "balance recovery" or "trip recovery" or "protective response" or "postural response" or "compensatory balance control" or "compensatory reaction" or "fall arrest" or "balance perturbation" or "balance reaction" OR "reach to grasp" or "reach grasp" or “reach and grasp” or “compensatory arm movement” or “protective arm movement" or "grasping reaction" or "arm activation" or "arm reaction" AND “accidental falls” or “postural balance” or “fall” or “slip” or “balance” or “trip” or “perturbation” or “stability”.

## Study Selection

The search strategy retrieved a total of 665 articles with 231 articles between 1809 and 2019 in pubmed, 258 articles between 1974 and 2019 in Embase, 114 articles from Cochrane Central Register of Controlled Trials (Wiley), and 62 articles between 1937 and 2019 in CINAHL. Following deduplication, 390 articles remained. The PRISMA flow diagram is depicted in Figure. 1.



**Figure 1.** PRISMA flow diagram of search results and identification of appropriate articles to be included in the review

Two independent reviewers [authors R.A. and K.W.] determined eligibility of the 390 studies. K.W. has experience with writing systematic reviews, N.A., R.A., and K.W. have conducted experimental research related to the review topic, and each reviewer consulted with the librarian and co-author, A.S. throughout the review process. Any conflicts in determination of study eligibility were resolved through discussion between

the reviewers. Criteria included (1) studies comparing age related differences between healthy older and younger adults (2) studies that focused on reactive arm balance responses where balance perturbations during stance or gait were induced unexpectedly and/or unpredictably. Studies were excluded if they were not written in English and if study participants had neurological deficits, fractures, or any other medical condition that could impede their natural response to sudden loss of balance. Following abstract and title review, 21 studies were selected for full text review. After hand-searching the reference lists of these studies to identify studies that were not captured by the search strategy, 5 studies were added. Therefore, a total of 26 studies were moved forward to full text review after which 11 studies were removed due to having the wrong study design, wrong comparator group, wrong patient population, and wrong outcomes. Following these methods, a total of 15 studies were selected for review.

### **Quality Assessment**

Two independent reviewers [R.A. and a doctor of physical therapy student, A.B.] were then tasked with the quality assessment of all eligible studies. We used the Appraisal tool for Cross-Sectional Studies (AXIS), which is a quality appraisal tool specifically designed for use in observational cross-sectional studies. Each of these reviewers were trained using the AXIS manual, which then served as a reference during the assessment of each article. This tool is composed of 20 questions regarding the quality of reporting all aspects of the methods and results, quality of study design, and risk of bias. The quality of reporting is assessed using seven questions (1, 4, 10, 11, 12, 16, and 18), the quality of study design is assessed using another seven questions (2, 3, 5, 8, 17, 19, and 20), and the risk of bias is assessed using 6 questions (6, 7, 9, 13, 14, and

15). The answer options for each question are “yes”, “no”, or “do not know”. Three of the questions regarding the possible risk of bias (7, 13, and 14) involved information about non-responders. However, these questions were not applicable to the studies included in this review and were therefore excluded from the quality analysis. Answers were scored as 1 if the criteria were met and 0 if the criteria were not met. A total score was calculated as the percentage of quality criteria (N = 17) that were met. Study quality with a score of  $\geq 66.7\%$  was classified as “high”, between 50 and 66.6% as “fair”, and below 50% as “low”.<sup>55</sup> The two article appraisers [R.A. and A.B.] demonstrated 99.8% agreement for the assessment of articles, leaving 3 conflicts, which were resolved through discussions between R.A., A.B., and a third reviewer and co-author [KW]. Following quality assessment, data were extracted and summarized by N.A.

## **RESULTS**

### **Quality Assessment**

A careful assessment of study quality using the AXIS tool concluded that the 15 studies included in this review were of high quality (range 70.59 – 94.12%). More specifically, all 15 studies met at least 5 of the 7 questions assessing quality of reporting, at least 5 of the 7 questions assessing quality of study design, and at least 2 of the 3 questions assessing risk of bias. Scores for each article are included in Table 1, Table 2, Table 3.

### **Types of Arm Responses**

Based on the perturbation type and aims of the selected studies, results were divided into 3 categories, which included counterbalance, reach-to-grasp, and protective

responses to a balance perturbation. The counterbalance category included all studies assessing upper extremity responses during perturbations requiring full-body reactions. The protective category included studies assessing the ability to reach out and attenuate the impact of a fall. The reach-to-grasp category included all studies assessing the ability to reach out and grasp a nearby stationary handrail or handhold. Tables 1–3 provide details of data extracted from the identified studies.

### **Counterbalancing Responses**

Four studies compared counterbalancing arm reactions in older adults (OA) and young adults (YA) during unrestricted arm movement<sup>13,39,48,56</sup> and two studies compared arm use despite being restricted at perturbation onset<sup>57,58</sup> (Table 1). Overall, the age range for the YA groups was 20 – 35 years and 50 – 87 years for the OA group. Unrestricted arm responses were assessed using unpredictable perturbations from a static standing position with stepping restrained (anterior and posterior surface tilts<sup>39</sup> or translations<sup>13</sup> or anterolateral and posterolateral tilts<sup>39</sup>), or slips<sup>56</sup> or trips<sup>48</sup> while walking over ground. Studies in which arm responses were initially restricted included instructions to hold a lightweight rod behind the back<sup>57</sup> or to walk with arms lightly folded across the chest<sup>58</sup>. Perturbations for these two studies included lateral surface translations from either standing or walking in place<sup>57</sup> or slips while walking<sup>58</sup>. Outcome measures included shoulder movement onset times, EMG amplitude for the anterior deltoid,<sup>13</sup> middle deltoid,<sup>13,39</sup> and posterior deltoid,<sup>13</sup> angular velocity,<sup>48,56</sup> flexion/extension moments,<sup>56</sup> momentum,<sup>48</sup> and frequency of arm responses<sup>57,58</sup>.

All studies that included movement onset times with respect to perturbation onset found delays in OA compared to YA. Allum et al.<sup>39</sup> reported delays in EMG onset of

deltoid muscles during posterolateral platform tilts, but not during pure plane anterior or posterior directions. On the other hand, Laing et al.<sup>13</sup> using anterior and posterior surface translations from static standing, identified EMG delays in deltoid muscles that were present regardless of the presence of a secondary cognitive task. In support of these delays in EMG onset latencies, Merrill et al.<sup>56</sup> also found delays in the onset of shoulder movement using kinematic data.

Age-related differences were also displayed in the direction of arm response strategies. Both Allum et al.<sup>39</sup> and Roos et al.<sup>48</sup> found that arm movement in YA tended to be opposite to the direction of a tilt or trip perturbation whereas arm movement in OA tended to be in the same direction as the perturbation. The consequence of these directional differences is an attempt to restore an upright position by decreasing fall directed center of mass displacement in YA (i.e. to restore balance and prevent a fall) and an attempt to arrest the fall at impact in OA (i.e. to brace against impact). Merrill et al.<sup>56</sup> observed the opposite tendency in OA and YA during slips. Both OA and YA generated a shoulder flexion moment (i.e. to restore balance) at low slip severity, which was modulated at high slip severities towards a shoulder extension moment (i.e. to brace against impact) in YA, but not in OA.

Although Maki et al.<sup>57</sup> and Tang et al.<sup>58</sup> did not focus on the arm response as a primary outcome, age-related differences in frequency of use were reported. Maki et al. instructed participants to hold a lightweight rod behind their back during lateral stance or walking in place perturbations.<sup>57</sup> Tang et al.<sup>58</sup> instructed participants to walk with arms folded across their chest prior to a slip perturbation. Both studies reported an increased

number of trials in which the arms were used as part of a balance response, either by dropping the rod or by increased shoulder flexion in OA compared to YA.

### **Protective Arm Responses**

Three studies compared protective arm responses between OA and YA (Table 2). Overall, the age range was 18 – 30 years and 60 – 78 years for the YA and OA groups, respectively. In each study, participants were suspended in a forward lean position at an angle of 10 degrees<sup>50</sup> or 30 degrees from vertical,<sup>51,59</sup> with arms positioned alongside the body<sup>50</sup> or extended forward with hands hovering 1 cm above force plates.<sup>51,59</sup> Arm responses were assessed following an unpredictable release with the hands landing on force plates.<sup>50,51,59</sup> Outcome measures included peak impact force and braking time,<sup>50</sup> upper extremity joint kinematics<sup>50,51,59</sup> and angular velocity,<sup>50,51,59</sup> EMG activity of the biceps brachii,<sup>51,59</sup> triceps brachii,<sup>51,59</sup> anterior deltoid,<sup>51</sup> pectoralis major,<sup>51</sup> and external and internal oblique muscles,<sup>51</sup> and energy absorption at impact<sup>59</sup>.

Overall, these studies found age-related differences during both impact and post-impact phases, but only during conditions in which distance to impact was minimized. Kim et al.<sup>50</sup> found that at short fall distances of 40 or 60 cm, OA had higher peak impact force and shorter peak braking time than YA. At the point of touchdown, OA demonstrated decreased wrist extension, increased elbow extension, and twice the elbow extension and shoulder flexion angular velocities compared to YA. These age-related differences were not found during cable releases from larger fall distances of 80 or 100 cm. Lattimer et al.<sup>59</sup> found reduced elbow flexion angle at point of impact and 200 ms post-impact, reduced elbow flexion angular velocity at impact, and reduced energy absorption at 200 ms post-impact in OA compared to YA. Also at the point of impact,

OA demonstrated reduced activity in internal oblique/transverse abdominus compared to YA.<sup>51</sup> The relationship between muscle strength, tested during an upper extremity task designed to simulate the movement plane of a controlled descent, and measures of impact were also assessed. In OA, concentric, eccentric, and isometric strength correlated with post impact energy absorption and eccentric strength correlated with impact velocity. In YA, correlations were only found between concentric strength and energy absorption.<sup>59</sup>

### **Reach to Grasp Responses**

Six studies compared reach to grasp responses to a nearby handrail or handhold between OA and YA (Table 3). Overall, the age range was 19 – 30 years for YA and 60 – 79 years for OA. Perturbations were in the form of surface translations in anterior,<sup>10,54,60–62</sup> posterior,<sup>62</sup> or lateral<sup>14</sup> directions or waist cable pulls in a posterior<sup>60</sup> direction from static standing with feet restrained. Grasping responses were to handholds or rails placed anteriorly<sup>10,61</sup> or laterally<sup>14,54,60,62</sup>. The unpredictable nature of the grasping task was achieved through unanticipated direction of surface translation either with or without random placement of the handhold. Additional conditions included vision occluded prior to<sup>10,61,62</sup> or at the time of perturbation,<sup>61</sup> and/or secondary cognitive task conditions<sup>10,14</sup>. Outcome measures included EMG onset latencies of the anterior deltoid,<sup>10,14,61,62</sup> middle deltoid,<sup>14,54,60,61</sup> posterior deltoid,<sup>62</sup> and biceps brachii<sup>10,54,60,61</sup> muscles, kinematic data,<sup>10,14,54,60,61</sup> time from perturbation onset to EMG onset,<sup>10,14,61</sup> time to contact handrail,<sup>10,60,61</sup> time from EMG onset to handrail contact,<sup>10,14,61</sup> grasp errors (overshoot<sup>14,54</sup> and collision<sup>10,14,54,61</sup>), grasp completion,<sup>10,14,54,61</sup> direction of grasp,<sup>14</sup> and which arm was used<sup>10,14,61</sup>.

Conflicting results in age-related changes were identified in the timing of reach to grasp execution. Using anterior surface translations, Cheng et al.,<sup>61</sup> Mansfield et al.,<sup>60</sup> and Weaver et al.<sup>62</sup> reported delayed EMG onset in either deltoid or biceps brachii muscles and time to handhold contact from perturbation onset in OA compared to YA. Delays in peak deltoid EMG amplitude in OA were also found, but only during trials in which handhold position was predictable. However, these timing differences were not found during posterior waist pull perturbations,<sup>60</sup> or posterior<sup>60</sup> or lateral<sup>14</sup> surface translations.

Of the three studies that investigated the accuracy of grasp responses (end point error, handrail collisions, trajectory, likelihood of grasping handrail or reaching with the wrong limb), Cheng et al.<sup>61</sup> found age-related differences, while Cheng et al.<sup>10</sup> and Westlake et al.<sup>14</sup> did not. Cheng et al.<sup>61</sup> found that OA were more likely to sustain handhold collisions, less likely to achieve full grasp, and tended to reach with the ‘wrong’ limb (contralateral to the handhold) compared to YA. OA were also more likely to raise both hands up prior to grasping. Although Westlake et al.<sup>14</sup> found no age-related differences in handhold collisions, OA were more likely than YA to grasp the handrail positioned opposite to the direction of the fall or to demonstrate a bilateral grasping response compared to single rail grasps in the direction of the fall in YA.

Both Westlake et al.<sup>14</sup> and Cheng et al.<sup>10</sup> investigated the age-related effects of cognitive tasks on the reach to grasp response. Westlake et al. reported age-related increases in movement time to handrail contact and grasping errors (i.e. collisions) under unpredictable lateral perturbations with simple and complex non-spatial working memory tasks, but not under the no-cognitive task predictable or unpredictable trials. In contrast, although Cheng et al. identified greater grasp response latencies compared to YA during

unpredictable anterior-posterior perturbations with spatial and non-spatial working memory tasks, these differences were no greater than during the no cognitive task conditions described above. These authors did, however, report more frequent cognitive errors in OA compared to YA.

King et al.<sup>54</sup> and Cheng et al.<sup>10,61</sup> explored the role of vision in the control of reach to grasp reactions. King et al. used an unexpected and unpredictable anterior perturbation and a deception paradigm while participants walked across a room. OA were found to be less likely to visually fixate on available handrails prior to perturbation. In addition, although OA grasped the handrail more than YA, there were no age-related differences in the number of grasping errors and no relationship between grasp error and prior gaze behavior. Cheng et al.<sup>10,61</sup> studied the effects of the timing of visual information on grasp responses following anterior perturbations. OA were more likely to use wrong arm reaches (i.e. contralateral to the handhold) and raise up both hands when forced to rely on online vision. When relying on stored vision, OA tended to raise hand higher prior to grasp, increase the hand trajectory curvature<sup>10</sup> and demonstrate greater grasping errors<sup>61</sup> compared to YA.

**Table 1.** Counterbalance

<b>Authors</b>	<b>AXIS Score</b>	<b>N, Age range</b>	<b>Perturbation type/characteristics</b>	<b>Instructions</b>	<b>Outcome</b>
<b>Allum et al, 2002</b> <sup>39</sup>	Reporting: 5/7 Design: 5/7 Bias: 2/3	12 YA (20-34) 12 OA (60-75)	Unpredictable stance perturbation: 6 combinations of support-surface roll & pitch (laterally) or pure pitch (forward/ backward) with feet lightly strapped to the platform.	Recover balance as quickly as possible, grasping handrails located to the front and sides, if needed.	All differences between YA and OA occurred in the lateral directions, but not pure pitch directions. Initial trunk and arm roll movements was in opposite direction to platform roll in YA (i.e. counterbalancing motion) and same direction as platform roll in OA (i.e. protective motion); mid-deltoid EMG onset earlier in YA than OA, but with similar EMG amplitude.
<b>Roos et al 2008</b> <sup>48</sup>	Reporting: 6/7 Design: 5/7 Bias: 3/3	8 YA (20-35) 7 OA (65-75)	Unpredictable trip perturbations during gait	Walk at a self-selected pace	OA demonstrated a protective strategy and YA demonstrated a preventative strategy. Arm movements in YA led to elevating the COM and decreasing forward angular momentum of the body (i.e. counterbalancing strategy) whereas older adults reached forward to arrest a fall (protective strategy). In counterbalancing strategies, the displacement of the arm contralateral to the recovery limb was a larger % of overall body recovery in YA than YA.
<b>Maki et al, 2000</b> <sup>57</sup>	Reporting: 6/7 Design: 5/7 Bias: 2/3	10 YA (20-30) 10 OA (65-73)	Unpredictable lateral stance or walking in place perturbation while holding a light-weight rod behind back to deter arm movements.	Try not to move arms and do whatever comes naturally to prevent falling.	OA released rod more frequently than YA

**Table 1.** continued

<p><b>Merrill et al, 2017</b><sup>56</sup></p>	<p>Reporting: 7/7 Design: 6/7 Bias: 2/3</p>	<p>16 YA (20-31) 17 OA (50-65)</p>	<p>Unpredictable slip perturbation</p>	<p>Walk at a comfortable pace while looking straight ahead.</p>	<p>Onset of kinematic arm reaction and peak shoulder moment was delayed in OA. An average shoulder flexion moment was generated in OA, whereas an extension moment was generated in YA. OA did not modulate their response based on slip severity whereas YA did.</p>
<p><b>Laing et al, 2016</b><sup>13</sup></p>	<p>Reporting: 7/7 Design: 6/7 Bias: 2/3</p>	<p>19 YA (20-27) 16 OA (62-77)</p>	<p>Unpredictable forward and backward surface translations from static standing during single-and dual-tasks. Foam barriers used to discourage stepping.</p>	<p>Do whatever is needed to regain balance without stepping</p>	<p>Delayed EMG onset in OA in MD and AD, but not PD. No functionally relevant differences in onset between single-and dual-task conditions in OA or YA. AD and PD EMG amplitude greater in OA across single- and dual-task conditions. The effect of translation direction was omitted.</p>
<p><b>Tang et al, 1998</b><sup>58</sup></p>	<p>Reporting: 7/7 Design: 5/7 Bias: 2/3</p>	<p>33 YA (19-34) 32 OA (70-87)</p>	<p>Unpredictable slip perturbation during gait.</p>	<p>Walk along the walkway with arms lightly folded across the chest, but use any arm movement necessary to regain balance.</p>	<p>Trunk hyperextension or shoulder flexion were to a greater extent and more frequently used in OA.</p>
<p>AXIS: appraisal tool for cross-sectional studies; YA: young adults; OA: older adults; MD: middle deltoid; AD: anterior deltoid; PD: posterior deltoid; COM: center of mass</p>					

Table 2. Protective

Authors	AXIS Score	N, Age range	Perturbation type/ characteristics	Instructions	Outcome
<b>Kim et al, 2003</b> <sup>50</sup>	Reporting: 7/7 Design: 5/7 Bias: 3/3	10 YA (age range not provided) 10 OA (61-80)	Self-initiated & cable released falls starting with arms at sides and feet placed 40, 60, 80, and 100cm from a set of force plates mounted on the wall 120 cm from the ground inclined 10° vertically.	Move head, trunk and lower limbs as one unit during both voluntary and cable-released trials. Break the fall by placing hands on force plates.	At the 2 close release distances and compared to YA, OA had higher peak impact force and shorter breaking peak time after cable-released falls than self-initiated falls. During cable-released falls, less wrist extension and greater elbow extension at touchdown were found in OA. At close distances, elbow extension and shoulder flexion angular velocities were twice as much in OA than YA. No age-related differences were found at the 2 farther release distances.
<b>Lattimer et al, 2018</b> <sup>59</sup>	Reporting: 7/7 Design: 5/7 Bias: 3/3	19 YA (18-30) 16 OA (60-78)	Simulated FOOSH by a quick release onto force plates in front with the subjects' arms extended and hands hovering above. Shoulders flexed 90°, elbows and wrists extended, feet stationary.	Have a soft landing by using elbow flexion and do not descend farther than 90° of elbow flexion.	Elbow angle at impact, elbow angular velocity at impact, and elbow angle at 200 ms post-impact were reduced in OA. Total energy absorbed with UE was reduced by 36% in OA compared to YA. Energy absorption correlated with eccentric, concentric, and isometric shoulder and elbow strength in OA and only with concentric strength in YA. Eccentric elbow strength also correlated with impact velocity in OA, but not YA.
<b>Lattimer et al, 2016</b> <sup>51</sup>	Reporting: 7/7 Design: 6/7 Bias: 2/3	20 YA (18-30) 20 OA (60-78)	Simulated FOOSH by a quick release onto force plates in front with the subjects' hands hovering above. Shoulders flexed 90°, elbows and wrists extended, feet stationary.	Have a soft landing by using elbow flexion and do not descend farther than 90° of elbow flexion.	Reduced TrA/IO activity in OA compared to YA from time of release to impact. Pattern of muscle activation prior to impact was similar between OA and YA and different at post impact. Within YA group, post impact increases in activation compared to baseline were found in AD, PecMaj, Tri, IO. Within OA group differences at post impact only included increased activation in PecMaj and Bic compared to baseline.
<p>AXIS: appraisal tool for cross-sectional studies; YA: young adults; OA: older adults; FOOSH: fall on the outstretched hand; UE: upper extremities; TrA/IO: transversus abdominus/internal oblique; PecMaj: pectoralis major</p>					

**Table 3.** Reach to Grasp

Authors	AXIS Score	N, Age range	Perturbation type/ characteristics	Instructions	Outcome
<b>Westlake et al, 2016</b> <sup>14</sup>	Reporting: 7/7 Design: 6/7 Bias: 3/3	10 YA (23-27) 12 OA Fallers (65-75) 12 OA Non-fallers (65-73)	Lateral surface translations during stance under predictable, unpredictable, and unpredictable with and without simple and complex non-spatial cognitive task conditions. Handrails placed on right and left and feet were restrained.	In response to the perturbation, grasp the rail that will help you recover balance. Do not take a step.	Group differences only found under the 2 unpredictable with cognitive task conditions. OA fallers demonstrated delays in movement time to handrail grasp compared to YA and reduced grasp accuracy compared to both OA non-fallers and YA. No group differences found for EMG onset latencies (i.e. reaction time). YA nearly always grasped rail in direction of fall, whereas OA tended to grasp rail opposite to fall direction or one consistent side.
<b>King et al, 2009</b> <sup>54</sup>	Reporting: 7/7 Design: 6/7 Bias: 3/3	12 YA (22-30) 12 OA (64-79)	Single trial of unpredictable horizontal translation of platform in a room configured to simulate a realistic office environment with door, step, handrail, and visual distractors.	Open the door, walk to the end of a room at normal pace, and make a telephone call	OA grasped the handrail more than YA after perturbation. OA less likely to visually fixate on the handrails prior to perturbation. No age differences in the number of grasping errors and no relationship between grasp error and prior gaze behavior. Neither OA or YA fell into safety harness.
<b>Cheng et al, 2012</b> <sup>61</sup>	Reporting: 6/7 Design: 5/7 Bias: 3/3	12 YA (19-29) 12 OA (65-79)	Unpredictable forward platform translation during stance under 3 visual conditions (occlude vision before perturbation, occlude after perturbation, and un-occluded). Handhold was moved to one of 4 positions during each trial. Feet were restrained. Backward translations included to reduce anticipation.	Recover balance by grasping a target section of handhold as quickly as possible.	Compared to YA, OA had slower onset times and time to handhold contact, were more likely to sustain handhold collisions (3.1% vs. 0.5%), and less likely to achieve full grasp (but due to low scores in 2 OA). OA also tended to reach with the wrong limb (3% vs. 0%) and were more likely to raise both hands up prior to grasping (13.5% vs. 2.8%) than YA, primarily during online visual condition. OA had greater landing position variability and tended to undershoot handhold when dependent on stored visual input. No participant fell into safety harness.
<b>Cheng et al, 2013</b> <sup>10</sup>	Reporting: 6/7 Design:	10 YA (22-30) 10 OA (60-76)	Unpredictable forward platform translations. Handrail location at unpredictable location in front of participant. Vision un-occluded for 2s to allow participants to view	Recover balance by grasping a marked target section handhold as quickly as possible.	OA had slower reach to grasp responses (i.e. EMG onset latency, movement time, time to handhold contact, time after peak velocity) than YA, regardless of recall time or cognitive task. OA demonstrated increased curvature of the hand trajectory and

**Table 3.** continued

	6/7 Bias: 3/3		handhold location, then occluded again with delay of 0, 2s, 5s, or 10s before perturbation. For 5s and 10s delays, non-spatial and spatial secondary cognitive tasks were performed. Stepping deterred by barriers.		increased height of the hand raise prior to grasp, but no age-related differences in handhold collisions or end point error across any condition. More cognitive task errors during spatial-memory task found in OA than YA. Neither OA or YA fell into the safety harness.
<b>Weaver et al, 2012</b> <sup>62</sup>	Reporting: 6/7 Design: 5/7 Bias: 3/3	12 YA (22-24) 12 OA (62-76)	Unpredictable forward or backward platform translation. Handrails were placed to right during predictable trials and either the right or left side during unpredictable trials. Vision was occluded using liquid crystal goggles until the start of each trial.	Recover your balance by reaching and grasping the handrail using right arm (predictable) or arm closest to handrail (unpredictable) as fast as possible. Do not take a step.	OA had delays in PD onset latency during anterior translations regardless of handrail predictability. The peak PD amplitude was earlier for predictable trials compared to unpredictable in YA only. No differences between YA and OA for AD activity during posterior translations.
<b>Mansfield et al, 2009</b> <sup>60</sup>	Reporting: 7/7 Design: 6/7 Bias: 3/3	10 YA (22-28) 30 OA (64-79)	Unpredictable backward surface translation or cable-pull perturbations during stance. Foot motion was restricted. Other conditions included anterior-posterior perturbation and were focused on stepping responses with arm motion restricted.	Recover balance as quickly as possible by grasping the handrail	Age-effects were found under both types of perturbations, although surface translations caused increased difficulty for OA than YA with delayed BB and MD onset times and handrail contact time. OA demonstrated increased arm reactions compared to YA even during conditions with arm constraints.
<p>AXIS: appraisal tool for cross-sectional studies; YA: young adults; OA: Older adults; PD: posterior deltoid; AD: anterior deltoid; MD: middle deltoid; BB: biceps brachii</p>					

## **DISCUSSION**

This systematic review compared upper extremity response timing, kinematics, and kinetics in OA and YA following unpredictable perturbations. The methodological quality of the 15 included studies was high. Key findings highlight age-related differences in reactive arm responses to balance perturbations, whether in an attempt to prevent a fall (i.e. counterbalancing or reach to grasp responses) or to protect against injury.

### **Onset Latency**

Age-related differences in onset latencies of shoulder responses were found in all included counterbalancing studies with this outcome<sup>13,39,56</sup> although mixed results were identified for reach-to-grasp tasks. A startle reflex has been suggested as one possible reason for arm reactions following perturbations. However, in all studies except Westlake et al.<sup>14</sup> onset latencies ranged from 100-265 ms in both older and younger adults, which is above the characteristically fast threshold of <100 ms for startle reflexes.<sup>63</sup> As a result, this reflex is not likely to account for age-related differences in onset latencies even during first trial exposure to the perturbation.<sup>62</sup> A more likely explanation is the decline in sensory input and the central integration of balance-related information in OA compared to YA that have been previously identified.<sup>64-67</sup> Additional contributing factors are age-related decreases in neural transmission speed along the motor fibers and impairments in the basic muscle contractile properties.<sup>68-71</sup> Nevertheless, without first ensuing a necessity to restore balance, the urgency to use the arms as a means to restore stability may have been lessened and the use of a voluntary rather than reactive response cannot be ruled out. Indeed, evidence of age-related differences in voluntary, but not

reactive responses has been identified elsewhere.<sup>72</sup> The lack of age-related differences in reach to grasp responses when individualized perturbation magnitudes were used also lend support to this theory.<sup>14</sup> Moreover, it is conceivable that the magnitudes needed to induce a reactive as opposed to a potentially voluntary arm response differ based on the direction of perturbation. The lack of an aging effect in arm response time during a posterior compared to an anterior surface translation using similar perturbation magnitudes shed some light on this possibility.<sup>62</sup>

### **Whole Body Response**

During whole body balance responses, two upper limb response strategies emerged that differentiated older and young adults. During trips and lateral platform tilts, OA demonstrated a tendency to outstretch the arms towards the ground in an attempt to minimize injury and protect against fall impact.<sup>39,48</sup> In contrast, YA tended to elevate the arms in a direction opposite to the fall in an attempt to decrease the forward momentum of the body and restore balance.<sup>39,48</sup> Slip perturbations resulted in an attempt for OA to restore balance rather than break the fall, even at high slip severities when YA transitioned to a protective response.<sup>56</sup> Taken together, results of these studies suggest that the direction of arm responses in OA tends to follow the passive displacement of center of mass at perturbation onset (i.e. downward during trips and lateral tilts, and upward during slips). The reasons for these differences in response strategies between older and young adults are unclear but may be related to a fear of falling and decreased confidence in the ability to restore balance in OA, particularly when combined with delays in arm movement initiation after an imbalance. A second possibility is trunk

stiffness or weakness in OA, which may prevent an immediate active reversal in COM displacement as has been shown by Allum et al.<sup>39</sup>

### **Landing Strategy**

Age-related differences in the landing strategies of protective arm responses after simulated falls onto outstretched arms were also found across several studies. Regardless of the position of the arms prior to fall release (either at the sides or hovering above a force plate), OA demonstrated greater elbow extension and greater impact forces or reduced energy absorption at the point of impact compared to YA. The combination of these results provide key insights into the mechanisms of fall-related injuries, such as wrist and hip fractures and even head trauma. One possible explanation for these age-related differences is the need for adequate eccentric elbow strength to effectively control the descent of the body at impact. Relationships identified between eccentric upper extremity strength and elbow flexion velocity as well as energy absorption provide some support to this possibility. An additional consideration is that the extended elbow position at impact may be compensatory in nature to offer biomechanical stabilization in the presence of reduced activation of internal obliques/transverse abdominus found in OA. However, this landing strategy in OA does not come without a cost as it has been identified as a key risk factor for increased fall-related wrist fractures.<sup>40,73</sup> Nevertheless, it is important to note that age-related differences in protective arm responses were not identified at fall release distances greater than 60 cm from the point of impact, suggesting that the timing in which arm responses can be employed after fall initiation is critical.

## **Reach to Grasp**

Studies investigating the timing of reach to grasp responses produced the greatest variability in results, which may be due to perturbation type and direction as well as location of handrail placement. During anterior surface translations, age-related delays in reach to grasp movement time were identified regardless of handrail location predictability or whether it was placed in front or to the side of participants.<sup>60-62</sup> However, age-related differences in movement time were not identified during posterior or lateral surface translations when reaching for a handrail placed to the side.<sup>14,62</sup>

Studies investigating age-related differences in the accuracy of reach to grasp responses also yielded conflicting results.<sup>14,61</sup> Only Cheng et al. found age-related differences in grasp response accuracy. However, both Cheng et al. and Westlake et al. found that OA were more likely to grasp the rail or handhold with the limb opposite to the limb used in YA, which was either contralateral to the handhold placed in front or contralateral to the direction of the fall. A tendency to either raise both hands, grasp bilaterally, or grasp the handrail opposite to the fall were strategies used by OA in what may be attempts to 'buy time' prior to grasping. In other words, these strategies may be compensatory in nature due to age-related decreases in sensory feedback regarding falling direction. While the end result may be increased grasp accuracy, the very specific laboratory-based circumstances may not always translate to the variable environments and additional cognitive demands of real-world falls.

## **Role of Cognition**

Although both Westlake et al.<sup>14</sup> and Cheng et al.<sup>10</sup> introduced cognitive tasks prior to perturbation, only Westlake et al. reported age-related differences in movement times to handrail contact and grasping errors under these cognitive conditions. The increased frequency of cognitive task errors in OA in Cheng et al. seems to suggest the presence of an interference effect between attentional resources for reactive reaching and the cognitive task. However, because the cognitive errors occurred prior to perturbation, the interference cannot be attributed to the execution of reactive balance responses.

Participants were required to retain handhold position within working memory with vision occluded during cognitive task performance. Therefore, age-related errors in cognitive tasks of this study are likely due to reduced working memory capacity and prioritization of an anticipated grasp response. Nevertheless, both studies demonstrate similar attention shifting requirements from an ongoing cognitive task to reactive reaching demands at the point of perturbation. The lack of age-related differences in grasping execution errors in Cheng et al. may therefore be due to the relatively smaller perturbation magnitudes and the easily accessed anterior rather than laterally placed handhold.

## **Limitations**

Results should be interpreted with consideration of the limitations of this review. The heterogeneity of methods and outcomes limit the generalization of some findings. Perturbation type, intensity, velocity, and displacement varied between studies which limited comparison across study outcomes. In addition, all findings were reported without an evaluation of arm responses during first trial exposure, which are known to result in

more exaggerated findings than the mean of subsequent trials<sup>63,74</sup>. It should also be noted that none of these studies took into account arm dominance or the physical activity level to see what effect, if any, these two factors had on study results.

### **Clinical Implications & Future Directions**

The findings of this systematic review have a number of clinical and research implications. First, differences in arm responses to balance perturbations in older adults compared to young adults are highlighted across many perturbation types. These results support the importance of developing early assessments and interventions that integrate the arms as part of a whole-body response. A few studies have already begun to assess the ability to train grasp responses.<sup>75-78</sup> However, protocols aimed at training counterbalancing and protective arm responses have yet to be developed. Moreover, given that older adults are more likely to use their arms to assist in balance recovery,<sup>57,58</sup> preventative training programs should incorporate the use of upper limbs under different perturbation conditions and environmental constraints. In terms of research implications, there is a need to develop a common set of variables and clinically accessible assessment methods of reactive arm responses to balance perturbations. An agreement of such assessment tools will strengthen the comparisons across studies and define key variables to address in clinical rehabilitation. Further, there is a need to explore the relationship between age-related differences in arm responses and the risk of falls. At present, it is unknown if the differences between older and young adults are compensatory for other age-related deficits or if they are a risk factor for falls. Such studies are necessary in order to better direct balance rehabilitation and fall prevention efforts.

## **CONCLUSION**

Age-related differences have been identified in reactive arm responses to balance perturbations, whether for counterbalancing, protection against impact, or reach to grasp purposes. In general, older adults exhibited delayed EMG and movement onset times during counterbalancing and protective responses. During whole body perturbations, they tended to move their arms in the direction of the initially passive movement of the trunk (i.e. in a protective direction to arrest a fall following a lateral tilt or trip or in a counterbalancing motion to restore balance following a slip), which was opposite to the direction of arm movement in young adults. When evaluated at the point of impact of the hand, older adults demonstrated higher impact forces, resulting in greater potential for injuries and fractures. Reach to grasp strategies were also found to be different, with older adults tending to grasp with the opposite limb to young adults. Age-related differences in cognitive interference have also been identified, although with limited research in this area, further investigations are warranted. Therefore, with age-related differences in arm responses identified across a variety of perturbation conditions, an understanding of the importance of these differences in terms of falls prevention is needed before targeted rehabilitation efforts can be established.

### **CRedit authorship contribution statement**

Nesreen Alissa: Writing - original draft, Investigation, Formal analysis. Ruth Y.

Akinlosotu: Methodology, Investigation, Writing - review & editing. Andrea G. Shipper:

Methodology. Kelly P. Westlake: Conceptualization, Supervision, Methodology,

Investigation, Formal analysis, Writing - review & editing.

### **Declaration of Competing Interest**

None.

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# CHAPTER THREE: VALIDATION OF THE FES-I AND ABC AS MEASURES OF FALL-RELATED STATE ANXIETY DURING REACTIVE BALANCE PERTURBATIONS IN OLDER ADULTS

## ABSTRACT

**Background:** Fear of falling (FOF) is a common concern among older adults, affecting balance and heightening the likelihood of falls. However, research on the direct link between FOF and fall risk is constrained by the lack of validated tools for measuring real-time or ‘state’ anxiety related to falls. The Falls Efficacy Scale-International (FES-I) and Activities-Specific Balance (ABC) scale, while commonly used for assessing FOF, were originally developed and validated for different fall-related psychological constructs – specifically, concern or worry about falling and confidence in maintaining balance during imagined activities. This study aimed to validate the use of FES-I and ABC in reflecting fall-related state anxiety during unpredictable balance challenges by examining the relationship between skin conductance levels (SCLs) as a measure of psychophysiological state anxiety and clinical assessments of falls efficacy (FES-I) and balance confidence (ABC). Furthermore, we investigated the difference in subjective state anxiety (assessed using the subjective units of distress scale (SUDS)) between older adults with high and low concern about falls using an established cut off score of the FES-I.

**Methods:** Sixteen community-dwelling and ambulatory older adults (average age 70.29 ± 5.31 years) completed three walking trip perturbations. Outcomes included FES-I and ABC, SUDS, and SCL. To confirm the presence of perturbation-induced state anxiety, we used the Wilcoxon signed rank test to compare SCL measurements before and after

the perturbations. Spearman's correlations were then used to analyze the relationship between change in psychophysiological state anxiety (SCL) before to after the perturbations with the FES-I and ABC scales. Additionally, we investigated differences in post-perturbation subjective state anxiety as measured by SUDS between older adults with low (FES-I < 23, n = 8) and high (FES-I ≥ 23, n = 8) concern for falls using the Mann Whitney U test.

**Results:** A significant increase in SCL from pre- to post-perturbation was identified ( $p = 0.026$ ), suggesting the occurrence of perturbation-induced state anxiety. This increase in SCL was positively correlated with both the FES-I ( $p = 0.011$ ) and ABC ( $p = 0.017$ ). Additionally, SUDS scores differed significantly ( $p = 0.008$ ) between older adults with high vs low concern for falls as determined by FES-I ≥ 23 and FES < 23, respectively.

**Conclusions:** Results suggest that FES-I and ABC scores are related to perturbation-induced state anxiety in older adults during balance challenges, thereby providing a tool to evaluate how fear of falling may directly impact balance responses and fall risk. Further investigations with larger cohorts encompassing a wider range of falls efficacy and balance confidence levels are warranted.

## INTRODUCTION

Falls are the leading cause of fatal injuries among older adults and are a significant contributor to severe injuries in this population.<sup>1</sup> Fear of falling (FOF) is prevalent among older adults, affecting between 20 and 85% of this population.<sup>3</sup> Often described as a persistent worry about falling, FOF can lead individuals to avoid activities they are still

capable of performing.<sup>4</sup> This heightened fear increases the risk of falling by a factor of 3.7 compared to those who do not experience FOF.<sup>2</sup>

The falls efficacy scale-international (FES-I) and the activities specific balance confidence (ABC) scale are considered gold standards for what is generally assumed to be ‘fear of falling’ in both research and clinical settings. However, they were originally validated for the assessment of self-efficacy in relation to falls (i.e., perception of balance capabilities during particular activities<sup>4,24,79</sup> and balance confidence (i.e., confidence in the ability to complete particular activities without losing balance or becoming unsteady<sup>25,80</sup> rather than directly measuring fear or anxiety.

Trait anxiety - a personality characteristic that predisposes individuals to perceive situations as threatening - and state anxiety - defined as a temporary emotional response to perceived threats - can significantly impact balance control. Individuals with high generalized anxiety exhibit reduced stability during static standing<sup>81,82</sup> and perturbed<sup>81,83</sup> balance. Conversely, state anxiety induced by situational postural threats can lead to altered balance control strategies such as adopting a stiffening posture, increased center of pressure (COP) sway frequency, and reduced COP sway magnitude.<sup>18,19,84-87</sup> Although these adjustments can provide protective benefits during unperturbed standing, they may hinder reactive balance – defined as the ability to maintain or restore stability in response to unexpected balance disturbances – as the stiffening response can limit both the magnitude and efficiency of corrective responses. To better understand the effects of fall-related static anxiety on reactive balance following unexpected balance disturbances, it is necessary to establish the relationship between clinical measures of fall-related psychological constructs and fall-related anxiety during balance perturbations.

Studies investigating the effects of FOF on balance often use the FES-I and ABC to classify study participants as either fearful or not fearful of falling. Both the FES-I and ABC are known to correlate with trait anxiety,<sup>88</sup> however, it remains uncertain whether they also capture aspects of state anxiety. Given that individuals with trait anxiety are more prone to experiencing state anxiety<sup>89</sup> and considering the situation-specific nature of the items of the FES-I and ABC, it is reasonable to propose that these scales may also reflect state anxiety. Understanding the relationship between an individual's concern about falling or balance confidence and the presence of fall-related situational anxiety during reactive balance responses could help guide the development of more effective and targeted treatment strategies.

Skin conductance, a psychophysiological measure of changes in the electrical conductance of skin, serves as a valid indicator of state anxiety.<sup>31,90,91</sup> The activation of the sympathetic nervous system in response to heightened anxiety from threatening stimuli leads to increased sweat secretion and elevated skin conductance levels (SCLs). Although SCL is a validated measure of state anxiety, it is not commonly accessible to clinicians and requires a highly controlled environment, which can be challenging to achieve in clinic settings. Additionally, assessing psychophysiological fall-related state anxiety via SCL requires specialized equipment and trained personnel. In contrast, the FES-I and ABC are well-known clinical measures, do not require specialized equipment or personnel, and can be easily implemented in clinical practice.

This study aimed to validate the FES-I and ABC as effective tools for capturing fall-related state anxiety and to investigate the relationship between FOF, SCL, and subjective anxiety experiences during balance perturbations. To accurately evaluate the primary

effects of FOF on balance responses, it is important to establish valid methods to reflect state anxiety during perturbations. We sought to investigate the correlation between an established psychophysiological measure of state anxiety (SCL) and the commonly used measures of falls efficacy and balance confidence, FES-I and ABC. We hypothesized that increases in SCL immediately following unpredictable balance perturbations would significantly correlate with scores on the FES-I and ABC scores in older adults. Additionally, we aimed to compare subjective state anxiety, as measured by the Subjective Units of Distress scale (SUDS),<sup>92</sup> between older adults with low (FES-I < 23) vs high (FES-I ≥ 23) concern for falls,<sup>93</sup> positing that those with higher concern would report greater distress during perturbations.

## **METHODS**

This study employed a cross-sectional design involving a single group of 16 healthy older adults recruited from the local community. Participants were over 60 years of age and capable of independently walking at least one city block. Exclusion criteria were neurological disorders, significant musculoskeletal or cardiovascular impairments, recent major surgery (within the last 6 months), recent hospitalization (within the last 3 months), osteoporosis or osteopenia, a Saint Louis University Mental Status Exam score below 27 indicating cognitive impairments,<sup>94</sup> reports of dizziness or shortness of breath, pain exceeding 3/10 on the visual analog scale during walking, clinically diagnosed visual or hearing loss, and the use of sedative or psychotropic drug use. The study was approved by the University of Maryland Institutional Review Board and all participants provided written informed consent prior to the start of study assessment procedures.

## **Procedure**

Participants completed three walking trip perturbation trials, interspersed with no-trip walking trials using customized profiles on the ActiveStep computerized treadmill (Simbex, Lebanon, NH). Participants were kept unaware of the direction or timing of the perturbation trials. The treadmill walking speed was adjusted to either 0.9 or 0.8 m/s, tailored to each participant's preferred overground walking speed determined during a 10m walk test. Treadmill perturbations were induced via a quick posterior acceleration of  $25 \text{ m/s}^2$  over 90ms, resulting in a displacement of 0.2 m. This trip perturbation intensity was chosen for this study based on previous trip perturbation study that used an acceleration of  $16.75 \text{ m/s}^2$  to induce trip-like perturbations using the ActiveStep<sup>95</sup>. As this study aimed to investigate fall-related anxiety, this acceleration was then tested and modified during protocol testing to ensure that it was sufficient to trigger fall-related state anxiety. An overhead safety harness was used to prevent falls, and participants were instructed to "respond naturally to any balance challenges that may occur." Immediately following each perturbation, participants rated their distress levels using the SUDS, indicating their responses during each trial on a scale from 0 (no distress, totally relaxed) to 100 (highest anxiety or distress they have ever experienced).

## **Psychophysiological Outcome Measures**

Skin conductance was measured using a non-invasive technique that involves conducting a small electric current between two surface electrodes placed on the second and third fingers. This method allows for the assessment of SCL, which increases with arousal and activation of the sympathetic nervous system.<sup>90</sup> SCL data were recorded

using Biopac software (BIOPAC Systems, Goleta, CA, USA) and analyzed using BIOPAC AcqKnowledge 5.0.6 software.

For SCL measurement, disposable surface electrodes filled with isotonic gel were placed on the middle phalanges of the second and third finger of the left hand. This placement was chosen based on a previous investigation of 16 sites for the recording of skin conductance.<sup>96</sup> Placement on the second and third fingers of the hand was found to be the most reliable method when recording from the upper limbs. SCL signals were sampled continuously at 62.5 Hz for 60 s<sup>30</sup> at three specific time points: during quiet sitting prior to stepping onto the treadmill (baseline), during quiet standing on the treadmill before testing (pre-perturbation), and while standing on the treadmill immediately after the first walking trip perturbation (post-perturbation). SCL signals were low pass filtered at 1 Hz<sup>97</sup> as the frequency of sympathetic physical and cognitive stress responses are under 0.25 Hz. External influences on SCL were minimized by providing a quiet relaxing atmosphere without any distractions including sounds, smells, or excessive heat or cold.

To account for generalized anxiety (trait anxiety), both pre- and post-perturbation SCL values were normalized to the mean SCL recorded during baseline. The normalization formula used was:

$$\text{Normalized SCL (\%)} = [100 \times (\text{mean SCL}_n - \text{mean SCL sit}) / \text{mean SCL sit}]^{30}$$

Where mean SCL<sub>n</sub> represents the average skin conductance over a 60 s period pre-perturbation or post-perturbation, while mean SCL sit refers to the average SCL during

the 60 s period at baseline. The change in SCL was determined by calculating the difference between normalized SCL values from pre-perturbation to post-perturbation.

### **Subjective Measures of Fall-Related Psychological Concern**

Subjective measures collected during this study included the FES-I, ABC, and SUDS. The FES-I and ABC were administered following the completion of the perturbation testing procedure. Participants were allowed to rest for a period of approximately 15 minutes before administering further tests. The instructions for FES-I and ABC stressed that responses should reflect how the participants usually feel in order to prevent any influence of the perturbation testing on their responses. The SUDS was administered immediately after each trip perturbation to assess state anxiety during the balance challenges. Participants were instructed to rate their experience using a scale from 0 (no distress, totally relaxed) to 100 (highest anxiety or distress they have ever felt), responding to the prompt, “How did the balance challenge make you feel?”

### **Statistical Analysis**

Data was tested for normality using the Shapiro-Wilk test and verified through visual inspection of histograms. As most outcome data was found to be non-normally distributed, all statistical analyses employed non-parametric methods. The Wilcoxon signed-rank test was used to compare normalized SCL while standing on the treadmill before and after the perturbations, confirming the presence of a perturbation-induced increase in state anxiety. Correlation analyses were performed using a Spearman’s rank correlation coefficient. To account for the known exaggerated ‘first-trial’ effects, mean SUDS scores from the second and third perturbations were utilized. Group comparisons

were conducted with non-parametric Mann Whitney U test. All statistical analyses were performed using SPSS (IBM version 29.0.0.0), with an alpha level set at 0.05, subsequently adjusted for multiple correlations (SCL and FES-I, SCL and ABC) using the Bonferroni correction, resulting in a modified alpha level of 0.025.

## RESULTS

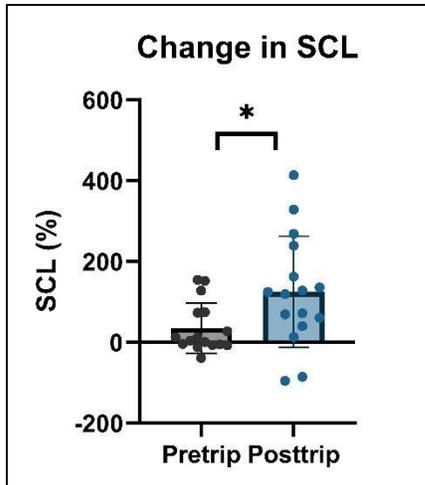
Data from 16 healthy older adults were included in this study. Participant characteristics are presented in Table 4.

**Table 4.** Participant Characteristics

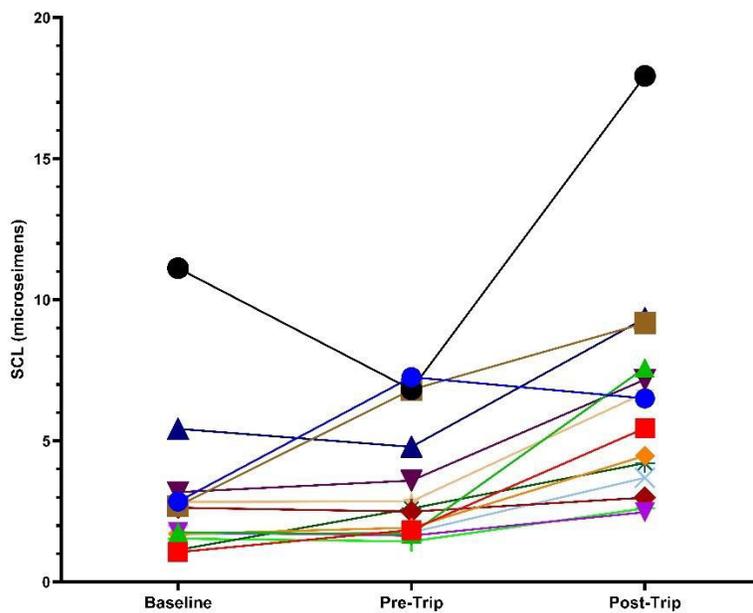
<b>Characteristics</b>	<b>Mean ± SD</b>
Age (years)	70.29 ± 5.31
Sex (F, M)	9 F, 7 M
Height (m)	1.67 ± 0.09
Weight (kg)	78.52 ± 15.18
FES-I	23.59 ± 7.05
ABC (%)	82.65 ± 13.82

FES-I: falls efficacy scale-international, ABC: activities-specific balance confidence scale.

Normalized SCL post-perturbation was significantly greater than normalized SCL pre-perturbation ( $Z = -2.223$ ,  $p = 0.026$ ), confirming that the change in SCL was indeed due to perturbation-induced anxiety (Figure 2). The changes in raw SCL values at baseline to pre-perturbation and post-perturbation are depicted in Figure 3.

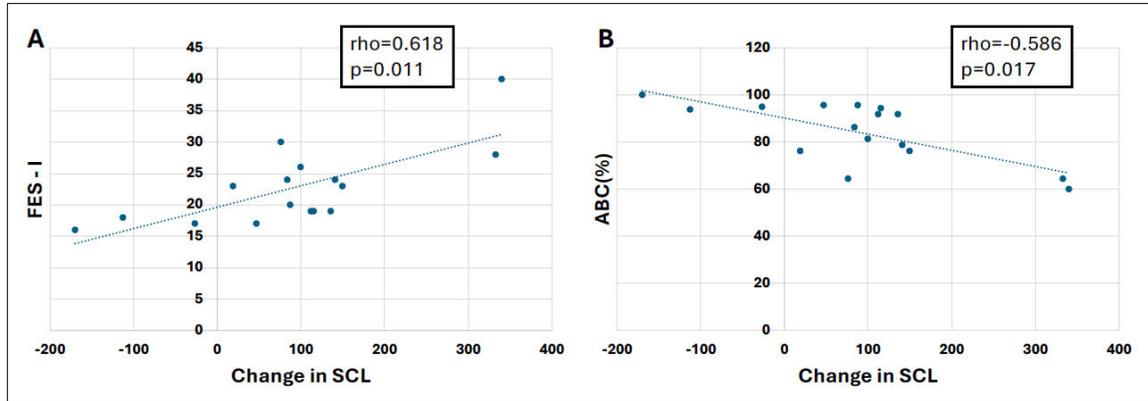


**Figure 2.** Change in normalized skin conductance level (SCL) from pre- to post-perturbation



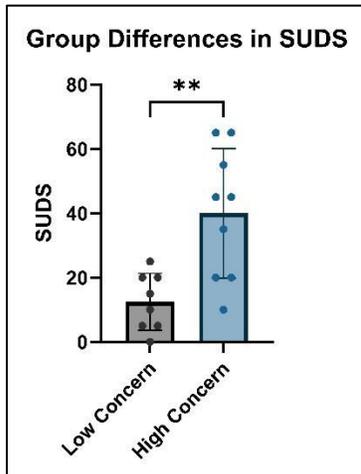
**Figure 3.** Raw SCL values showing the pattern of change in SCL from baseline to pre- to post-perturbation

Significant moderate correlations were found between change in SCL post-perturbation and the FES-I ( $\rho = 0.618$ ,  $p = 0.011$ ) and ABC ( $\rho = -0.586$ ,  $p = 0.017$ ) scores. These correlations are depicted in Figure 4.



**Figure 4.** Correlations between change in normalized skin conductance level (SCL) and falls efficacy (FES-I; A) and balance confidence (ABC; B)

Significant between group differences were found in mean SUDS scores between older adults with high ( $40.0 \pm 20.16$ ) and low ( $12.5 \pm 8.86$ ) concern for falls ( $Z = -2.669$ ,  $p = 0.008$ ). This group difference is illustrated in Figure 5.



**Figure 5.** Group differences in mean SUDS scores between high and low concern for falls groups

## DISCUSSION

Overall, our findings suggest that, while the FES-I and ABC scales were designed to assess falls efficacy and balance confidence, they may also reflect fall-related state anxiety during balance perturbations. Notably, we observed a significant difference in SUDS scores between older adults with high and low concern about falls.

As anticipated, we recorded a significant increase in SCL from pre- to post-perturbation, demonstrating that our balance perturbation successfully induced fall-related state anxiety. Experimental manipulation of perceived stability is known to increase physiological responses including SCL and are accompanied by simultaneous increases in self-reported anxiety and fear;<sup>85</sup> however, to our knowledge, this is the first study to investigate the change in SCL using physical balance perturbations. When perceived stability is threatened, the “fight-or-flight” response is activated wherein sympathetic nervous system activity increases rapidly, resulting in increased sweat secretion, increased heart rate, and pupil dilation. These physiological changes all work to help the response to a perceived threat. Previous research has reported similar increases in SCL in response to fear- or threat-inducing conditions.<sup>85,86,98–101</sup> Studies investigating height- and perturbation-induced threats while measuring SCL and subjective state anxiety<sup>85,98,100</sup> have shown significant increases in both measures; however, they did not directly compare changes in SCL with subjective fall-related psychological assessments following such threats.

Our results revealed a significant correlation between the change in SCL from pre- to post-perturbation and FES-I and ABC scores. As far as we are aware, this study is the first to explore the validity of the FES-I and ABC as indicators of subjective fall-related

state anxiety during balance perturbations. Previous investigations into the relationship between these scales and generalized anxiety have produced mixed results<sup>88,102</sup>; however, none have specifically addressed the association of state anxiety with FES-I and ABC in the context of acute fear-inducing activities like balance perturbations. By examining the relationship between FES-I and ABC with perturbation-induced state anxiety, we can assess whether these scales adequately capture the emotional responses that occur during a perceived threat on balance recovery. Although the instructions within the FES-I and ABC address concern and confidence in general terms of how a person “usually” feels, this does not preclude the possibility that these scales also reflect state anxiety. Studies have shown that people who experience trait anxiety are also likely to experience state anxiety during threatening situations.<sup>103,104</sup> When completing the FES-I and ABC, participants are asked to respond in the context of situation-specific items. This implies a form of state anxiety in the moment of those situations as opposed to other measures of trait anxiety which ask about the frequency of specific anxiety-related feelings or emotions. During the initial development of the original FES, the individual items were chosen by asking clinicians to “name the 10 most important activities essential to independent living that, while requiring some position change or walking, would be safe and nonhazardous to most elderly persons”. When the ABC was developed, Powell and colleagues asked participants to name the 10 most important activities of independent living that would be safe and nonhazardous to most elderly persons – the same question asked during the development of the FES – with the additional question of “Are you afraid of falling during any normal daily activities, and if so, which ones?” These

questions refer to activities that induce a state of concern or fear in the moment of that particular activity, which is closely related to the definition of state anxiety.

A previous study found a significant association between ABC and subjective state anxiety measured using the State–Trait Anxiety Inventory in people with stroke, where lower balance confidence was related to higher state anxiety.<sup>105</sup> Significant associations have been found between the FES-I and ABC with fall risk and fall incidence.<sup>106–110</sup> The FES-I and ABC have also been identified as predictors for falls.<sup>111–113</sup> The predictive capacity of the FES-I and ABC for falls and fall risk may be linked to their relationship with state anxiety during fall-inducing activities, such as balance perturbations. Our finding that participants in the high concern group exhibited higher SUDS scores indicates the presence of greater fall-related state anxiety during perturbations. Future research with larger cohorts is warranted to further investigate this relationship.

It is important to note that this study serves as an initial investigation into the relationship of the FES-I and ABC with fall-related state anxiety during balance perturbations in older adults. Additional research including larger samples is needed to further validate the use of the FES-I and ABC in this context. While guidelines for respondent-to-item ratios can vary considerably,<sup>114</sup> larger sample sizes are generally preferable. A more expansive participant pool would also facilitate an examination of the discriminate validity of the FES-I and ABC compared to other fall-related psychological measures such as the modified Fear of Falling Avoidance Behavior Questionnaire (mFFABQ).

## **Clinical Implications**

Balance control during perceived postural threat in older adults is known to be influenced by state anxiety.<sup>18,84,85</sup> The ability to clinically identify the presence of state anxiety in patients is crucial as fall-related state anxiety can influence balance responses thereby contributing to balance impairments. The FES-I and ABC were not designed to measure the construct of FOF; however, results of this study suggest that they may also reflect fall-related state anxiety during balance perturbations and may be used for this purpose. It is important to account for how FOF or fall-related state anxiety influence clinical balance assessments and treatment efficacy in older adults.

## **Limitations**

The current study has several limitations that should be considered. First, the sample size was relatively small, which may affect the generalizability of the findings. Future research should aim to include larger samples to better assess the discriminate validity of the FES-I and ABC in relation to fall-related state anxiety during reactive balance tasks. Second, we did not measure the ambient temperature of the laboratory, despite its potential impact on sweat production, with both increased and decreased temperatures influencing SCL. However, since the change in SCL was normalized to quiet sitting within the session, we believe this approach would have helped mitigate the effects of any daily temperature variations in the lab.

## **CONCLUSION**

This study is the first to assess the validity of the FES-I and ABC scale in relation to fall-related state anxiety during unpredictable balance perturbations. Both FES-I and

ABC were found to significantly correlate with physiological measures of state anxiety during reactive balance tasks in older adults. Additionally, we observed that older adults with greater concern about falling reported higher fall-related state anxiety during balance perturbations. Together, these results show that the FES-I and ABC could be valuable clinical and research tools to help identify older adults who are prone to experiencing FOF or fall-related anxiety during reactive balance responses, potentially placing them at a higher risk for falls. Future research should leverage the FES-I and ABC to reflect state anxiety in the context of unpredictable balance perturbations, allowing for a deeper investigation into the primary effects of FOF on balance responses in older adults.

## CHAPTER FOUR: REACH TO GRASP TRAINING TO IMPROVE REACH TO GRASP EFFICIENCY IN OLDER ADULTS

### ABSTRACT

**Background:** Compensatory reach to grasp responses are critical protective mechanisms against falls, particularly among older adults. While this strategy is common, older adults demonstrate decreased grasp accuracy rates and prolonged movement execution times compared to younger adults. An effective reach to grasp response requires rapid attention shifting from ongoing activities to the visuo-spatial processing of potential support surfaces. Despite its importance in fall prevention, limited research has investigated how cognitive-motor training might enhance this protective response. This study investigated the efficacy of a perturbation-based dual task training protocol on reach to grasp performance and balance recovery. A secondary aim was to determine whether baseline balance confidence corresponded with improvements in reach-to-grasp timing and balance confidence.

**Methods:** Twenty community dwelling older adults ( $70 \pm 6.2$  years) completed a 3-week perturbation-based dual task cognitive-motor training intervention consisting of six-sessions designed to enhance reach to grasp balance responses. Training involved 30 randomized slip and trip walking perturbations, delivered at four distinct intensities with a handrail positioned on the participant's dominant side. Pre-training assessments consisted of three treadmill-induced slip perturbations - two with concurrent cognitive tasks and one without – also with the handrail on the dominant side. Post-training testing replicated these conditions and included two more: a cognitive task trial with the handrail on the non-dominant side (untrained arm) and another cognitive task trial without

handrail support. Participants wore a safety harness equipped with a load cell to prevent falls and quantify recovery assistance. Responses were video recorded and categorized by grasp type (successful grasp, overshoot, undershoot, collision). Kinematic analysis quantified grasp timing (perturbation onset to handrail contact) and stability at first foot touchdown (FFTD). The assessment battery also included psychological measures (Activities-Specific Balance Confidence (ABC) scale, Subjective Units of Distress Scale (SUDS)), psychophysiological anxiety indicators (skin conductance levels (SCLs), pulse rate variability (PRV)), and sensory function evaluations.

**Results:** Following the reach to grasp intervention, significant improvements in grasp accuracy ( $p = 0.007$ ), reduced grasp time ( $p = 0.009$ ), and decreased perturbation-induced anxiety as measured by SUDS ( $p = 0.046$ ) were found. Transfer effects to the untrained arm were also identified by improved grasp accuracy ( $p = 0.008$ ), although grasp timing remained unchanged ( $p = 0.379$ ). Additionally, reduced subjective fall-related anxiety was noted ( $p = 0.043$ ). In trials without handrail support, post-training assessments revealed no significant changes in either stability at FFTD or required harness assistance.

Psychophysiological anxiety measures, including SCL and PRV metrics, remained stable from pre- to post-training. Notably, improvements in grasp timing showed no correlation with the baseline ABC.

**Conclusions:** Our findings indicate that perturbation-based dual task training can effectively improve compensatory reach to grasp responses in older adults, enhancing both grasp accuracy and movement time while also reducing perturbation induced anxiety. The observed transfer of improved grasp accuracy to the untrained arm suggests the potential generalization of motor learning, although temporal aspects of the response

may require specific training. Future research should investigate the long-term retention of these improvements and explore whether dual task perturbation training that includes bilateral reach-to-grasp and stepping responses can achieve greater transfer effects.

## **INTRODUCTION**

Falls are the principal cause of injury and death in older adults over the age of 65 with approximately 1 in 4 adults reporting at least one fall every year.<sup>1</sup> Home hazards are the most common environmental risk factor for falls.<sup>115</sup> Mean falls indoors among institutional and community dwelling older adults was 64.72% (range 20-76%) compared to 40.23% (range 16-45%) of falls outdoors.<sup>115</sup> Circumstances of these indoor falls usually involve slips and trips in the kitchen and bathroom, and going up and downstairs.<sup>5-7</sup> In fact, going up and down stairs was the second leading circumstance for injurious falls among older women.<sup>7</sup> Despite the availability of nearby handholds in these environments (e.g., counters, tables, handrails), falls are still very common.

Although older adults, compared to young adults, have a greater tendency to employ reactive arm responses such as the reach to grasp response following a balance perturbation, this response is not always successful in improving balance recovery.<sup>9</sup> Older adults have more frequent grasp errors, leading to collision with, overshoot, or undershoot of available handholds. Older adults also experience greater delays in the initiation and execution of the reach to grasp response. To our knowledge, only one previous study has attempted to investigate the effects of a static perturbation-based training intervention on the reach to grasp response<sup>76</sup>. While improvements in grasp accuracy were found, grasp movement time during multi-directional surface translations

with the feet immobilized was unchanged. However, this study did not account for the effects of cognition or anxiety on the reach to grasp response.

Dual-task paradigms of simultaneous postural and cognitive tasks show that cognitive tasks can interfere with gait and postural control.<sup>14,116–118</sup> When one encounters an unexpected balance perturbation during daily life, an efficient grasp response requires a rapid reallocation of cognitive resources from any ongoing cognitive and/ or motor task to the planning and execution of an appropriate reactive balance response via cortical integration of visuospatial information.<sup>17,119</sup> This rapid attention switching process, which involves intact visuospatial working memory to locate and reach for an available handhold<sup>14,61</sup> becomes slower with age.<sup>20,79,120</sup>

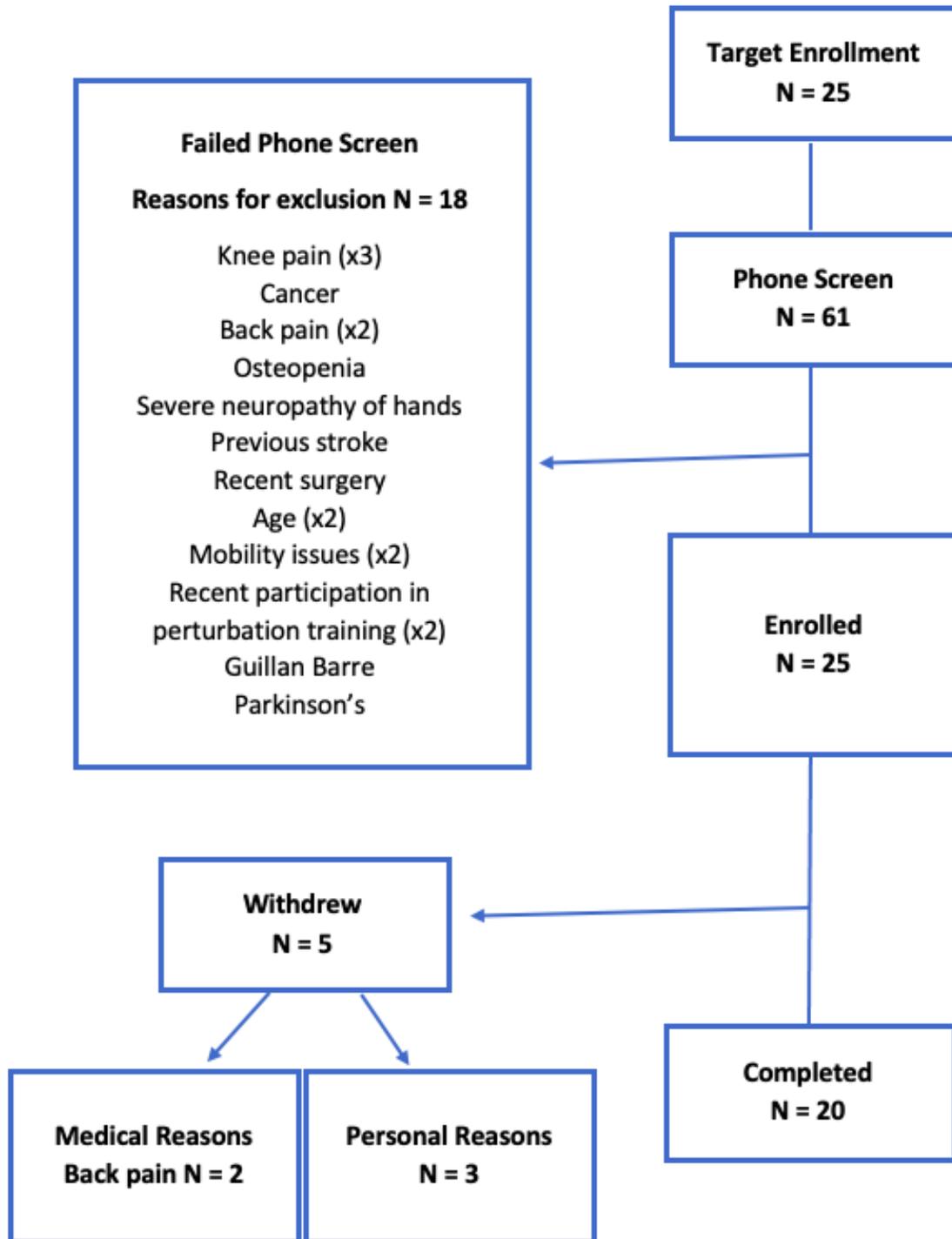
The rapid attention switching necessary for an efficient reach to grasp response is also affected by anxiety and stress.<sup>12,80</sup> Compared to older adult non-fallers, older adult fallers produce a greater percentage of grasp errors and increased grasp movement time with the addition of a cognitive dual task.<sup>14</sup> This difference between older fallers and non-fallers could be due to the presence of fall-related state anxiety, leading to deficits in attention shifting ability. Anxiety can have deleterious effects on attention switching<sup>121</sup> and working memory.<sup>122,123</sup> Compared to a neutral cognitive task, a stressful cognitive task results in a greater frequency of grasp errors, which implies an important role for the emotional interference of a cognitive task, not merely interference of the cognitive task alone.<sup>12</sup> This emotional interference is likely due to the shared role of the amygdala in both attention control and emotional regulation, leading to over-taxation of the amygdala and negatively impacting attention switching capacity.<sup>124,125</sup> Thus, an effective reach to grasp training intervention must address both cognitive attentional and emotional factors.

Previous studies have shown improved reaction times for the lower limbs with reactive balance training, indicating the ability to improve neural processing with training.<sup>126</sup> However, these studies have not addressed attentional or emotional influences during reactive balance training of the upper limbs. This study aimed to investigate the effects of a dual task unpredictable reach to grasp balance perturbation intervention in improving the reach to grasp response in older adults. Furthermore, we investigated the impact of emotional interference on responsiveness to reach to grasp training by examining the relationship between pre-training balance confidence and the change in fall-related state anxiety from pre- to post-training with the change in reach to grasp time from pre- to post-training. We hypothesized that following the intervention, 1) reach to grasp accuracy would increase and grasp time would decrease in the trained arm and the untrained arm will exhibit similar improvements through interlimb transfer, 2) the reach to grasp training would generalize to the lower limbs in the absence of the handrail in the form of increased stability at recovery step touchdown, and 3) pre-training balance confidence (assessed using the activities specific balance confidence (ABC) scale) would positively correlate with the change in reach to grasp time from pre- to post-training.

## **METHODS**

This was a single group pre-post intervention study including 20 community dwelling older adults. Older adults over the age of 60 who were able to walk at least one city block with or without a cane were enrolled. The study excluded anyone with significant musculoskeletal or neurological impairments as indicated by limitations in activities of daily living (less than 6/6 on Katz Index<sup>127</sup>), clinically identified uncorrected visual loss, complaints of dizziness or known vestibular disorders, unable to move through full range

of motion against moderate resistance at the shoulder, elbow, or wrist, or a Mini Mental State Examination score of less than 24 indicating cognitive impairment<sup>128</sup>. Although the total recruitment goal was 20 subjects, target enrollment was set to 25 to account for a 20% attrition rate observed in previous older adult intervention studies in our lab. The process of participant recruitment is summarized in the recruitment flowchart in Figure 6. This study was approved by the University of Maryland Institutional Review Board and all participants provided written informed consent before beginning the intervention and testing.



**Figure 6.** Recruitment flowchart

## Testing Procedure

At pre-intervention, participants completed three walking slip perturbations (two slips with a simultaneous cognitive task and one slip without a cognitive task) using customized profiles on the ActiveStep computerized treadmill (Simbex, Lebanon, NH). The slip perturbations were interspersed with walking trials with and without a cognitive task. Participants were unaware of the direction or timing of the perturbation trials. The trials without a cognitive task were included to further increase the unpredictability of the perturbations. The testing conditions were not randomized as the only condition of interest was the second slip with a cognitive task and there were only three perturbation trials total. Therefore, there was no danger of within-session training effects influencing the results of this study. The second perturbation trial with a cognitive task was the trial of interest in order to investigate the rapid reallocation of attention required during the reach to grasp response without the potential influence of first trial effects. The treadmill walking speed varied between 0.7 - 0.9 m/s based on each participant's comfortable walking speed. Comfortable walking speed was determined through a trial-and-error process. Starting at a moderate speed of 0.8 m/s, the speed was adjusted up or down based on participant feedback. Treadmill perturbations were induced via a quick forward acceleration of  $-6.29 \text{ m/s}^2$  over 0.35 s and a displacement of 0.14 m. A single handrail was placed lateral to the participant at wrist height on the side of the dominant arm (the trained arm). An overhead safety harness with an integrated loadcell was used to prevent falls and calculate the amount of harness assistance. The simultaneous cognitive task during testing was a category naming task such as "name as many animals as you can" or "name as many fruits as you can" with a different category for each trial. Participants

were instructed to “respond to any balance challenges by reaching for the handrail”. After each slip perturbation, participants were asked to specify their distress levels using the Subjective Units of Distress Scale (SUDS) which indicates the level of distress during the slip perturbation from 0 (no distress, totally relaxed) to 100 (highest anxiety or distress ever felt). Post-intervention testing followed the same procedure as pre-intervention testing but with two additional testing conditions: 1) a slip with a cognitive task and the handrail placed on the side of the non-dominant arm (untrained arm), and 2) a slip with a cognitive task but without a handrail. The sequence of these two additional slip tests were randomized between subjects to avoid the potential influence of within-session training effects on the results of this study. Testing and training protocols are illustrated in Figure 7.

### **Day 1: Pretest**

Testing Conditions (handrail present on trained side):

- Two walking acclimation trials
- Slip with cognitive task
- Walk with cognitive task
- Walk without cognitive task
- Slip without cognitive task
- Walk with cognitive task
- Slip with cognitive task

### **Days 1 - 6: Training**

30 randomized walking slip and trip perturbations with the handrail placed on the dominant side

### **Day 6: Posttest**

Testing Conditions:

- Two walking acclimation trials, handrail on trained side
- Slip with cognitive task, handrail on trained side
- Walk with cognitive task, handrail on trained side
- Walk without cognitive task, handrail on trained side
- Slip without cognitive task, handrail on trained side
- Walk with cognitive task, handrail on trained side
- Slip with cognitive task, handrail on trained side
- Walk with no cognitive task, handrail on untrained side
- Walk with cognitive task, handrail on untrained side
- Slip with cognitive task, handrail on untrained side (randomized)
- Walk no cognitive task, handrail absent
- Slip with cognitive task, handrail absent (randomized)

**Figure 7.** Testing and training protocol

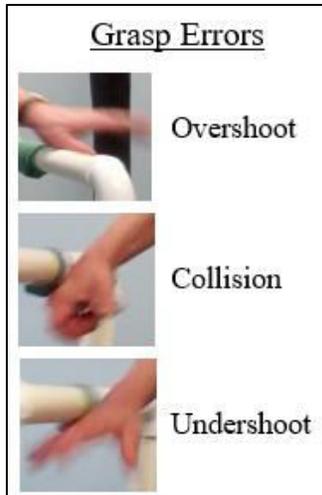
## Training Protocol

Reach to grasp training consisted of two training sessions per week over a period of three weeks.<sup>129</sup> Previous reactive balance training using a similar frequency and duration resulted in improved reaction time during stepping responses.<sup>129</sup> In addition, previous studies have investigated neural changes following motor skill learning. They found that three weeks of complex motor task learning increased activation in the primary motor cortex<sup>130</sup> and that only two sessions of complex whole body balance training can induce a significant increase in gray matter volume in the frontal and parietal brain areas<sup>131</sup>. The training protocol was similar for each session and consisted of 30 trials of randomized dual task mixed walking slip and trip trials. The number of training trials used in this study was determined based on reach to grasp improvements observed in a prior, unpublished pilot study conducted in our laboratory. The simultaneous cognitive task during training was a continuous verb generation task where the trainer read from a list of nouns such as “horse” and the participant responded with a verb related to that word such as “ride”. Training slip perturbations were induced via a quick forward acceleration of the treadmill belt at two intensities:  $-6.29 \text{ m/s}^2$  over 0.35 s and a displacement of 0.14 m and  $-5.50 \text{ m/s}^2$  over 0.40 s and a displacement of 0.16 m. Training trip perturbations were induced via a quick backward acceleration of the treadmill belt at two intensities:  $11.54 \text{ m/s}^2$  over 0.13 s and a displacement of 0.10 m and  $17.0 \text{ m/s}^2$  over 0.10 s and a displacement of 0.09 m. Previous research has shown that mixed perturbation direction<sup>76,132–134</sup> (i.e., slip and trip) training at different intensities resulted in reduced fall incidence<sup>132,134</sup> and improved dynamic balance,<sup>132</sup> balance confidence,<sup>132</sup> and grasp accuracy<sup>76</sup>. Previous studies investigating random and blocked

perturbation-based balance training found that, although they produced similar results<sup>135–137</sup> during post-intervention testing, random training resulted in better retention and transfer<sup>137</sup> of training effects. On a practical note, high intensity perturbations in general produce better results, but can lead to fatigue.<sup>138</sup> The inclusion of lower intensity perturbations can help reduce the potential for activity-induced fatigue. The specific perturbation intensities used were based on preset ActiveStep profiles which were then modified to ensure that they produced slip-like and trip-like intensities sufficient to induce perceived high and low threat to balance. A single handrail was placed lateral to the participant on their dominant side at wrist height. An overhead safety harness was used to prevent falls. Participants were instructed to “respond naturally to any balance challenges” During the assessments, participants were not explicitly told to reach for the handrail.

### **Grasp Accuracy**

Grasp accuracy was identified using video recordings of reach to grasp responses during slip perturbations and was calculated as the percentage of successful grasps (i.e. not grasp errors) out of total number of grasps across all participants. Grasp errors were defined as an undershoot, overshoot, or collision with the handrail (Figure 8).<sup>12</sup>



**Figure 8.** Illustration of grasp errors

### **Kinematic Outcome Measures**

Kinematic data was collected using a 6-camera Vicon motion capture system (Vicon Motion Systems, Inc., Denver, CO) with a sampling frequency of 120 Hz and Nexus software version (2.12.5). Data was recorded using the Vicon plug-in gait marker set to capture elbow, shoulder, and heel position and movement. Data was sampled at 120 Hz and filtered using a low-pass Butterworth filter with a 10 Hz cutoff frequency.

Grasp time was defined as the time from slip perturbation onset to handrail contact<sup>12</sup>. Slip perturbation onset was defined as the time at which acceleration of the slipped foot heel marker exceeds  $0.2 \text{ m/s}^2$ . Handrail contact was defined as the time at which acceleration of the lateral wrist marker of the reaching arm falls below  $0.2 \text{ m/s}^2$ . Previous studies defined the start of a perturbation and end of marker movement using a  $0.1 \text{ m/s}^2$  acceleration threshold<sup>139</sup>. However, this acceleration threshold was not appropriate in our study because our test included walking perturbations, meaning that the heel and wrist markers never decreased to zero acceleration. Visual confirmation of

grasp at an acceleration cut-off of 0.1 m/s<sup>2</sup> showed that this acceleration threshold was too late (grasp had already occurred). Therefore, we used a wrist marker acceleration threshold of 0.2 m/s<sup>2</sup> which was found to be appropriate after visual inspection and confirmation.

Stability at FFTD in the mediolateral direction ( $S_{ML}$ ) was calculated as the distance in the ML plane between the COM and the lateral malleolus marker of the FFTD foot. Stability at FFTD in the anteroposterior direction ( $S_{AP}$ ) was calculated as the distance in the AP plane between the COM and the heel malleolus marker of the FFTD foot. FFTD was defined as the minimum vertical position of the heel marker immediately after the slip perturbation onset. COM was calculated using Plug-in-Gait marker set based on the positions of body segments, which are derived from marker trajectories using the following equation:

$$COM_{body} = \frac{\sum(m_i \cdot COM_i)}{\sum m_i}$$

140

Where  $m_i$  is the mass of the  $i$ -th segment, as a proportion of the total body mass,  $COM_i$  is the COM position of the  $i$ -th segment, and the sums are over all body segments.

Anthropometric data including segment lengths and mass proportions were based on standard estimates<sup>141</sup> of segment masses and COM positions.

### **Psychophysiological Measures**

Skin conductance is a measure of the electrical conductance of skin, which increases with arousal and activation of the sympathetic nervous system.<sup>90</sup> SCL was recorded using disposable surface electrodes filled with isotonic gel and placed on the

middle phalanges of the second and third finger of the left hand.<sup>96</sup> SCL signals were sampled continuously at 62.5 Hz for a duration of 60 s<sup>30</sup> at each of the following three time points: during quiet sitting before standing on the treadmill (baseline), during quiet standing on the treadmill before testing (pre-perturbation), and while standing on the treadmill immediately after testing (post-perturbation). SCL signals were low pass filtered at 1 Hz<sup>97</sup> as the frequency of sympathetic physical and cognitive stress responses are under 0.25 Hz. Both pre-perturbation SCL and post-perturbation SCL were normalized to baseline SCL to rule out generalized anxiety:

$$\text{Normalized SCL (\%)} = [100 \times (\text{mean SCL}_n - \text{mean SCL sit}) / \text{mean SCL sit}]^{30}$$

Where mean SCL<sub>n</sub> refers to mean skin conductance over a 60 s period pre-perturbation and 60 s immediately post-perturbation, and mean SCL sit was defined as the mean SCL over a 60 s at baseline. Change in SCL was calculated as the difference between normalized pre-perturbation SCL and normalized post-perturbation SCL.

Photoplethysmography (PPG) is a non-invasive technique that uses infrared light to detect changes in blood oxygenation levels.<sup>142</sup> PPG was recorded using an infrared sensor placed on the palmar side of the thumb. PPG signals were sampled continuously at 2,000 Hz for a duration of 5 minutes at the same three time points that SCL was recorded.<sup>143</sup> We used PPG recordings to perform power frequency domain analyses of pulse rate variability (PRV).<sup>142</sup> Power spectral density analyses were chosen over time domain analyses because they provide distinct insights into specific frequency bands that reflect autonomic sympathetic and parasympathetic activity, which time-domain analyses cannot discern.<sup>142</sup> The power domain analyses are capable of capturing dynamic changes in sympathetic and parasympathetic activity in response to stressors (such as reactive

balance perturbations).<sup>29</sup> Power spectral density was analyzed after a band pass filter between 0.1 – 1 Hz to account for motion artifact and baseline drift.<sup>144</sup> Measures of power domain included power in the high frequency (HF) band (0.15 – 0.4 Hz) and the LF/HF ratio (low frequency (0.04 – 0.15 Hz) power to high frequency power ratio). Power in the ultra low frequency band ( $\leq 0.003$  Hz) was not investigated as it requires a long recording duration of 24 hours which was not feasible for this study.<sup>142</sup> The very low frequency (0.0033 – 0.4 Hz) and low frequency bands were not investigated as there is some controversy in the literature regarding the interpretation of these measures.<sup>142,143</sup>

PRV power indices were normalized by dividing the individual power components by the total power:

$$\text{Normalized PRV (\%)} = [100 \times \text{Power}_n / (\text{Total power})]^{143}$$

Where  $\text{Power}_n$  refers to PRV indices pre- and post-perturbation and total power was the sum of power in the very low frequency, low frequency, and HF bands. Changes in PRV power indices were calculated as the difference between normalized power indices pre- to post-perturbation.

Both SCL and PRV measures were recorded using Biopac software (BIOPAC Systems, Goleta, CA, USA) and analyzed using BIOPAC AcqKnowledge 5.0.6 software.

### **Harness Assistance**

Loadcell data was collected using a Noraxon TeleMyo wireless EMG system (Noraxon, Scottsdale, AZ). Loadcell signals were lowpass filtered at 8 Hz. Harness assistance was defined as the maximal percentage of harness assist over a 1s period

immediately after perturbation onset, then converted to a percentage of body weight for each individual participant.<sup>145</sup>

### **Clinical Measures**

All clinical measures were collected after the pre-intervention slip perturbation test. These measures were used in order to assess participant's baseline characteristics and to ensure that there were no notable differences in baseline dynamic balance, physical activity, balance confidence, or sensory function. Clinical balance was measured using the Four-Square Step Test (FSST) and the Cognitive Timed Up and Go Test (TUG<sub>Cog</sub>). Subjective state and trait anxiety were measured using the SUDS and Beck Anxiety Inventory (BAI), respectively. Balance confidence was measured using the Activities Specific Balance Confidence (ABC) Scale. The Physical Activity Scale for the Elderly (PASE) was used to measure physical activity. Sensory tests included bilateral testing of 1) the Achilles reflex, 2) proprioception testing of the first toe and ankle, 3) vibration testing at the distal interphalangeal joint of the first toe and the lateral malleolus of the ankle using a 128 Hz tuning fork, and 4) monofilament testing for loss of protective sensation using a 10g monofilament on the plantar side of the first toe and heel.

### **Statistical Analysis**

Data were tested for normality using the Shapiro-Wilk test of normality and visually confirmed using histograms. The majority of our outcomes were not normally distributed, therefore we used non-parametric tests for all our statistical analyses. Non-parametric Wilcoxon signed rank tests were used to investigate changes in grasp accuracy, grasp time, stability at FFTD, and subjective and psychophysiological fall-related state anxiety

from pre- to post-intervention. Non-parametric Spearman's correlations were used to investigate the relationship between ABC and change in reach to grasp time from pre- to post-training. All tests were conducted using SPSS (IBM version 29.0.0.0). The alpha level was set to 0.05, then corrected to 0.025 for multiple correlations using the Bonferroni method.

## **RESULTS**

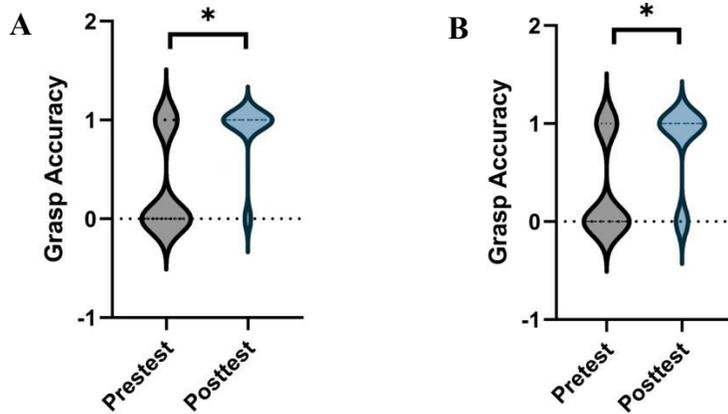
Data from 20 healthy older adults were included in this study. COM data could not be analyzed for three participants due to issues with the motion capture. Participant characteristics pre- and post-intervention are shown in Table 5.

**Table 5.** Participants characteristics

<b>Characteristics</b>	<b>Mean ± SD</b>
Age (years)	70.25 ± 6.21
Gender (#F, #M)	10 F, 10 M
Height (m)	1.71 ± 0.09
Weight (kg)	81.54 ± 12.17
<b>Questionnaires</b>	
PASE	183.19 ± 119.11
ABC (%)	87.37 ± 14.53
BAI	4.80 ± 3.60
<b>Clinical Balance Tests</b>	
TUG <sub>Cog</sub> (%)	1.81 ± 1.67
FSST	9.62 ± 1.64
<b>Sensory Tests</b>	
<b>Left</b>	
Proprioception (1 <sup>st</sup> Toe)	19 N, 1 I
Proprioception (Heel)	20 N, 0 I
Vibration (1 <sup>st</sup> Toe)	17 N, 3 I
Vibration (Heel)	20 N, 0 I
Monofilament (1 <sup>st</sup> Toe)	18 N, 2 I
Monofilament (Heel)	17 N, 3 I
Achilles Reflex	17 N, 3 A
<b>Right</b>	
Proprioception (1 <sup>st</sup> Toe)	20 N, 0 I
Proprioception (Heel)	20 N, 0 I
Vibration (1 <sup>st</sup> Toe)	17 N, 3 I
Vibration (Heel)	20 N, 0 I
Monofilament (1 <sup>st</sup> Toe)	18 N, 2 I
Monofilament (Heel)	17 N, 2 I
Achilles Reflex	17 N, 3 A

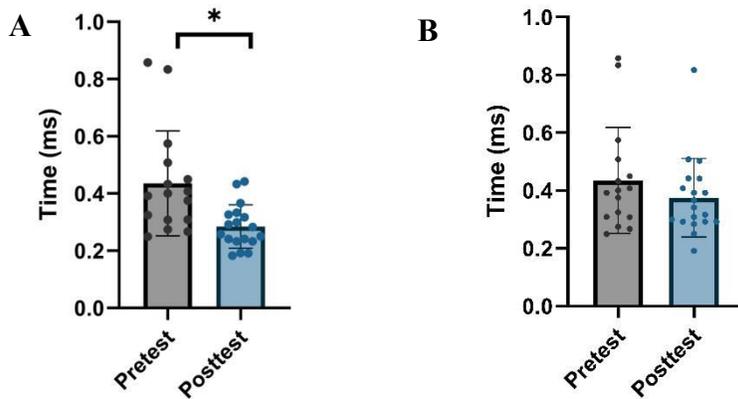
PASE: physical activity scale for the elderly, ABC: activities-specific balance confidence scale, BAI: Beck anxiety inventory, TUG<sub>Cog</sub>: percent change in the timed up and go test with and without a cognitive task, FSST: four-square step test, N: normal, I: impaired, A: absent.

A significant increase was found in grasp accuracy of the trained arm ( $Z = -2.714$ ,  $p = 0.007$ ), and this increase in grasp accuracy transferred to the untrained arm ( $Z = -2.646$ ,  $p = 0.008$ ) (Figure 9).



**Figure 9.** Violin plot illustrating the change in grasp accuracy of the trained (A) and untrained (B) arms where 0 represents a grasp error and 1 represents an accurate grasp.

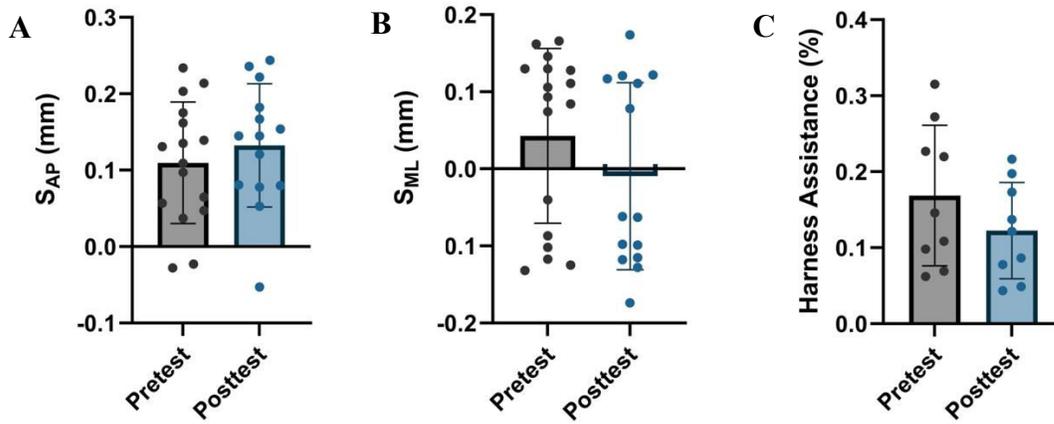
Grasp time also significantly decreased in the trained arm ( $Z = -2.613$ ,  $p = 0.009$ ), but this decrease did not transfer to the untrained arm ( $Z = -0.879$ ,  $p = 0.379$ ) (Figure 10).



**Figure 10.** Change in grasp time of the trained (A) and untrained (B) arm.

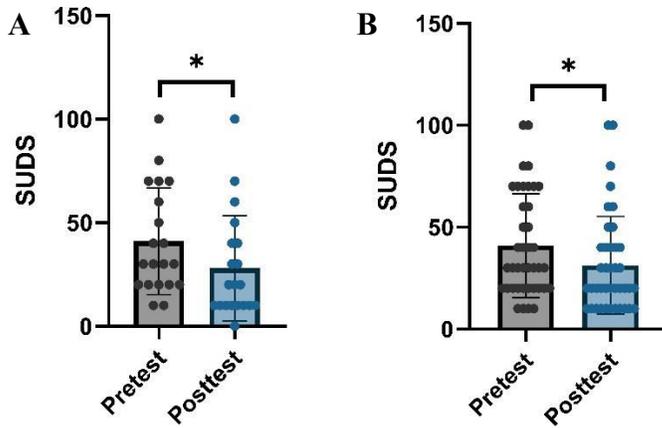
Regarding generalization of reach to grasp training to the stepping response, posttest  $S_{AP}$  and  $S_{ML}$  at FFTD in the absence of a handrail was compared to pretest  $S_{AP}$  and  $S_{ML}$  at FFTD during the slip with a cognitive task and handrail. No significant change was found in  $S_{AP}$  ( $Z = -1.293$ ,  $p = 0.196$ ) or  $S_{ML}$  ( $Z = -0.910$ ,  $p = 0.363$ ) at FFTD, or in

percent harness assist ( $Z = -1.362, p = 0.173$ ). Changes in  $S_{AP}$  and  $S_{ML}$  at FFTD are presented in Figure 11.

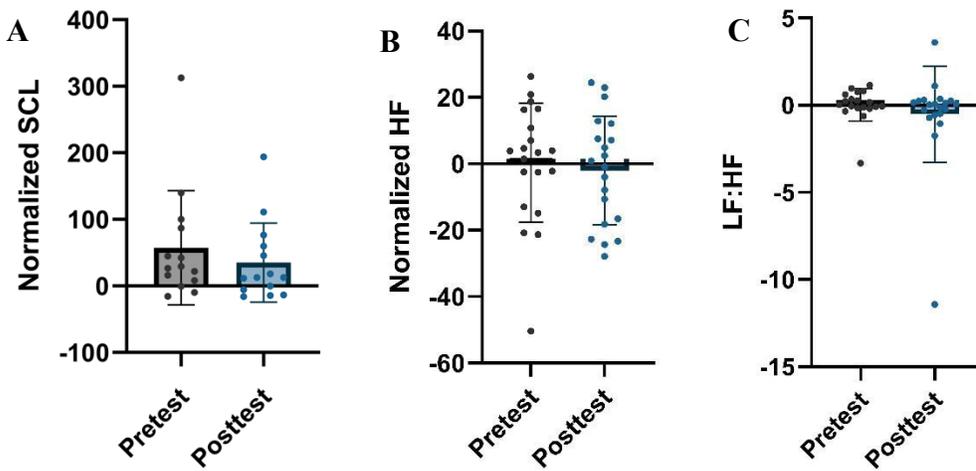


**Figure 11.** Change in  $S_{AP}$  (A) and  $S_{ML}$  (B) at FFTD and percent harness assistance (C) from pretest to posttest.

No significant correlations were found between pre-training ABC scores ( $\rho = -0.375, p = 0.125$ ) with the change in reach to grasp time from pre- to post-training. Posttest SUDS scores significantly decreased during the reach to grasp response with the trained arm ( $Z = -2.000, p = 0.046$ ). Posttest SUDS scores with the untrained arm also significantly decreased ( $Z = -2.025, p = 0.043$ ) compared to pretest SUDS scores with the trained arm. These changes in SUDS are illustrated in Figure 12. There were no significant changes in any of the psychophysiological measures of state anxiety: SCL ( $Z = -1.136, p = 0.256$ ), HF power ( $Z = -0.597, p = 0.550$ ), and LF/HF ratio ( $Z = -0.483, p = 0.629$ ) (Figure 13). Changes in all outcomes are summarized in Table 6.



**Figure 12.** Change in SUDS scores during reach to grasp of the trained arm (A) and untrained arm (B).



**Figure 13.** Change in SCL (A), HF power (B), and LF/HF ratio (C) from pretest to posttest.

**Table 6.** Change in outcome measures from pretest to posttest

	<b>Pretest</b>	<b>Posttest</b>	<b>Z</b>	<b>p-value</b>
<b>Grasp Accuracy (Trained Arm (%))</b>	25	90	-2.714	0.007
<b>Grasp Time (Trained Arm (s))</b>	0.435 ± 0.18	0.284 ± 0.07	-2.613	0.009
<b>Grasp Accuracy (Untrained Arm (%))</b>	25	80	-2.646	0.008
<b>Grasp Time (Untrained Arm (s))</b>	0.435 ± 0.18	0.376 ± 0.14	-0.879	0.379
<b>SUDS (Trained Arm)</b>	41.43 ± 25.16	33.0 ± 30.97	-2.000	0.046
<b>SUDS (Untrained Arm)</b>	41.43 ± 25.16	33.0 ± 23.64	-2.025	0.043
<b>SCL (%)</b>	57.40 ± 82.55	39.45 ± 59.54	-1.136	0.256
<b>HF Power (%)</b>	0.33 ± 17.90	-2.03 ± 16.42	-0.597	0.550
<b>LF/HF Ratio</b>	0.02 ± 0.94	-0.54 ± 2.77	-0.483	0.629
<b>Harness Support (%BW)</b>	0.17 ± 0.09	0.12 ± 0.06	-1.362	0.173
<b>S<sub>AP</sub> at FFTD</b>	0.11 ± 0.08	0.13 ± 0.08	-1.293	0.196
<b>S<sub>ML</sub> at FFTD</b>	0.04 ± 0.11	0.01 ± 0.12	-0.910	0.363

SUDS: subjective units of distress, SCL: skin conductance level, HF: high frequency, LF: low frequency, %BW: percent body weight, S<sub>AP</sub>: stability in the anteroposterior direction, S<sub>ML</sub>: stability in the mediolateral direction, FFTD: first foot touchdown.

## DISCUSSION

The purpose of this study was to determine whether a perturbation-based reach to grasp training intervention improves the reach to grasp response of the trained arm and whether improvements transfer to the untrained arm. Generalization of reach to grasp training to the stepping response in the absence of a handrail and the relationship between pre-intervention ABC and change in grasp time from pre- to post-intervention were also investigated. Overall, our results reveal that the accuracy and speed of the reach to grasp response can be trained and that improved grasp accuracy, but not grasp time, transfers to the untrained arm. We also showed that training the grasp response does not generalize to the stepping response in the absence of a handrail. Additionally, we found that our intervention reduced subjective, but not psychophysiological, state anxiety. Balance

confidence pre-training and the change in SUDS from pre- to post-training did not significantly correlate with the change in reach to grasp time from pre- to post-training.

Our finding of improved grasp accuracy and grasp time in the trained arm is consistent with previous research in lower limb motor learning during reactive balance responses. Studies investigating training paradigms of single and mixed stance and walking slip and trip perturbations found improved lower limb and trunk responses.<sup>76,146–150</sup> Our findings are also consistent with one other study that investigated the effects of grasp training on grasp response.<sup>76</sup> This previous study by Mansfield and colleagues only found improvement in grasp accuracy, whereas this study resulted in improved grasp accuracy and grasp time of the trained arm. This study also adds to the literature by investigating whether training one arm transfers to the other arm. Differences between this intervention and the previous reach to grasp study intervention include type of perturbations, immobilization of the feet, and intervention dosage. Perhaps the most important difference between interventions was our use of a cognitive-motor dual task paradigm during training and testing. This is especially important for a reaching response due to the crucial role of working memory in the attention switching and visuospatial aspects of grasp. A successful reach to grasp response following a sudden unpredictable balance perturbation requires rapid reallocation of attention from the cognitive task to the salient visuospatial information.<sup>17,119,151</sup> The observed improvements in grasp accuracy and time may have occurred as a result of strengthening of the neural pathways responsible for attention switching as well as those responsible for the planning and execution of a reach to grasp motion.<sup>152,153</sup>

Attention in the brain is an ongoing competition between incoming sensory input where top-down sensitivity control increases or decreases the neural representation of certain information which increases or decreases its probability of access to the working memory.<sup>151</sup> Working memory then makes the decision on which input is given greater attention. However, in the case of sudden unexpected salient stimuli (such as a sudden unpredictable external perturbation) the sensitivity of sensory input can be modulated by the salient stimuli, allowing them quick access to working memory and attentional priority.<sup>151</sup> Our findings suggest that dual task cognitive and reach to grasp reactive balance training may improve the reach to grasp response by enhancing the capacity of neural networks to improve attention switching and emotional regulation of attention during a reaching response.

It is unclear in this study whether improvements in grasp time (time from perturbation onset to handrail contact) were the result of improvements in the initiation or execution of grasp due to the difficulty of determining grasp movement onset when the arm is already in motion (arm swing during walking). However, we believe that the improvement was in the execution of the grasp. This is based on a previous investigation of the reach to grasp response, which found improvements in the movement time of grasp, but not in biceps muscle onset time.<sup>76</sup> Additionally, a study comparing the reach to grasp response in older adult fallers and non-fallers found significant differences in movement time of the wrist, but not in anterior and middle deltoid muscle onset times.<sup>14</sup>

The finding of improved grasp accuracy in the untrained arm provides evidence that some benefits of perturbation-based reach to grasp training of one arm can be transferred to the other arm. This is consistent with previous studies investigating

interlimb transfer during simple tasks in the upper limbs<sup>154,155</sup> and during repeated reactive balance perturbations in the lower limbs.<sup>156,157</sup> However, not all aspects of reach to grasp training (i.e., grasp timing) transferred to the untrained arm. It is possible that during a novel condition such as a reach to grasp response of the untrained arm, accuracy is given priority over speed (i.e., faster responses are less accurate and slower responses are more accurate).<sup>158</sup>

Contrary to our hypotheses, stability at FFTD and in-task falls did not significantly increase when the handrail was removed, indicating that the reach to grasp training did not generalize to the stepping response. However, stability at FFTD and in-task falls did not significantly decrease either, which indicates that reach to grasp training does not negatively impact the stepping response in the absence of a handrail. It is possible that backward acceleration of COM velocity during the slip perturbations<sup>159</sup> decreased with training or that participants shifted their COM forward in anticipation of a slip,<sup>160</sup> thereby reducing the need to increase stability. Both of these COM strategies have been documented in previous studies investigating COM changes in response to repeated slip perturbations.<sup>159,160</sup>

Also contrary to our hypotheses, ABC scores pre-training did not significantly correlate with the change in reach to grasp time from pre- to post-training. Our study sample included participants with relatively high balance confidence. This limited our ability to examine the relationship between pre-training ABC scores and the change in grasp time as older adults with lower balance confidence may have responded differently to the reach to grasp intervention. We would expect that older adults with lower balance confidence at the start of the intervention would produce a smaller change in reach to

grasp time due to difficulty in coping with the emotional perturbations associated with the physical perturbations.

Although psychophysiological state anxiety did not decrease from pre- to post-intervention, subjective state anxiety did significantly decrease. However, there was a high level of variability in the pretest and posttest SUDS scores which leads to difficulty in the reliable interpretation of this result. The discrepancy between the results of subjective and physiological state anxiety measures may have been due to the documented disparities between perceived and physiological fall risk.<sup>161,162</sup>

The lack of change in psychophysiological state anxiety may have been due to the role of threat and state anxiety in the allocation of attention. Increased perceived threat results in greater attention being directed towards movement and threat-related stimuli (i.e., the balance response) and less attention directed towards task-irrelevant information (i.e., tasks unrelated to the movement).<sup>163</sup> A study using pain-induced threat found that higher trait anxiety was associated with a slower response rate whereas higher state anxiety was associated with a faster response rate.<sup>164</sup> Therefore, a certain amount of state anxiety may be beneficial to reactive balance by facilitating the rapid allocation of attention necessary for a successful reach to grasp response. However, excessive or chronic levels of anxiety such as those exhibited in people with trait anxiety may result in reduced efficiency of the reach to grasp response. This is supported by research in various anxiety disorders wherein structures of the salient network such as the amygdala and anterior insula become overactive.<sup>165,166</sup> This in turn leads to a decrease in the excitability threshold of the salient network and upregulation of non-threatening stimuli and exaggerated stress responses.<sup>167,168</sup>

The lack of reduction in psychophysiological state anxiety may have also contributed to the lack of change in stability at FFTD. Several studies have documented the presence of a stiffening strategy of the COM in the presence of a perceived threat.<sup>20,84,85,163,169,170</sup> Exposure to a height-induced threat during static standing results in a stiffening strategy characterized by increased co-contraction of the tibialis anterior and soleus muscles, decreased COM sway amplitude, increased COM sway frequency, increased autonomic activity, increased FOF, and decreased balance confidence.<sup>84,167,168,171–173</sup> This stiffening strategy becomes more prominent with age and the addition of a cognitive task.<sup>167,168</sup>

## **Limitations**

It is possible that a portion of the state anxiety levels recorded by SCL and PRV resulted from performance anxiety during the cognitive task. Participants in this study expressed some anxiety in relation to their responses to the cognitive task. However, state anxiety levels in this study were confirmed by the SUDS scores, where participants were instructed to indicate their perceived levels of distress specifically during balance perturbations. In addition, there were a few participants for whom COM could not be calculated, which may have contributed to the lack of significant change in stability at FFTD in our sample. We also did not compare responses during left foot vs right foot perturbations; however, this limitation will be addressed in subsequent analyses investigating the mechanisms contributing to the improvements observed in this study. Finally, our study sample was skewed in terms of balance confidence towards a higher balance confidence sample, which limited our ability to examine the influence of low

balance confidence on the responsiveness of older adults to the reach to grasp intervention.

## **CONCLUSION**

In summary, a three-week unpredictable perturbation-based reach to grasp training intervention resulted in improved grasp accuracy and reduced grasp time in the trained arm, but only the improved grasp accuracy transferred to the untrained arm. The reach to grasp training did not generalize to the stepping response in the absence of a handrail and there was no significant correlation between pre-training ABC and the change in grasp time from pre- to post-perturbation. Subjective, but not psychophysiological, state anxiety decreased following the reach to grasp intervention. Overall, perturbation-based reach to grasp training appears to be a promising intervention for improving reactive balance and preventing falls in older adults. However, the role of balance confidence and fall-related anxiety in the responsiveness to a reach to grasp training intervention remains unclear. The next step in this research would be to further investigate the mechanisms contributing to improved reach to grasp with training. Future studies could also investigate the effects of a reach to grasp training intervention on balance recovery and stability in real-world indoor and outdoor settings.

## **CHAPTER FIVE: DISCUSSION AND SUMMARY OF FINDINGS**

### **MAJOR FINDINGS AND DISCUSSION**

The purpose of this dissertation was to investigate the relationship of the falls efficacy scale-international (FES-I) and activities-specific balance (ABC) scale with fall-related state anxiety and to explore the efficacy of a dual task reach to grasp training intervention in older adults. Chapter one began with a brief introduction highlighting the importance of the upper limbs during reactive balance responses and how state anxiety in the moment of a balance perturbation and trait anxiety in the form of fear of falling (FOF) may affect reach to grasp reactive responses. Furthermore, we explain the importance of clinical identification of fall-related state anxiety and how these measures contribute to investigations of the mechanisms by which fall-related state anxiety influences reactive balance responses. Chapter two systematically summarized the literature regarding age-related differences in the role of the upper limbs during reactive balance responses. We established that, compared to young adults, older adults used the reach to grasp responses more frequently, but with greater delays and reduced grasp accuracy. Furthermore, the addition of a cognitive task resulted in greater detrimental effects on the reach to grasp response. These results gave rise to the specific aims of this dissertation. Specific Aim 1 (chapter three) investigated the construct validity of the Falls Efficacy Scale-International (FES-I) and the Activities-Specific Balance (ABC) scale for the measurement of fall-related state anxiety during unpredictable balance perturbations in older adults. We hypothesized that the FES-I and ABC would significantly correlate with a validated measure of physiological fall-related state anxiety (skin conductance levels (SCLs)) during unpredictable balance perturbations in older adults. Specific Aim 2 (chapter four)

examined the effects of a three week perturbation-based dual task cognitive-motor reach to grasp reactive balance training intervention in older adults on 1) the reach to grasp response of the trained arm and whether this training transferred to the untrained arm, 2) generalization of reach to grasp training to stability of the stepping response (stability at first foot touch down (FFTD)) in the absence of a handrail, and 3) the relationship between pre-intervention ABC and the change in grasp time from pre- to post-intervention. We hypothesized that the reach to grasp training intervention would result in 1) improvement of the reach to grasp response (i.e., increased grasp accuracy and reduced grasp time) of the trained arm which would also transfer to the untrained arm, 2) generalization of improvements to the stepping response resulting in increased stability at FFTD in the absence of a handrail, and 3) positive correlations between pre-training ABC scores and the change in reach to grasp time from pre- to post-training.

Given the difficulties of examining the effects of FOF and state anxiety on reactive balance responses, we began our investigation by exploring the validity of widely used clinical measures of fall-related psychological constructs (falls efficacy assessed by the FES-I and balance confidence assessed by the ABC) as indicators of perturbation-induced state anxiety. We also investigated whether fall-related state anxiety (assessed using SUDS) differed between older adults with high vs low concern about falls. In chapter three, we determined that both the FES-I and ABC significantly correlated with SCL during unpredictable balance perturbations. We also found significant group differences in SUDS scores between older adults with high and low concerns for falling. This relationship between FES-I and ABC with fall-related state anxiety is likely due to the situation-specific nature of the items in these scales. Although

the FES-I and ABC inquire about falls efficacy and balance confidence in general, the individual items themselves relate to these constructs in the context of a specific task. During the development of the FES-I and ABC, the individual items were chosen by asking clinicians to name the most important activities for daily living for the development of the FES-I, with an additional question about which normal daily activities induce a fear of falling for the development of the ABC. Such questions are essentially asking which activities induce a state-fear response; therefore, it was not surprising that the observed correlations with fall-related state anxiety were significant.

Next, we explored the efficacy of a three-week perturbation-based dual task reach to grasp training intervention on the reach to grasp balance response, whether this intervention results in interlimb transfer or generalizes to the stepping response, and the relationship of pre-training ABC scores with responsiveness to the intervention in older adults. We found improved grasp accuracy and reduced grasp time in the trained arm; however, only improved grasp accuracy transferred to the untrained arm. Improvements did not generalize to the stepping response as there was no change in stability at FFTD or harness assistance when the handrail was removed. No significant correlations were found between pre-training ABC scores and the change in reach to grasp time from pre- to post-training. There was also a significant change in SUDS scores from pre- to post-training.

We found, in common between our aims, the presence of perturbation-induced state anxiety in the form of increased SCL from pre- to post-perturbation. During our intervention, this state anxiety likely affected the reactive reach to grasp response by interfering with the rapid switching of attention from the continuous cognitive task to the

reach to grasp response. The prefrontal cortex (PFC) acts as the executive controller for working memory, which is essential for the rapid reallocation of attention necessary to produce a quick and accurate grasp. A possible mechanism behind any observed increase in speed of attention switching is that training the reach to grasp task may have resulted in this movement becoming more automatic, thereby reducing the load on the PFC and improving the efficiency of working memory.

Anxiety is also associated with increased activity in the default mode network,<sup>165</sup> which works reciprocally with the PFC and salience network to control attention.<sup>151,165,166</sup> Additionally, anxiety is associated with reduced activity of the dorsolateral PFC and slower reaction times,<sup>22</sup> as well as increased activity of brain regions within the salient network. It is possible that anxiety causes a decrease in the excitability threshold of the salient network, leading to overactivity of the salient network and hindering its ability to identify and reallocate attention to true threats. Unfortunately, our sample included older adults with relatively high balance confidence on the ABC which hindered our ability to examine the effects of low balance confidence on the reach to grasp response in older adults.

We found, in common with previous studies,<sup>174-176</sup> that upper limb task accuracy training of one limb can transfer to the other limb; however, upper limb task timing did not transfer. Previous studies have found that muscle strength was associated with reduced reaction time in older adults.<sup>177,178</sup> Compared to the non-dominant arm, the dominant arm often has significantly reduced muscle strength and longer reaction time.<sup>179-181</sup> In addition, muscles of the dominant hand show long term adaptations in muscle fiber composition including lower motor unit average firing rates and lower

recruitment thresholds, indicating a possible increased percentage of slow twitch fibers and allowing greater force production to occur at lower firing rates.<sup>182</sup> These differences between the dominant and non-dominant arm may indicate that skills related to timing may not be transferrable, or that they require more intense training to produce results.

There was no significant correlation between pre-training ABC scores and changes in reach-to-grasp time from pre- to post-training. As our study sample primarily consisted of participants with relatively high balance confidence, we were unable to properly explore the relationship between initial ABC scores and responsiveness to the reach to grasp intervention.

We observed a lack of intervention-induced changes in stability at FFTD in the absence of a handrail which may have been due to the persistence of a stiffening strategy. Previous studies have observed stiffening strategies in older adults when exposed to greater postural threats.<sup>39,85</sup> A commonly suggested explanation for the stiffening strategy in older adults in FOF. Stiffening responses have been observed when state anxiety is induced in young adults without FOF,<sup>20,98,163,169,170,183</sup> indicating that stiffening may occur as a result of state anxiety. Whether or not a stiffening strategy is beneficial or detrimental to reactive balance may depend on the overall demands during the reactive response (i.e., postural, cognitive, and emotional demands). As the demands of a reactive balance response increase, stiffening becomes less beneficial.

Several theoretical frameworks of anxiety have proposed that anxiety can affect motor tasks. Three of those theories align closely with the results of this dissertation. The constrained action hypothesis, reinvestment theory, and dual-process theory all posit that anxiety-inducing situations lead to decreased fluidity and precision of motor control.<sup>184-</sup>

<sup>186</sup> Anxiety causes a shift from automatic (implicit) control to controlled (explicit) control (i.e., reinvestment of cognitive resources to control movements that are usually automatic). This leads to slower, less efficient, and error prone motor responses during tasks that require quick, fluid, and precise movements such as a reach to grasp response. By addressing the anxiety component involved in reactive balance, this dissertation shows that the effects of anxiety on speed, efficiency, and errors on motor control can be improved with training.

### **Limitations**

This dissertation had several limitations that should be considered when interpreting the results. First, both chapters included small sample sizes which may limit the generalizability of our results. Chapter three in particular would benefit from a larger sample size to better evaluate the FES-I and ABC's ability to distinguish fall-related anxiety during reactive balance tasks. Second, laboratory temperature was not recorded, which could influence sweat levels; however, normalizing SCL changes to quiet sitting within the session likely helped reduce temperature-related variability. Third, some recorded state anxiety in chapter four may reflect performance anxiety related to the cognitive task. We controlled for this by using SUDS scores to confirm participants' distress was specifically related to balance perturbations. Fourth, we were unable to calculate COM for a few participants, which may have contributed to the lack of significant change in stability at FFTD. Fifth, we did not account for potential asymmetry in responses depending on which foot is perturbed. This will be addressed via subsequent in-depth analyses of right vs. left foot perturbations. Lastly, the study sample in chapter four had a relatively high balance confidence, restricting our ability to examine how

balance confidence may influence older adults' responses to the reach to grasp intervention.

### **Clinical Implications**

The results described in this dissertation have many applications in the clinical setting. The ability to clinically recognize patients who may have a tendency to experience fall-related state anxiety using the FES-I and ABC can help clinicians identify the influence of fall-related state anxiety on balance responses and employ more targeted rehabilitation strategies. The perturbation-based dual task reach to grasp training intervention employed in chapter four produced promising results. Similar interventions may be used clinically to improve reach to grasp reactive balance responses and prevent falls in older adults. Given the prevalence of indoor falls among older adults, where handholds are often available, a dual task reach to grasp training intervention would be beneficial.

The following are a set of recommendations for the implementation of a perturbation-based dual-task reach to grasp training intervention. Based on the data presented in this dissertation, participants selected for this type of training should have moderate to high balance confidence as assessed using the ABC. The intervention may still be effective for people with lower balance confidence, but the current dissertation was unable to determine this properly. Patients who would benefit from this training include individuals with mild to moderate balance impairments who can safely engage in reactive balance perturbations. Surface translation perturbations in particular can exacerbate existing back and knee pain. Therefore, the presence of these conditions

would be a contraindication for this intervention. This intervention would also be contraindicated for patients prone to dizziness.

Regarding the training environment, this type of intervention should only be implemented in a safe, controlled environment with proper safety measures in place such as a safety harness. Regarding intervention dosage, a frequency of 2 sessions per week, session duration of 30-45 minutes, and an overall intervention duration of at least 3 weeks is recommended to allow for skill acquisition in the trained arm. The cognitive task included should mimic the complexity of everyday cognitive dual tasks without being overly complex.

This dissertation provides valuable insights into the role of fall-related anxiety and reactive balance responses in older adults, which can advance our understanding in multiple ways. First, it validates the use of the FES-I and ABC scales to reflect heightened state anxiety during unpredictable balance challenges in older adults. This offers clinicians a reliable tool for assessing the impact of anxiety on balance control. Additionally, this dissertation evaluates the effectiveness of a novel dual task reach to grasp intervention and emphasizes the complexity of training transfer and generalization. Our findings of no transfer or generalization indicate that either targeted interventions or more prolonged training may be necessary to enhance specific reactive responses in older adults.

## **FUTURE DIRECTIONS**

This dissertation highlights the potential of a perturbation-based dual task reach to grasp response training intervention to improve grasp timing and accuracy, yet several aspects related to this work remain to be explored. Further research is needed to better

elucidate the relationship between fall related state anxiety and established clinical measures of fall-related psychological concerns such as the FES-I and ABC scale. Future studies could utilize these measures to assess state anxiety in situations involving unpredictable balance perturbations. Using these scales in this context will enable researchers to more accurately explore the effects of FOF on reactive balance responses.

The influence of balance confidence on responsiveness of older adults to the dual task reach to grasp training intervention requires further study. Understanding the psychological factors involved in reactive balance responses could help tailor interventions to maximize their effectiveness for older adults with various levels of balance confidence.

Future studies should also investigate the underlying mechanisms that led to improvements in the reach to grasp response with training, as well as why not all improvements transferred to the untrained arm or generalized to the stepping response. Investigating how specific aspects of motor control and neuroplasticity contribute to these improvements could offer insights into optimizing training protocols. Additionally, assessing the impact of reach-to-grasp training on reactive responses and stability in real-world settings – both indoors and outdoors – would provide valuable information on the practical applications of such interventions.

The effectiveness of the reach to grasp training intervention also has promising applications in populations with diminished sensory input such as people with peripheral neuropathy. Peripheral sensation is essential for recognizing that a destabilizing event has occurred and for proper triggering and scaling of reactive balance responses. Reduced peripheral sensation results in delayed balance responses and increased fall risk. While

some mechanisms of peripheral sensory loss can be reversible, some are not. For these populations, encouraging the use of the reach to grasp response may be beneficial as a compensatory arm response to offset for loss of sensation in the legs.

## COMPREHENSIVE LIST OF REFERENCES

1. CDC WISQARS: Web-based Injury Statistics Query and Reporting System. <https://wisqars.cdc.gov/infographics/>
2. Asai T, Oshima K, Fukumoto Y, Yonezawa Y, Matsuo A, Misu S. The association between fear of falling and occurrence of falls: a one-year cohort study. *BMC Geriatr.* 2022;22(393). doi:10.1186/s12877-022-03018-2
3. Scheffer AC, Schuurmans MJ, Van dijk N, Van der hooff T, De rooij SE. Fear of falling: Measurement strategy, prevalence, risk factors and consequences among older persons. *Age Ageing.* 2008;37(1):19-24. doi:10.1093/ageing/afm169
4. Tinetti ME, Powell L. Fear of falling and low self-efficacy: a case of dependence in elderly persons. *J Gerontol.* 1993;48 Spec No(SPEC. ISS.):35-38. doi:10.1093/GERONJ/48.SPECIAL\_ISSUE.35
5. Lee S. Falls associated with indoor and outdoor environmental hazards among community-dwelling older adults between men and women. *BMC Geriatr.* 2021;21(1). doi:10.1186/S12877-021-02499-X
6. Duckham RL, Procter-Gray E, Hannan MT, Leveille SG, Lipsitz LA, Li W. Sex differences in circumstances and consequences of outdoor and indoor falls in older adults in the MOBILIZE Boston cohort study. *BMC Geriatr.* 2013;13(1). doi:10.1186/1471-2318-13-133
7. Timsina LR, Willetts JL, Brennan MJ, et al. Circumstances of fall-related injuries by age and gender among community-dwelling adults in the United States. *PLoS ONE.* 2017;12(5). doi:10.1371/journal.pone.0176561
8. Maki BE. Postural Strategies. *Encycl Neurosci.* Published online 2009:3222-3227. doi:10.1007/978-3-540-29678-2\_4714
9. Alissa N, Akinlosotu RY, Shipper A, Westlake KP. A systematic review of upper extremity responses during reactive balance perturbations in aging. *Gait Posture.* 2020;82:138-146. doi:10.1016/j.gaitpost.2020.08.134
10. Cheng KC, Pratt J, Maki BE. Do aging and dual-tasking impair the capacity to store and retrieve visuospatial information needed to guide perturbation-evoked reach-to-grasp reactions? *PLoS ONE.* 2013;8(11). doi:10.1371/journal.pone.0079401
11. Cheng KC, Pratt J, Maki BE. Effects of spatial-memory decay and dual-task interference on perturbation-evoked reach-to-grasp reactions in the absence of online visual feedback. *Hum Mov Sci.* 2013;32(2):328-342. doi:10.1016/j.humov.2012.11.001

12. Akinlosotu RY, Alissa N, Waldstein SR, Creath RA, Wittenberg GF, Westlake KP. Examining the influence of mental stress on balance perturbation responses in older adults. *Exp Gerontol.* 2021;153. doi:10.1016/j.exger.2021.111495
13. Laing JM, Tokuno CD. The effects of dual-tasking on arm muscle responses in young and older adults. *Hum Mov Sci.* 2016;46:159-166. doi:10.1016/j.humov.2016.01.003
14. Westlake KP, Johnson BP, Creath RA, Neff RM, Rogers MW. Influence of non-spatial working memory demands on reach-grasp responses to loss of balance: Effects of age and fall risk. *Gait Posture.* 2016;45:51-55. doi:10.1016/j.gaitpost.2016.01.007
15. Ghafouri M, McIlroy WE, Maki BE. Initiation of rapid reach-and-grasp balance reactions: Is a pre-formed visuospatial map used in controlling the initial arm trajectory? *Exp Brain Res.* 2004;155(4):532-536. doi:10.1007/s00221-004-1855-8
16. Maki BE, McIlroy WE. Cognitive demands and cortical control of human balance-recovery reactions. *J Neural Transm.* 2007;114(10):1279-1296. doi:10.1007/S00702-007-0764-Y/METRICS
17. Akram SB, Miyasike-Dasilva V, Van Ooteghem K, McIlroy WE. Role of peripheral vision in rapid perturbation-evoked reach-to-grasp reactions. *Exp Brain Res.* 2013;229(4):609-619. doi:10.1007/S00221-013-3624-Z/FIGURES/5
18. Davis JR, Campbell AD, Adkin AL, Carpenter MG. The relationship between fear of falling and human postural control. *Gait Posture.* 2009;29(2):275-279. doi:10.1016/j.gaitpost.2008.09.006
19. Adkin AL, Frank JS, Carpenter MG, Peysar GW. Fear of falling modifies anticipatory postural control. *Exp Brain Res.* 2002;143(2):160-170. doi:10.1007/s00221-001-0974-8
20. Young WR, Mark Williams A. How fear of falling can increase fall-risk in older adults: Applying psychological theory to practical observations. *Gait Posture.* 2015;41(1):7-12. doi:10.1016/j.gaitpost.2014.09.006
21. Xu J, Van Dam NT, Feng C, et al. Anxious brain networks: A coordinate-based activation likelihood estimation meta-analysis of resting-state functional connectivity studies in anxiety. *Neurosci Biobehav Rev.* 2019;96:21-30. doi:10.1016/J.NEUBIOREV.2018.11.005
22. Forster S, Nunez Elizalde AO, Castle E, Bishop SJ. Unraveling the Anxious Mind: Anxiety, Worry, and Frontal Engagement in Sustained Attention Versus Off-Task Processing. Published online 2013. doi:10.1093/cercor/bht248

23. Akinlosotu RY, Alissa N, Sorkin JD, Wittenberg GF, Westlake KP. Age-related differences in arm and trunk responses to first and repeated exposure to laterally induced imbalances. *Brain Sci.* 2020;10(9):1-14. doi:10.3390/brainsci10090574
24. Yardley L, Beyer N, Hauer K, Kempen G, Piot-Ziegler C, Todd C. Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age Ageing.* 2005;34(6):614-619. doi:10.1093/ageing/afi196
25. Powell LE, Myers AM. The Activities-Specific Balance Confidence (ABC) scale. *J Gerontol - Ser Biol Sci Med Sci.* 1995;50A(1):M28-M34. doi:10.1093/gerona/50A.1.M28
26. Tanner BA. Validity of global physical and emotional SUDS. *Appl Psychophysiol Biofeedback.* 2012;37(1):31-34. doi:10.1007/s10484-011-9174-x
27. Yardley L, Smith H. A prospective study of the relationship between feared consequences of falling and avoidance of activity in community-living older people. *The Gerontologist.* 2002;42(1):17-23. doi:10.1093/GERONT/42.1.17
28. Zijlstra GAR, Van Haastregt JCM, Ambergen T, et al. Effects of a multicomponent cognitive behavioral group intervention on fear of falling and activity avoidance in community-dwelling older adults: Results of a randomized controlled trial. *J Am Geriatr Soc.* 2009;57(11):2020-2028. doi:10.1111/J.1532-5415.2009.02489.X
29. Kim HG, Cheon EJ, Bai DS, Lee YH, Koo BH. Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature. *Psychiatry Investig.* 2018;15(3):235-245. doi:10.30773/pi.2017.08.17
30. Sugimine S, Saito S, Takazawa T. Normalized skin conductance level could differentiate physical pain stimuli from other sympathetic stimuli. *Sci Rep 2020 101.* 2020;10(1):1-12. doi:10.1038/s41598-020-67936-0
31. Greaves MD, Felmingham KL, Ney LJ, et al. Using electrodermal activity to estimate fear learning differences in anxiety: A multiverse analysis. *Behav Res Ther.* 2024;181:104598. doi:10.1016/J.BRAT.2024.104598
32. Older Adult Falls - Important Facts about Falls, Home and Recreational Safety, CDC.
33. Ambrose AF, Paul G, Hausdorff JM. Risk factors for falls among older adults: A review of the literature. *Maturitas.* 2013;75(1):51-61. doi:10.1016/j.maturitas.2013.02.009
34. Kamitani T, Yamamoto Y, Kurita N, et al. Longitudinal Association Between Subjective Fatigue and Future Falls in Community-Dwelling Older Adults: The Locomotive Syndrome and Health Outcomes in the Aizu Cohort Study (LOHAS). *J Aging Health.* 2019;31(1):67-84. doi:10.1177/0898264317721825

35. Romero-Ortuno R, Cogan L, Foran T, Kenny RA, Fan CW. Continuous noninvasive orthostatic blood pressure measurements and their relationship with orthostatic intolerance, falls, and frailty in older people. *J Am Geriatr Soc.* 2011;59(4):655-665. doi:10.1111/j.1532-5415.2011.03352.x
36. Menant JC, Steele JR, Menz HB, Munro BJ, Lord SR. Effects of footwear features on balance and stepping in older people. *Gerontology.* 2008;54(1):18-23. doi:10.1159/000115850
37. Ferber R, Osternig LR, Woollacott MH, Wasielewski NJ, Lee JH. Reactive balance adjustments to unexpected perturbations during human walking. *Gait Posture.* 2002;16(3):238-248. doi:10.1016/S0966-6362(02)00010-3
38. Maki BE, McIlroy WE, Perry SD. Influence of lateral destabilization on compensatory stepping responses. *J Biomech.* 1996;29(3):343-353. doi:10.1016/0021-9290(95)00053-4
39. Allum JHJ, Carpenter MG, Honegger F, Adkin AL, Bloem BR. Age-dependent variations in the directional sensitivity of balance corrections and compensatory arm movements in man. *J Physiol.* 2002;542(Pt 2):643-663.
40. DeGoede KM, Ashton-Miller JA. Biomechanical simulations of forward fall arrests: Effects of upper extremity arrest strategy, gender and aging-related declines in muscle strength. *J Biomech.* 2003;36(3):413-420. doi:10.1016/S0021-9290(02)00396-2
41. Hsiao ET, Robinovitch SN. Common protective movements govern unexpected falls from standing height. *J Biomech.* 1997;31(1):1-9. doi:10.1016/S0021-9290(97)00114-0
42. Talbot LA, Musiol RJ, Witham EK, Metter EJ. Falls in young, middle-aged and older community dwelling adults: perceived cause, environmental factors and injury. *BMC Public Health.* 2005;5:86. doi:10.1186/1471-2458-5-86
43. Schonnop R, Yang Y, Feldman F, Robinson E, Loughin M, Robinovitch SN. Prevalence of and factors associated with head impact during falls in older adults in long-term care. *CMAJ Can Med Assoc J J Assoc Medicale Can.* 2013;185(17):E803-10. doi:10.1503/cmaj.130498
44. Dietz V, Fouad K, Bastiaanse CM. Neuronal coordination of arm and leg movements during human locomotion. *Eur J Neurosci.* 2001;14(11):1906-1914. doi:10.1046/j.0953-816X.2001.01813.x
45. McIlroy WE, Maki BE. Early activation of arm muscles follows external perturbation of upright stance. *Neurosci Lett.* 1995;184(3):177-180. doi:10.1016/0304-3940(94)11200-3

46. Marigold DS, Bethune AJ, Patla AE. Role of the Unperturbed Limb and Arms in the Reactive Recovery Response to an Unexpected Slip During Locomotion. *J Neurophysiol.* 2003;89(4).
47. Pijnappels M, Kingma I, Wezenberg D, Reurink G, van Dieën JH. Armed against falls: the contribution of arm movements to balance recovery after tripping. *Exp Brain Res.* 2010;201(4):689-699. doi:10.1007/s00221-009-2088-7
48. Roos PE, McGuigan MP, Kerwin DG, Trewartha G. The role of arm movement in early trip recovery in younger and older adults. *Gait Posture.* 2008;27(2):352-356. doi:10.1016/j.gaitpost.2007.05.001
49. Sran MM, Stotz PJ, Normandin SC, Robinovitch SN. Age differences in energy absorption in the upper extremity during a descent movement: implications for arresting a fall. *J Gerontol A Biol Sci Med Sci.* 2010;65(3):312-317. doi:10.1093/gerona/65.3.glp153
50. Kim KJ, Ashton-Miller JA. Biomechanics of fall arrest using the upper extremity: age differences. *Clin Biomech.* 2003;18(4):311-318. doi:10.1016/S0268-0033(03)00005-6
51. Lattimer LJ, Lanovaz JL, Farthing JP, Madill S, Kim S, Arnold C. Upper limb and trunk muscle activation during an unexpected descent on the outstretched hands in young and older women. *J Electromyogr Kinesiol.* 2016;30:231-237. doi:10.1016/j.jelekin.2016.08.001
52. Sabick MB, Hay JG, Goel VK, Banks SA. Active responses decrease impact forces at the hip and shoulder in falls to the side. *J Biomech.* 1999;32(9):993-998.
53. King EC, McKay SM, Cheng KC, Maki BE. The use of peripheral vision to guide perturbation-evoked reach-to-grasp balance-recovery reactions. *Exp Brain Res.* 2010;207(1-2):105-118. doi:10.1007/s00221-010-2434-9
54. King EC, McKay SM, Lee TA, Scovil CY, Peters AL, Maki BE. Gaze behavior of older adults in responding to unexpected loss of balance while walking in an unfamiliar environment: A pilot study. *J Optom.* 2009;2(3):119-126. doi:10.3921/joptom.2009.119
55. Newell SA, Bowman JA, Cockburn JD. Can compliance with nonpharmacologic treatments for cardiovascular disease be improved? *Am J Prev Med.* 2000;18(3):253-261. doi:10.1016/S0749-3797(99)00157-9
56. Merrill Z, Chambers AJ, Cham R. Arm reactions in response to an unexpected slip-Impact of aging. *J Biomech.* 2017;58:21-26. doi:10.1016/j.jbiomech.2017.04.011
57. Maki BE, Edmondstone MA, McIlroy WE. Age-related differences in laterally directed compensatory stepping behavior. *J Gerontol - Ser Biol Sci Med Sci.* 2000;55(5):M270-7. doi:10.1093/gerona/55.5.M270

58. Tang PF, Woollacott MH. Inefficient postural responses to unexpected slips during walking in older adults. *J Gerontol - Ser Biol Sci Med Sci.* 1998;53(6):M471-80. doi:10.1093/gerona/53A.6.M471
59. Lattimer LJ, Lanovaz JL, Farthing JP, et al. Biomechanical and physiological age differences in a simulated forward fall on outstretched hands in women. *Clin Biomech Bristol Avon.* 2018;52:102-108. doi:10.1016/j.clinbiomech.2018.01.018
60. Mansfield A, Maki BE. Are age-related impairments in change-in-support balance reactions dependent on the method of balance perturbation? *J Biomech.* 2009;42(8):1023-1031. doi:10.1016/j.jbiomech.2009.02.007
61. Cheng KC, McKay SM, King EC, Maki BE. Does aging impair the capacity to use stored visuospatial information or online visual control to guide reach-to-grasp reactions evoked by unpredictable balance perturbation? *J Gerontol Biol Sci Med Sci.* 2012;67(11):1238-1245. doi:10.1093/gerona/gls116
62. Weaver TB, Hamilton LE, Tokuno CD. Age-related changes in the control of perturbation-evoked and voluntary arm movements. *Clin Neurophysiol Off J Int Fed Clin Neurophysiol.* 2012;123(10):2025-2033. doi:10.1016/j.clinph.2012.03.012
63. Oude Nijhuis LB, Allum JHJ, Valls-Solé J, Overeem S, Bloem BR. First Trial Postural Reactions to Unexpected Balance Disturbances: A Comparison With the Acoustic Startle Reaction. *J Neurophysiol.* 2010;104(5):2704-2712. doi:10.1152/jn.01080.2009
64. Westlake KP, Wu Y, Culham EG. Sensory-Specific Balance Training in Older Adults: Effect on Position, Movement, and Velocity Sense at the Ankle. *Phys Ther.* 2007;87(5):560-568. doi:10.2522/ptj.20060262
65. Bhandari A, Radhu N, Farzan F, et al. A meta-analysis of the effects of aging on motor cortex neurophysiology assessed by transcranial magnetic stimulation. *Clin Neurophysiol.* 2016;127(8):2834-2845. doi:10.1016/j.clinph.2016.05.363
66. Seidler RD, Bernard JA, Burutolu TB, et al. Motor control and aging: Links to age-related brain structural, functional, and biochemical effects. *Neurosci Biobehav Rev.* 2010;34(5):721-733. doi:10.1016/j.neubiorev.2009.10.005
67. Piitulainen H, Seipäjärvi S, Avela J, Parviainen T, Walker S. Cortical proprioceptive processing is altered by aging. *Front Aging Neurosci.* 2018;10(JUN). doi:10.3389/fnagi.2018.00147
68. Shaffer SW, Harrison AL. Aging of the Somatosensory System: A Translational Perspective. *Phys Ther.* 2007;87(2):193-207. doi:10.2522/ptj.20060083
69. Manini TM, SI H, Clark BC. Aging and muscle: a neuron's perspective. doi:10.1097/MCO.0b013e32835b5880

70. Hunter SK, Pereira XHM, Keenan KG. The aging neuromuscular system and motor performance. *J Appl Physiol.* 2016;121(4):982-995. doi:10.1152/jappphysiol.00475.2016
71. Azpurua J, Eaton BA. Neuronal epigenetics and the aging synapse. *Front Cell Neurosci.* 2015;9(MAY). doi:10.3389/fncel.2015.00208
72. Luchies, ?denniswallace CW, Deyoung A. *Effects of Age on Balance Assessment Using Voluntary and Involuntary Step Tasks.* Vol 0.; 1999:40-44. Accessed March 2, 2020. <https://academic.oup.com/biomedgerontology/article-abstract/54/3/M140/564195>
73. DeGoede KM, Ashton-Miller JA. Fall arrest strategy affects peak hand impact force in a forward fall. *J Biomech.* 2002;35(6):843-848. doi:10.1016/S0021-9290(02)00011-8
74. Sanders OP, Hsiao HY, Savin DN, Creath RA, Rogers MW. Aging changes in protective balance and startle responses to sudden drop-perturbations. *J Neurophysiol.* Published online April 2019:jn.00431.2018. doi:10.1152/jn.00431.2018
75. Maki BE, Cheng KCC, Mansfield A, et al. Preventing falls in older adults: New interventions to promote more effective change-in-support balance reactions. *J Electromyogr Kinesiol.* 2008;18(2):243-254. doi:10.1016/j.jelekin.2007.06.005
76. Mansfield A, Peters AL, Liu BA, Maki BE. Effect of a Perturbation-Based Balance Training Program on Compensatory Stepping and Grasping Reactions in Older Adults: A Randomized Controlled Trial. *Phys Ther.* 2010;90(4):476-491. doi:10.2522/ptj.20090070
77. McKay SM, Fraser JE, Maki BE. Effects of uni- and multimodal cueing on handrail grasping and associated gaze behavior in older adults. *Accid Anal Prev.* 2013;59:407-414. doi:10.1016/j.aap.2013.06.031
78. Weerdesteyn V, Laing AC, Robinovitch SN. Automated postural responses are modified in a functional manner by instruction. *Exp Brain Res.* 2008;186(4):571-580. doi:10.1007/s00221-007-1260-1
79. Hogan MJ, Kelly CAM, Craik FIM. The effects of attention switching on encoding and retrieval of words in younger and older adults. *Exp Aging Res.* 2006;32(2):153-183. doi:10.1080/03610730600553935
80. Lukasik KM, Waris O, Soveri A, Lehtonen M, Laine M. The relationship of anxiety and stress with working memory performance in a large non-depressed sample. *Front Psychol.* 2019;10(JAN). doi:10.3389/fpsyg.2019.00004

81. Feldman R, Schreiber S, Pick CG, Been E. Gait, balance, mobility and muscle strength in people with anxiety compared to healthy individuals. *Hum Mov Sci.* 2019;67:102513. doi:10.1016/j.humov.2019.102513
82. Rahimi A, Abadi ZE. The effects of anxiety on balance parameters in young female university students. *Iran J Psychiatry.* 2012;7(4):176-179.
83. Kogan E, Lidor R, Bart O, Bar-Haim Y, Mintz M. Comorbidity between balance and anxiety disorders: verification in a normal population. *J Psychol.* 2008;142(6):601-613. doi:10.3200/JRLP.142.6.601-614
84. Carpenter MG, Frank JS, Silcher CP. Surface height effects on postural control: A hypothesis for a stiffness strategy for stance. *J Vestib Res Equilib Orientat.* 1999;9(4):277-286. doi:10.3233/ves-1999-9405
85. Adkin AL, Carpenter MG. New Insights on Emotional Contributions to Human Postural Control. *Front Neurol.* 2018;9(SEP). doi:10.3389/FNEUR.2018.00789
86. Carpenter MG, Frank JS, Adkin AL, Paton A, Allum JHJ. Influence of postural anxiety on postural reactions to multi-directional surface rotations. *J Neurophysiol.* 2004;92(6):3255-3265. doi:10.1152/jn.01139.2003
87. Carpenter MG, Adkin AL, Brawley LR, Frank JS. Postural, physiological and psychological reactions to challenging balance: does age make a difference? *Age Ageing.* 2006;35(3):298-303. doi:10.1093/AGEING/AFL002
88. Payette MC, Bélanger C, Léveillé V, Grenier S. Fall-related psychological concerns and Anxiety among community-dwelling older adults: Systematic review and meta-analysis. *PLoS ONE.* 2016;11(4). doi:10.1371/journal.pone.0152848
89. Hainaut JP, Caillet G, Lestienne FG, Bolmont B. The role of trait anxiety on static balance performance in control and anxiogenic situations. *Gait Posture.* 2011;33(4):604-608. doi:10.1016/j.gaitpost.2011.01.017
90. Kreibig SD. Autonomic nervous system activity in emotion: A review. *Biol Psychol.* 2010;84(3):394-421. doi:10.1016/j.biopsycho.2010.03.010
91. Pollock CL, Carpenter MG, Hunt MA, et al. Physiological arousal accompanying postural responses to external perturbations after stroke. *Clin Neurophysiol.* 2017;128(6):935-944. doi:10.1016/J.CLINPH.2017.03.008
92. Kaplan DM, Others A. A Validity Study of the Subjective Unit of Discomfort (SUD) Score. *Meas Eval Couns Dev.* 1995;27(4):195-199.
93. Delbaere K, Close JCT, Mikolaizak AS, Sachdev PS, Brodaty H, Lord SR. The falls efficacy scale international (FES-I). A comprehensive longitudinal validation study. *Age Ageing.* 2010;39(2):210-216. doi:10.1093/ageing/afp225

94. Tariq SH, Tumosa N, Chibnall JT, Perry MH, Morley JE. Comparison of the Saint Louis University Mental Status Examination and the Mini-Mental State Examination for Detecting Dementia and Mild Neurocognitive Disorder—A Pilot Study. *Am J Geriatr Psychiatry*. 2006;14(11). doi:10.1097/01.JGP.0000221510.33817.86
95. Patel PJ, Bhatt T. Fall risk during opposing stance perturbations among healthy adults and chronic stroke survivors. *Exp Brain Res*. 2018;236(2):619-628. doi:10.1007/s00221-017-5138-6
96. van Dooren M, de Vries JJGGJ, Janssen JH. Emotional sweating across the body: Comparing 16 different skin conductance measurement locations. *Physiol Behav*. 2012;106(2):298-304. doi:10.1016/J.PHYSBEH.2012.01.020
97. Pope GC, Halter RJ. Design and Implementation of an Ultra-Low Resource Electrodermal Activity Sensor for Wearable Applications ‡. *Sensors*. 2019;19(11):2450. doi:10.3390/s19112450
98. Hauck LJ, Carpenter MG, Frank JS. Task-specific measures of balance efficacy, anxiety, and stability and their relationship to clinical balance performance. *Gait Posture*. 2008;27(4):676-682. doi:10.1016/J.GAITPOST.2007.09.002
99. Sibley KM, Mochizuki G, Frank JS, McIlroy WE. The relationship between physiological arousal and cortical and autonomic responses to postural instability. *Exp Brain Res*. 2010;203(3):533-540. doi:10.1007/s00221-010-2257-8
100. Sibley KM, Mochizuki G, Esposito JG, Camilleri JM, McIlroy WE. Phasic electrodermal responses associated with whole-body instability: Presence and influence of expectation. *Brain Res*. 2008;1216:38-45. doi:10.1016/J.BRAINRES.2008.04.002
101. Sibley KM, Carpenter MG, Perry JC, Frank JS. Effects of postural anxiety on the soleus H-reflex. *Hum Mov Sci*. 2007;26(1):103-112. doi:10.1016/J.HUMOV.2006.09.004
102. Painter JA, Allison L, Dhingra P, Daughtery J, Cogdill K, Trujillo LG. Fear of falling and its relationship with anxiety, depression, and activity engagement among community-dwelling older adults. *Am J Occup Ther Off Publ Am Occup Ther Assoc*. 2012;66(2):169-176. doi:10.5014/ajot.2012.002535
103. Nagai M, Wada M, Sunaga N. Trait anxiety affects the pupillary light reflex in college students. *Neurosci Lett*. 2002;328(1):68-70. doi:10.1016/s0304-3940(02)00373-7
104. Endler NS, Kocovski NL. State and trait anxiety revisited. *J Anxiety Disord*. 2001;15(3):231-245. doi:10.1016/S0887-6185(01)00060-3

105. Yiu J, Miller WC, Eng JJ, Liu Y. Longitudinal analysis of balance confidence in individuals with stroke using a multilevel model for change. *Neurorehabil Neural Repair*. 2012;26(8):999-1006. doi:10.1177/1545968312437941
106. Reelick MF, van Iersel MB, Kessels RPC, Rikkert MGMO. The influence of fear of falling on gait and balance in older people. *Age Ageing*. 2009;38(4):435-440. doi:10.1093/ageing/afp066
107. Kamide N, Shiba Y, Sakamoto M, Sato H, Kawamura A. Fall-related efficacy is a useful and independent index to detect fall risk in Japanese community-dwelling older people: a 1-year longitudinal study. *BMC Geriatr*. 2019;19(1):293. doi:10.1186/s12877-019-1318-5
108. Kempen GIJM, Todd CJ, Van Haastregt JCM, et al. Cross-cultural validation of the Falls Efficacy Scale International (FES-I) in older people: results from Germany, the Netherlands and the UK were satisfactory. *Disabil Rehabil*. 2007;29(2):155-162. doi:10.1080/09638280600747637
109. Jung D, Kang Y, Kim MY, Ma RW, Bhandari P. Zero-Inflated Poisson Modeling of Fall Risk Factors in Community-Dwelling Older Adults. *West J Nurs Res*. 2016;38(2):231-247. doi:10.1177/0193945914553677
110. Moiz JA, Bansal V, Noohu MM, et al. Activities-specific balance confidence scale for predicting future falls in Indian older adults. *Clin Interv Aging*. 2017;12:645-651. doi:10.2147/CIA.S133523
111. Helbostad JL, Taraldsen K, Granbo R, Yardley L, Todd CJ, Sletvold O. Validation of the Falls Efficacy Scale-International in fall-prone older persons. *Age Ageing*. 2010;39(2):259. doi:10.1093/ageing/afp224
112. Cleary K, Skornyakov E. Predicting falls in community dwelling older adults using the Activities-specific Balance Confidence Scale. *Arch Gerontol Geriatr*. 2017;72:142-145. doi:10.1016/j.archger.2017.06.007
113. Lajoie Y, Gallagher SP. Predicting falls within the elderly community: Comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Arch Gerontol Geriatr*. 2004;38(1):11-26. doi:10.1016/S0167-4943(03)00082-7
114. Tsang S, Royse CF, Terkawi AS. Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. *Saudi J Anaesth*. 2017;11(Suppl 1):S80-S89. doi:10.4103/sja.SJA\_203\_17
115. Letts L, Moreland J, Richardson J, et al. The physical environment as a fall risk factor in older adults: Systematic review and meta-analysis of cross-sectional and cohort studies. *Aust Occup Ther J*. 2010;57(1):51-64. doi:10.1111/J.1440-1630.2009.00787.X

116. Hausdorff JM, Yogev G, Springer S, Simon ES, Giladi N. Walking is more like catching than tapping: gait in the elderly as a complex cognitive task. *Exp Brain Res Exp Hirnforsch Exp Cerebrale*. 2005;164(4):541-548. doi:10.1007/s00221-005-2280-3
117. Holtzer R, Friedman R, Lipton RB, Katz M, Xue X, Verghese J. The relationship between specific cognitive functions and falls in aging. *Neuropsychology*. 2007;21(5):540-548. doi:10.1037/0894-4105.21.5.540
118. Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. *J Gerontol Biol Sci Med Sci*. 2001;56(8):M489-96.
119. King EC, Lee TA, McKay SM, et al. Does the “eyes lead the hand” principle apply to reach-to-grasp movements evoked by unexpected balance perturbations? *Hum Mov Sci*. 2011;30(2):368-383. doi:10.1016/j.humov.2010.07.005
120. Cona G, Bisiacchi PS, Amodio P, Schiff S. Age-related decline in attentional shifting: Evidence from ERPs. *Neurosci Lett*. 2013;556:129-134. doi:10.1016/j.neulet.2013.10.008
121. Brown LA, White P, Doan JB, de Bruin N. Selective Attentional Processing to Fall-Relevant Stimuli Among Older Adults Who Fear Falling. *Exp Aging Res*. 2011;37(3):330-345. doi:10.1080/0361073X.2011.568833
122. Eysenck MW, Derakshan N, Santos R, Calvo MG. Anxiety and cognitive performance: attentional control theory. *Emot Wash DC*. 2007;7(2):336-353. doi:10.1037/1528-3542.7.2.336
123. Eysenck MW, Calvo MG. Anxiety and Performance: The Processing Efficiency Theory. *Cogn Emot*. 1992;6(6):409-434. doi:10.1080/02699939208409696
124. Alexander JK, Hillier A, Smith RM, Tivarus ME, Beversdorf DQ. Beta-adrenergic Modulation of Cognitive Flexibility during Stress. *J Cogn Neurosci*. 2007;19(3):468-478. doi:10.1162/jocn.2007.19.3.468
125. Sanger J, Bechtold L, Schoofs D, Blaszkewicz M, Wascher E. The influence of acute stress on attention mechanisms and its electrophysiological correlates. *Front Behav Neurosci*. 2014;8:353. doi:10.3389/fnbeh.2014.00353
126. Okubo Y, Schoene D, Lord SR. Step training improves reaction time, gait and balance and reduces falls in older people: a systematic review and meta-analysis. *Br J Sports Med*. 2017;51(7):586-593. doi:10.1136/BJSPORTS-2015-095452
127. Shelkey M, Wallace M. Katz Index of Independence in Activities of Daily Living. *J Gerontol Nurs*. 1999;25(3):8-9. doi:10.3928/0098-9134-19990301-05

128. Dick JP, Guiloff RJ, Stewart A, et al. Mini-mental state examination in neurological patients. *J Neurol Neurosurg Psychiatry*. 1984;47(5):496-499. doi:10.1136/jnnp.47.5.496
129. Rogers MW, Johnson ME, Martinez KM, Mille ML, Hedman LD. Step training improves the speed of voluntary step initiation in aging. *J Gerontol A Biol Sci Med Sci*. 2003;58(1):46-51. doi:10.1093/GERONA/58.1.M46
130. Karni A, Meyer G, Jezzard P, Adams MM, Turner R, Ungerleider LG. Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature*. 1995;377(6545):155-158. doi:10.1038/377155a0
131. Taubert M, Draganski B, Anwander A, et al. Dynamic properties of human brain structure: learning-related changes in cortical areas and associated fiber connections. *J Neurosci Off J Soc Neurosci*. 2010;30(35):11670-11677. doi:10.1523/JNEUROSCI.2567-10.2010
132. Lurie JD, Zagaria AB, Pidgeon DM, Forman JL, Spratt KF. Pilot comparative effectiveness study of surface perturbation treadmill training to prevent falls in older adults. *BMC Geriatr*. 2013;13(1):49. doi:10.1186/1471-2318-13-49
133. Gerards MHG, McCrum C, Mansfield A, Meijer K. Perturbation-based balance training for falls reduction among older adults: Current evidence and implications for clinical practice. *Geriatr Gerontol Int*. 2017;17(12):2294-2303. doi:10.1111/ggi.13082
134. Okubo Y, Sturnieks DL, Brodie MA, Duran L, Lord SR. Effect of Reactive Balance Training Involving Repeated Slips and Trips on Balance Recovery Among Older Adults: A Blinded Randomized Controlled Trial. Newman A, ed. *J Gerontol Ser A*. 2019;74(9):1489-1496. doi:10.1093/gerona/glz021
135. Jeon MJ, Jeon HS, Yi CH, Kwon OY, You SH, Park JH. Block and Random Practice: A Wii Fit Dynamic Balance Training in Older Adults. *Res Q Exerc Sport*. 2021;92(3):352-360. doi:10.1080/02701367.2020.1733456
136. Nachmani H, Paran I, Salti M, Shelef I, Melzer I. Examining Different Motor Learning Paradigms for Improving Balance Recovery Abilities Among Older Adults, Random vs. Block Training-Study Protocol of a Randomized Non-inferiority Controlled Trial. *Front Hum Neurosci*. 2021;15:624492. doi:10.3389/fnhum.2021.624492
137. Takazono PS, Ribeiro de Souza C, Ávila de Oliveira J, Coelho DB, Teixeira LA. High contextual interference in perturbation-based balance training leads to persistent and generalizable stability gains of compensatory limb movements. *Exp Brain Res*. 2020;238(5):1249-1263. doi:10.1007/s00221-020-05806-x

138. McCrum C, Bhatt TS, Gerards MHG, et al. Perturbation-based balance training: Principles, mechanisms and implementation in clinical practice. *Front Sports Act Living*. 2022;4:1015394. doi:10.3389/fspor.2022.1015394
139. Marteniuk RG, Leavitt JL, MacKenzie CL, Athenes S. Functional relationships between grasp and transport components in a prehension task. *Hum Mov Sci*. 1990;9(2):149-176. doi:10.1016/0167-9457(90)90025-9
140. Winter DA. *Biomechanics and Motor Control of Human Movement*. 1st ed. Wiley; 2009. doi:10.1002/9780470549148
141. Dempster WT. *SPACE REQUIREMENTS OF THE SEATED OPERATOR, GEOMETRICAL, KINEMATIC, AND MECHANICAL ASPECTS OF THE BODY WITH SPECIAL REFERENCE TO THE LIMBS*: Defense Technical Information Center; 1955. doi:10.21236/AD0087892
142. Shaffer F, Ginsberg JP. An Overview of Heart Rate Variability Metrics and Norms. *Front Public Health*. 2017;5:258. doi:10.3389/FPUBH.2017.00258
143. Malik M, Camm AJ, Bigger JT, et al. Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Eur Heart J*. 1996;17(3):354-381. doi:10.1093/oxfordjournals.eurheartj.a014868
144. Liao S, Liu H, Lin WH, Zheng D, Chen F. Filtering-induced changes of pulse transmit time across different ages: a neglected concern in photoplethysmography-based cuffless blood pressure measurement. *Front Physiol*. 2023;14:1172150. doi:10.3389/fphys.2023.1172150
145. Yang F, Pai YC. Automatic recognition of falls in gait-slip training: Harness load cell based criteria. *J Biomech*. 2011;44(12):2243-2249. doi:10.1016/j.jbiomech.2011.05.039
146. Bhatt T, Wang Y, Wang S, Kannan L. Perturbation Training for Fall-Risk Reduction in Healthy Older Adults: Interference and Generalization to Opposing Novel Perturbations Post Intervention. *Front Sports Act Living*. 2021;3. doi:10.3389/FSPOR.2021.697169
147. Dusane S, Bhatt T. Mixed slip-trip perturbation training for improving reactive responses in people with chronic stroke. *J Neurophysiol*. 2020;124(1):20-31. doi:10.1152/jn.00671.2019
148. Allin LJ, Brolinson PG, Beach BM, et al. Perturbation-based balance training targeting both slip- And trip-induced falls among older adults: A randomized controlled trial. *BMC Geriatr*. 2020;20(1). doi:10.1186/s12877-020-01605-9

149. Ferreira RN, Ribeiro NF, Figueiredo J, Santos CP. Provoking Artificial Slips and Trips towards Perturbation-Based Balance Training: A Narrative Review. *Sensors*. 2022;22(23). doi:10.3390/S22239254
150. Wang Y, Wang S, Lee A, Pai YC, Bhatt T. Treadmill-gait slip training in community-dwelling older adults: mechanisms of immediate adaptation for a progressive ascending-mixed-intensity protocol. *Exp Brain Res*. 2019;237(9):2305-2317. doi:10.1007/S00221-019-05582-3
151. Knudsen EI. Fundamental components of attention. *Annu Rev Neurosci*. 2007;30:57-78. doi:10.1146/ANNUREV.NEURO.30.051606.094256
152. Sung CM, Jen HJ, Liu D, et al. The effect of cognitive training on domains of attention in older adults with mild cognitive impairment and mild dementia: A meta-analysis of randomised controlled trials. *J Glob Health*. 2023;13. doi:10.7189/JOGH.13.04078
153. Sveistrup H, Woollacott MH. Practice modifies the developing automatic postural response. *Exp Brain Res*. 1997;114(1):33-43. doi:10.1007/PL00005621
154. Latash ML. Mirror Writing: Learning, Transfer, and Implications for Internal Inverse Models. *J Mot Behav*. 1999;31(2):107-111. doi:10.1080/00222899909600981
155. Sainburg RL, Wang J. Interlimb transfer of visuomotor rotations: independence of direction and final position information. *Exp Brain Res*. 2002;145(4):437-447. doi:10.1007/S00221-002-1140-7
156. McCrum C, Karamanidis K, Grevendonk L, Zijlstra W, Meijer K. Older adults demonstrate interlimb transfer of reactive gait adaptations to repeated unpredictable gait perturbations. *GeroScience*. 2020;42(1):39-49. doi:10.1007/s11357-019-00130-x
157. McCrum C, Karamanidis K, Willems P, Zijlstra W, Meijer K. Retention, savings and interlimb transfer of reactive gait adaptations in humans following unexpected perturbations. *Commun Biol* 2018 11. 2018;1(1):1-10. doi:10.1038/s42003-018-0238-9
158. Starns JJ, Ratcliff R. The effects of aging on the speed-accuracy compromise: Boundary optimality in the diffusion model. *Psychol Aging*. 2010;25(2):377-390. doi:10.1037/A0018022
159. Wang TY, Bhatt T, Yang F, Pai YC. GENERALIZATION OF MOTOR ADAPTATION TO REPEATED-SLIP PERTURBATION ACROSS TASKS. *Neuroscience*. 2011;180:85. doi:10.1016/J.NEUROSCIENCE.2011.02.039

160. Yang F, Su X, Wen PS, Lazarus J. Adaptation to repeated gait-slip perturbations among individuals with multiple sclerosis. *Mult Scler Relat Disord*. 2019;35:135-141. doi:10.1016/J.MSARD.2019.07.019
161. Delbaere K, Close JCT, Brodaty H, Sachdev P, Lord SR. Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. *BMJ*. 2010;341(aug18 4):c4165-c4165. doi:10.1136/bmj.c4165
162. Pua YH, Ong PH, Clark RA, Matcher DB, Lim ECW. Falls efficacy, postural balance, and risk for falls in older adults with falls-related emergency department visits: prospective cohort study. *BMC Geriatr*. 2017;17(1). doi:10.1186/S12877-017-0682-2
163. Zaback M, Carpenter MG, Adkin AL. Threat-induced changes in attention during tests of static and anticipatory postural control. *Gait Posture*. 2016;45:19-24. doi:10.1016/J.GAITPOST.2015.12.033
164. Meeker TJ, Emerson NM, Chien JH, et al. During vigilance to painful stimuli: slower response rate is related to high trait anxiety, whereas faster response rate is related to high state anxiety. *J Neurophysiol*. 2021;125(1):305-319. doi:10.1152/JN.00492.2020
165. Schimmelpfennig J, Topczewski J, Zajkowski W, Jankowiak-Siuda K. The role of the salience network in cognitive and affective deficits. *Front Hum Neurosci*. 2023;17:1133367. doi:10.3389/FNHUM.2023.1133367/BIBTEX
166. Menon V, Uddin LQ. Saliency, switching, attention and control: a network model of insula function. *Brain Struct Funct*. 2010;214(5-6):655. doi:10.1007/S00429-010-0262-0
167. Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: A review of an emerging area of research. *Gait Posture*. 2002;16(1):1-14. doi:10.1016/S0966-6362(01)00156-4
168. Gage WH, Sleik RJ, Polych MA, McKenzie NC, Brown LA. The allocation of attention during locomotion is altered by anxiety. *Exp Brain Res*. 2003;150(3):385-394. doi:10.1007/S00221-003-1468-7
169. Cleworth TW, Carpenter MG. Postural threat influences conscious perception of postural sway. *Neurosci Lett*. 2016;620:127-131. doi:10.1016/J.NEULET.2016.03.032
170. Cleworth TW, Horslen BC, Carpenter MG. Influence of real and virtual heights on standing balance. *Gait Posture*. 2012;36(2):172-176. doi:10.1016/J.GAITPOST.2012.02.010

171. Adkin AL, Frank JS, Carpenter MG, Peysar GW. Postural control is scaled to level of postural threat. *Gait Posture*. 2000;12(2):87-93. doi:10.1016/S0966-6362(00)00057-6
172. Staab JP, Balaban CD, Furman JM. Threat assessment and locomotion: clinical applications of an integrated model of anxiety and postural control. *Semin Neurol*. 2013;33(3):297-306. doi:10.1055/S-0033-1356462
173. Huffman JL, Horslen BC, Carpenter MG, Adkin AL. Does increased postural threat lead to more conscious control of posture? *Gait Posture*. 2009;30(4):528-532. doi:10.1016/j.gaitpost.2009.08.001
174. Wang J, Lei Y, Binder JR. Performing a reaching task with one arm while adapting to a visuomotor rotation with the other can lead to complete transfer of motor learning across the arms. *J Neurophysiol*. 2015;113(7):2302-2308. doi:10.1152/jn.00974.2014
175. Yadav G, Mutha PK. Symmetric interlimb transfer of newly acquired skilled movements. *J Neurophysiol*. 2020;124(5):1364-1376. doi:10.1152/jn.00777.2019
176. Criscimagna-Hemminger SE, Donchin O, Gazzaniga MS, Shadmehr R. Learned dynamics of reaching movements generalize from dominant to nondominant arm. *J Neurophysiol*. 2003;89(1):168-176. doi:10.1152/jn.00622.2002
177. Lord SR, Caplan GA, Ward JA. Balance, reaction time, and muscle strength in exercising and nonexercising older women: a pilot study. *Arch Phys Med Rehabil*. 1993;74(8):837-839. doi:10.1016/0003-9993(93)90010-8
178. Jiménez-García JD, Martínez-Amat A, Hita-Contreras F, Fábrega-Cuadros R, Álvarez-Salvago F, Aibar-Almazán A. Muscle Strength and Physical Performance Are Associated with Reaction Time Performance in Older People. *Int J Environ Res Public Health*. 2021;18(11):5893. doi:10.3390/ijerph18115893
179. Shen YC, Franz EA. Hemispheric competition in left-handers on bimanual reaction time tasks. *J Mot Behav*. 2005;37(1):3-9. doi:10.3200/JMBR.37.1.3-9
180. Incel NA, Ceceli E, Durukan PB, Erdem HR, Yorgancioglu ZR. Grip strength: effect of hand dominance. *Singapore Med J*. 2002;43(5):234-237.
181. Petersen P, Petrick M, Connor H, Conklin D. Grip strength and hand dominance: challenging the 10% rule. *Am J Occup Ther Off Publ Am Occup Ther Assoc*. 1989;43(7):444-447. doi:10.5014/ajot.43.7.444
182. Adam A, De Luca CJ, Erim Z. Hand dominance and motor unit firing behavior. *J Neurophysiol*. 1998;80(3):1373-1382. doi:10.1152/jn.1998.80.3.1373

183. Zaback M, Cleworth TW, Carpenter MG, Adkin AL. Personality traits and individual differences predict threat-induced changes in postural control. *Hum Mov Sci.* 2015;40:393-409. doi:10.1016/J.HUMOV.2015.01.015
184. Ong NT, Bowcock A, Hodges NJ. Manipulations to the timing and type of instructions to examine motor skill performance under pressure. *Front Psychol.* 2010;1:196. doi:10.3389/fpsyg.2010.00196
185. Nieuwenhuys A, Oudejans RRD. Anxiety and perceptual-motor performance: toward an integrated model of concepts, mechanisms, and processes. *Psychol Res.* 2012;76(6):747-759. doi:10.1007/s00426-011-0384-x
186. Mullen R, Faull A, Jones ES, Kingston K. Attentional focus and performance anxiety: effects on simulated race-driving performance and heart rate variability. *Front Psychol.* 2012;3:426. doi:10.3389/fpsyg.2012.00426