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How Baseline Testing Can Predict Walking Tasks

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ABSTRACT

The risk of falling and associated injuries increases with age. Thus, researchers investigate changes in gait mechanics, including fall mechanics and the role of visual input in motor control. This study determined how altering path visual color contrast affects walking performance and if common clinical baseline tests can predict task success. 20 older and 20 younger healthy adults were analyzed and compared after qualifying for the study. Each performed the following baseline assessments: the Iconographical Falls Efficacy Scale (Icon-FES), FrACT visual contrast sensitivity test, 5-meter walk test (5MWT), Timed Up and Go (TUG), and Four-Square Step Test (FSST). Participants then walked on four different virtual paths that were projected onto a treadmill within a virtual reality system. These paths varied in shape (straight and winding) and color contrast (high and low). We recorded steps off the path, or stepping errors, for each condition. Baseline tests showed older adults walked with similar preferred speeds to young adults ($p=0.844$), but slower TUG ($p=0.024$) and FSST ($p=0.008$) times, and decreased contrast sensitivity ($p=0.033$). During the walking task older adults made more stepping errors than younger adults on the low contrast winding path ($p=0.027$). FSST had significant correlation with the stepping errors made on the Low Contrast Windy path ($p=0.009$). By evaluating correlations between baseline assessments and step error percents while walking, this study aimed to identify predictors for walking performance. The reported findings offer a semi quantitative way healthcare professionals can assess patient's walking abilities.

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Most importantly I would like to acknowledge my family. I would not be here without their unconditional support through my educational journey, and for that, I am deeply grateful. Next I would like to thank my high school athletic trainer Walter Hildebrand, who introduced me to the field of sports medicine. Walter was one of the first people who challenged me to think about problems a different way. He helped me gain my foundations of professionalism and curiosity of the human body. I am also thankful to my mentor, Liz Weiner, who I matched with through the HHD mentorship program. Liz helped me navigate through my final two years of schooling and provided support when I faced a change in my career aspirations.

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Finally, I want to acknowledge Lori Gravish one of my kinesiology professors. I will always remember sitting in my PSU 9 class, as a freshman, with Dr. Williams when Lori came walking in offering the class her phone number to use. Lori helped me gain undergraduate lab experience as a freshman and obtain a job that I have held from my sophomore to senior year. Through Lori I have had the opportunity to participate in the ACSM/IDEA conference and was a part of her second ever street medicine class, KINES 414, which is affiliated with Keck School of Medicine. Lori made it possible for me to have many unique and enriching experiences during my time at Penn State

Chapter 1

Introduction

1.1 The Older Adult Population

From 2010 to 2020, the United States population of 65 and older increased from 13% to 16.8% (US Census, 2023). With the shift to an average older population there has been a measurable rise of deaths due to falls has been observed. The Center for Disease Control and Prevention (CDC) reported that, in 2020, an average of one in four older adults reported falling at least once that year (Kakara et al., 2023). In 2021, studies concluded that 100 older adults died each day due to a fall. With the rise of falls and injuries that could lead to death there is an increased economic consequence. In 2020, it was estimated that non-fatal falls accounted for an estimated $80 billion in healthcare costs (Haddad et al., 2024). It was also estimated that $23 billion was out of pocket costs. As people age, there is often a deterioration of health. Loss of hearing, osteoarthritis, muscle atrophy, and cataracts are often associated with aging (World Health Organization, 2024). Therefore, it is necessary to understand elements of aging to properly assist the elderly population.

1.2 Falls While Walking

While slipping and tripping are often cited as causes of falls, falls can result from other types of events. Robinovinch saw that slipping only accounted for 3% and tripping accounted for 21% of the 227 falls that they observed at different long term care facilities (Robinovitch et al., 2013). In this study, 41% of falls were attributed to incorrect weight shifting. During non-linear movements, older adults take more steps and longer times to complete turns (Thigpen et al., 2000). The reason older adults take more steps in non-linear walking is because of the absence of a pivot turn. Zhang found that when older adults walked for long bouts of time, medial arch pressure increased, suggesting gait instability (Zhang et al., 2021). Older adults must change their gait patterns to increase stability (Chien et al., 2018). Therefore, as people age, it becomes important to make proper gait adaptations to minimize the risk of falling while walking.

1.3 Visual Control While Walking

It is known that visual input is used in motor control. The Posterior Parietal Cortex (PPC) plays a crucial role in motor control (Drew & Marigold, 2015). Visual information, like object speed and size of the object, is sent to the PPC, where object coupling and limb coordination is initiated. This information then goes to the premotor cortex and basal ganglia before reaching motor cortex, where movement is initiated. Patla describes visual input as “essential for implementing avoidance strategies and crucial for proactive dynamic stability during locomotion” (Patla, 1997). Visual systems can override actions of the kinesthetic and vestibular systems. Proactive avoidance strategies use vision for instant transmission of visual information at a distance. During a variety of situations, like turning down a hallway and steering during walking eye fixations happen at the desired future path (Higuchi, 2013). There is clearly a factor while walking that requires a cognitive component. With age, vision and other cognitive components can become impaired which can lead to difficulties in walking.

1.4 What We Don’t Know

When analyzing movement, there is a perception-action cycle that dictates our movement that should be considered (Warren, 2006). Warren describes the two key figures in the cycle: the environment and the walker. From the environment, the walker gains information. When the walker receives the information, they can produce an action, which moves them into a new part of the environment, continuing the cycle. Warren's schema has three components to it: sensory, cognition, and physical. The environment is used to gain afferent information. Then, cognitive factors turn afferent information to efferent information. This task was found to be accomplished in the PPC (Drew & Marigold, 2015). With efferent information, an action is produced. It is not known currently which factors are most affected by aging. It is difficult to differentiate individual factors due to their inter-connectiveness. Hence, understanding aging can be a challenge when trying to find where the problem lies.

1.5 Experimental Overview

In this study, healthy young and older adults performed various baseline assessments and completed multiple walking tasks. The walking tasks consisted of straight, or winding paths presented in each of the two different color contrasts. Out experiments were designed to address these questions (1) how does aging affect task completion? (2) does visual ability affect tasks completion? (3) can baseline tests be good predictors of successful walking? To investigate these questions, we examined a variety of baseline tests aimed at establishing a correlation between stepping error rates during the walking task and the baseline tests. We expected that: (1) older adults would be less effective at the walking task, (2) people with a decreased contrast sensitivity would as be less effective at the walking task, and (3) baseline tests would be able to predict performance on the completed walking task.

Chapter 2

Methods

2.1 Participants

We recruited 25 young adults which consisted of 13 females and 12 males. 31 older adults were recruited which consisted of 27 females and 4 males. The study analyzed a final data set of 20 young healthy (YH) and 20 old healthy (OH) adults. The YH group consisted of 9 males and 11 females, while the OH group included 4 males and 16 females (Table 1). Before testing, participants completed three forms: study consent form, participant contact form, and a brief health history questionnaire. After, participants completed initial screening tests to ensure that they met the inclusion criteria for the study. Resting heart rate and blood pressure were taken, which needed to be less than 140/90. Basic measurements, including body mass, body height, and leg-length (from the greater trochanter to the lateral malleolus) were taken. Body Mass Index (BMI) was calculated using this data, and all participants had a BMI between 18 and 30. Finally, visual was assessed using a Snellen Chart, with participants required to have a visual acuity of at least 20/40.

Table 1 Participant Physical Characteristics

Characteristics	Older Adult Value	Younger Adult Value
Age (yrs)	**69.667± 3.33**	**22.046±3.341**
Sex (M/F)	**4/16**	**9/11**
Mass (kg)	**68.965 ± 12.962**	**69.388±13.414**
Height (cm)	**165.95±9.84**	**172.22±6.37**
Leg Length (cm)	**86.4±6.03**	**86.25±6.927**
Body Mass Index $(\frac{kg}{m^2})$	**24.917±3.131**	**23.261±3.469**

2.2 Baseline Assessments

Participants completed a series of baseline assessments to measure various physical and visual capabilities. The Iconographical Falls Efficacy Scale (Icon-FES) tested participants fear of falling based on 10 different events, with concerns of falling rated on a scale of 1-4 (Delbaere et al., 2011) (Table 2). After, participants used Freiburg Visual Acuity and Contrast Test (FrACT) to test color contrast sensitivity (Bach, 2007). For the FrACT participants sat one meter from the screen and used a number pad to identify the location of the gap in an optotype (Landolt C). Next, participants completed a series of walking screening assessments, and each was completed three times. The average completion time across the trials was calculated and used to ensure that each participant met the inclusion thresholds for each test (Table 2). The 5-Meter Walk Test (5MWT) was assessed first. A line was taped at the 5 meters distance, and participants walked at their normal pace one way while their time was recorded (Ng et al., 2013). Participant times needed to be less than 6.25 seconds to continue the study. Timed Up & Go (TUG) followed. Participants were timed as they stood up from a chair, walked 3 meters, turned around, and walked back to the same chair and sat down (Podsiadlo & Richardson, 1991). The average TUG time needed to be less than 12 seconds to continue in the study. Lastly, participants performed the Four-Square Step Test (FSST). A two-by-two square grid was made using canes. Participants had to step sequentially starting in square 1 then going into squares 2, 3,4,1 and then reverse the order 4,3,2,1 ensuring both feet were on the ground in one square before moving on to the next one (Moore & Barker, 2017) . Participants were instructed not to touch the canes. Each participant needed to complete the sequence under 15 seconds to continue in the study.

Table 2 Participant Baseline Test Data

Assessment	**Older Adult Value**	**Younger Adult Value**
5MWT (sec)	**3.7865±0.4285**	**3.7605±0.4012**
TUG (sec)	**8.838±1.085**	**8.1115±0.8611**
FSST (sec)	**8.906±1.3793**	**7.4995±1.7771**
ICON FES (range 10-40)	**13.150±2.277**	**12.45±1.820**
FrACT Percentage	**2.1440±3.3893**	**1.0285±0.0591**

2.3 Walking Protocol

To obtain motion capture data markers were placed on 1st and 5th metatarsal, lateral malleolus, calcaneus, anterior and posterior superior iliac spine, right shoulder, and the top of the head. Additionally, participants wore a headband with two markers in the front and two on the back. Nine Vicon motion capture cameras were positioned around the treadmill to capture kinematic data. Participants walked in a Motek virtual reality system.

Once subjects were on the treadmill, static and range of motion calibrations were taken. Participants wore a safety harness attached to the ceiling. All walking trials were performed at 1 m/s. Participants first completed several 90 second warm-up trials that progressively introduced elements of path walking, winding paths, and reduced path color contrast. The progression walking on no path, followed by a high contrast (HC) straight (ST) path, a HC slowly winding (WD) path and finally a HC more rapidly winding path. The lateral oscillation frequencies of the winding paths were defined in Anna Render's experiments (Render et al., 2025), with the slowly winding path corresponding to frequency level 1, and the rapidly winding path to frequency level 3. Once participants reached the level 3 WD path, the path's color contrast was adjusted to medium and then low contrast (LC). All paths were 0.45 m wide. After warm-up trials participants completed 4 experimental conditions: walking on High Contrast Straight (HCST), Low Contrast Straight (LCST), High Contrast Windy (HCWD; Fig.1A), and Low Contrast Windy (LCWD; Fig. 1B) paths. The order of conditions was pseudo-randomized across participants. For each condition, participants first completed a 1.5 min acclimation trial, followed by two 3-min experimental trials. Participants were instructed to complete the task to the best of their abilities trying to always stay on the path. If the participant stepped off the path, fireworks would be displayed on the screen. Participants were given time for breaks and water in-between trials as needed.

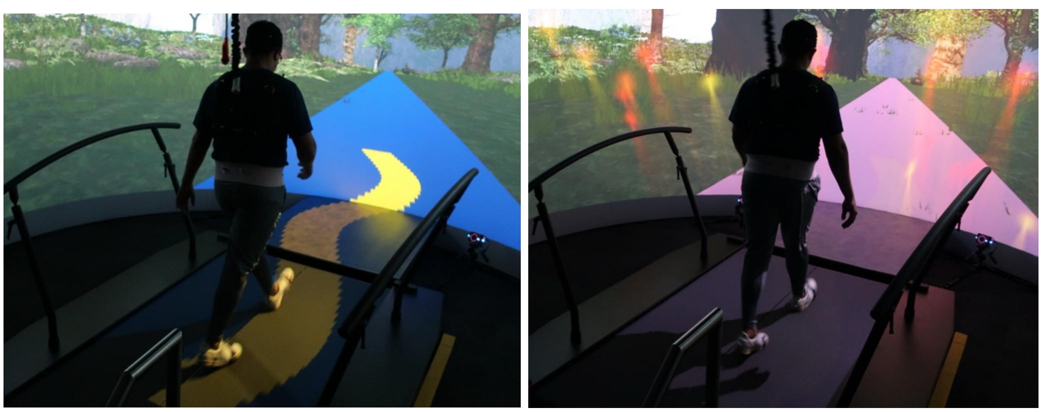


Figure 1 A) Walking on a HCWD path (Left). B) Walking on a LCWD Path while making a stepping error with fireworks showing up (Right).

2.4 Data Analysis

When participants stepped off either the winding path or the straight path, a stepping error would be marked down. At the end of each trial, the total number of stepping errors or the percentage of stepping errors were recorded. To calculate the final stepping error percentage for each condition, the averages from two trials were computed. For trials where only the number of stepping errors were recorded, we assumed that the total number of steps between the two trials were equivalent when calculating stepping error percentage.

While analyzing the average stepping error between the two trials for each condition, some data points were excluded due to technical difficulties. For the YH group, 5 LCWD and 4 HCWD data points were excluded. For the OH group, 6 LCWD and 8 HCWD data points were excluded. As a result, the HCWD path analysis included 16 YH and 12 OH data points. While the LCWD path analysis included 15 YH and 14 OH data points.

2.5 Statistical Analysis

The data was transferred into Minitab for statistical analysis. A summary report was run for physical characteristics and baseline testing for each group. One-way ANOVA tables and boxplots were made to compare physical characteristics and baseline tests outcomes between the OH and YH groups. For the FrACT results, the natural log was taken to normalize the data. To address cases where the average stepping error percentage was equal to 0, we added a small constant (0.001) to each average, and then the natural log was taken. Fitted line plots were then made to examine correlations between baseline walking tests for the combined groups and the HCWD and LCWD path conditions.

Chapter 3

Results

3.1 Summary of Participants

Upon statistical analysis, most of the participant characteristics showed little statistical significance between groups. Mass (kg) ($p= 0.92$; Fig.2A), leg length(cm) ($p=0.942$; Fig.2B), and BMI ($\frac{kg}{m^2}$) ($p=0.121$; Fig.2C) showed no statistical differences between YH and OH adults. YH adults were found to be taller than OH adults ($p=0.022$; Fig.2D).

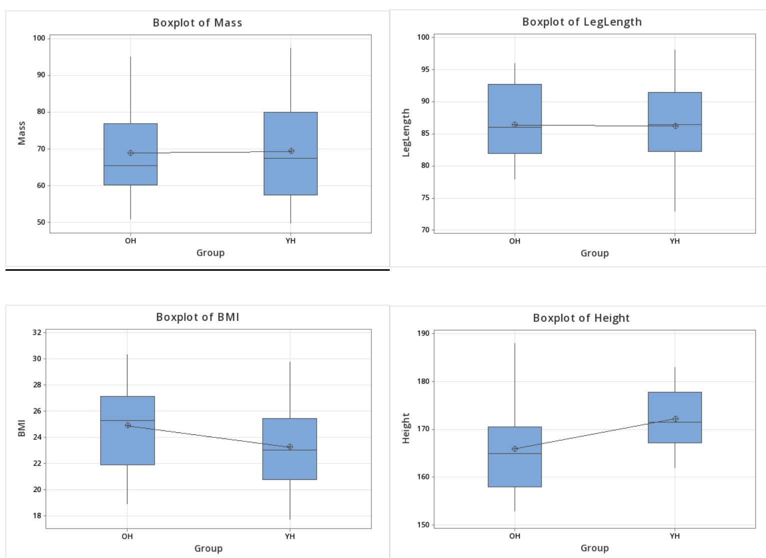


Figure 2 A) Comparison of the mass between YH and OH participants (top left). B) Comparison of the leg length between YH and OH Participants (top right). C) Comparison of BMI between YH and OH participants (bottom left). D) Comparison of the height between YH and OH participants (bottom right).

3.2 Baseline Test Scores

Baseline tests for fear of falling, contrast sensitivity, and physical assessments were conducted on each participant. YH and OH participants exhibited similar Icon-FES scores (p=0.290;Fig 3A) so there were no differences in concerns about falling between groups. OH participants exhibited higher FrACT scores than YH participants (p=0.033;Fig 3B), indicating that they had reduced contrast sensitivity.

Three tests were performed to test walking physical ability. YH and OH participants performed the 5MWT older and younger groups completed the task in similar times (p=0.844;Fig 3C), indicating similar preferred walking speeds. However, during nonlinear stepping tests, there were statistically significant differences in task performance times between the two groups. OH participants performed both the TUG (p=0.024;Fig 3D) and FSST (p=0.008;Fig 3E) slower than YH participants.

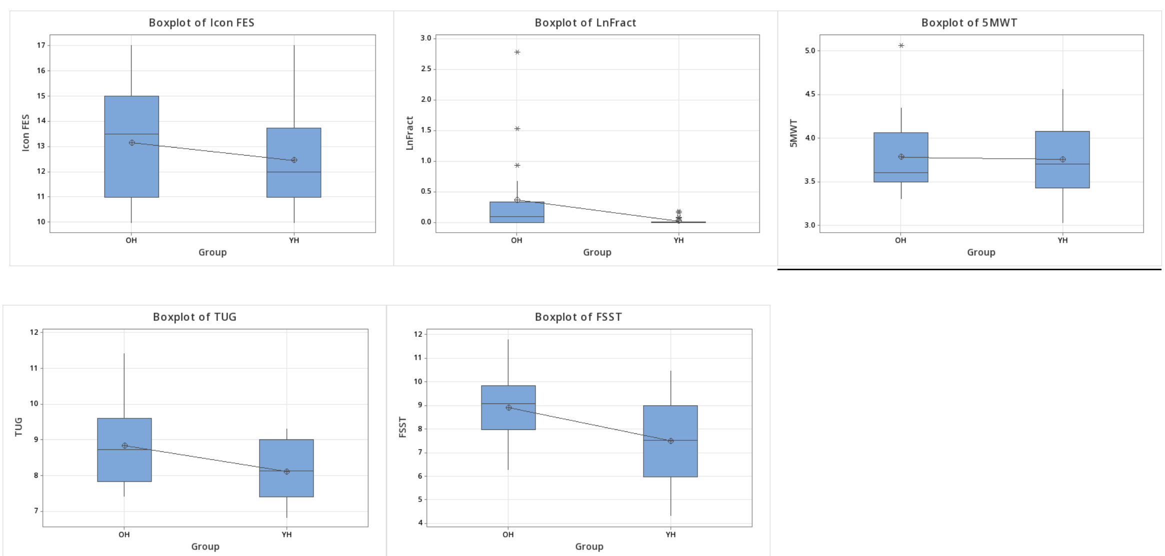


Figure 3 A) Comparison of the Icon-FES between YH and OH participants (top left). B) Comparison of natural log FrACT scores between YH and OH participants (top middle). C) Comparison of the 5MWT times between YH and OH participants (top right). D) Comparison of TUG times between YH and OH participants (bottom left). E) Comparison of FSST times between YH and OH participants (bottom right).

3.3 Results of the Walking Task

The HCST and LCST path conditions were not analyzed here since the majority of participants in both groups made no stepping errors. Walking on the HCWD path, there was no statistical difference in stepping errors between OH and YH groups (p=0.293; Fig.4A). However, OH participants made more stepping errors than YH participants on the LCWD path (p=0.027; Fig.4B).

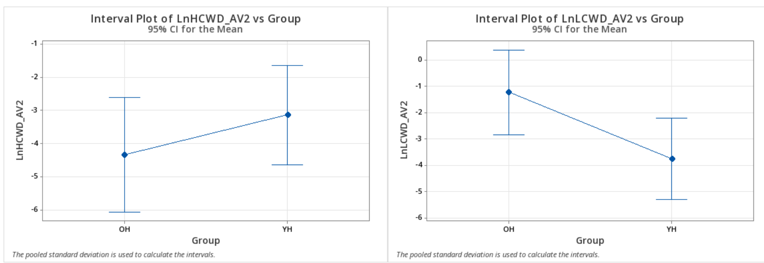


Figure 4 A) Comparison of the natural log of the average stepping error on the HCWD path between non-excluded OH and non-excluded YH participants (left). B) Comparison of the natural log of the average stepping error on the LCWD path between non-excluded OH and non-excluded YH participants (right).

3.4 Correlations

There was no statistically significant correlation between the 5MWT and stepping errors for either HCDW (p=0.101; Fig.5A) or LCDW (p=0.424; Fig. 5B). Participants' TUG times also did not yield a significant correlation with stepping errors on either the HCWD (p=0.639; Fig. 6A) or LCWD (p=0.179; Fig. 6B) paths. Participants' FSST times did not significantly predict stepping errors on the HCWD (p=0.210; Fig. 7A) but did on the LCWD path (p=0.009; Fig. 7B). Participants' visual acuity did not provide a significant correlation with stepping errors on either the HCWD (p=0.216; Fig. 8A) or LCWD (p=0.159; Fig. 8B) paths.

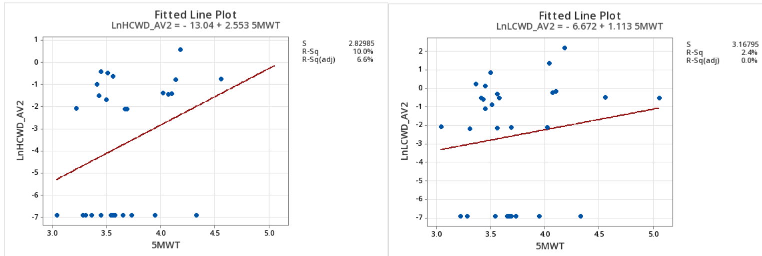


Figure 5 A) Natural log of the HCDW path average stepping error vs the combined non excluded YH and OH participants 5MWT times (left). B) Natural log of LCDW path average stepping error vs the combined non excluded YH and OH participants 5MWT times (right).

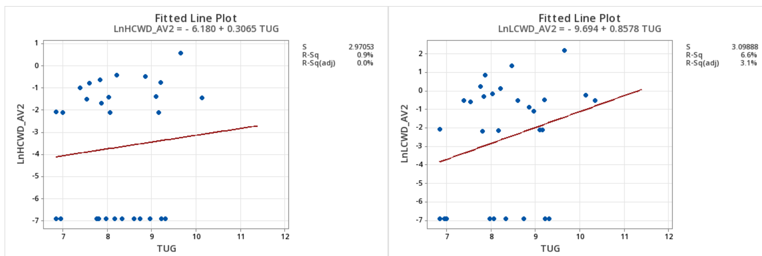


Figure 6 A) Natural log of the HCDW path average stepping error vs the combined non excluded YH and OH participants TUG times (left). B) Natural log of LCDW path average stepping error vs the combined non excluded YH and OH participants TUG times (right).

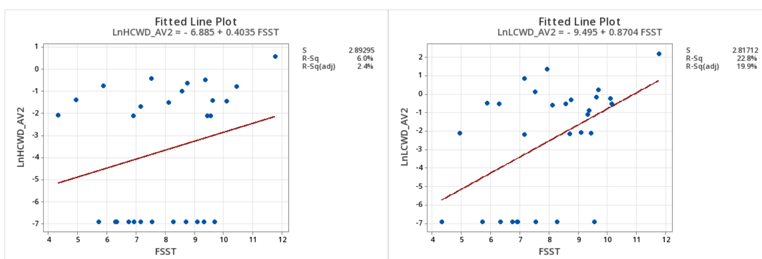


Figure 7 A) Natural log of the HCDW path average stepping error vs the combined non excluded YH and OH participants FSST times (left). B) Natural log of LCDW path average stepping error vs the combined non excluded YH and OH participants FSST times (right).

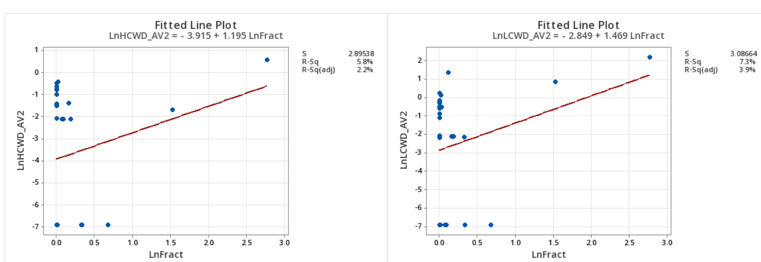


Figure 8 A) Natural log of the HCDW path average stepping error vs the combined non excluded YH and OH participants natural log of FrACT percentage (left). B) Natural log of LCDW path average stepping error vs the combined non excluded YH and OH participants natural log of FrACT percentage (right).

Chapter 4

Discussion

4.1 Overview

Aging in healthy adults showed no difference in preferred walk speeds. However, more complex, non-straight walking tests, like FSST and TUG, did show differences between OH and YH participants. YH adults had better contrast sensitivity compared to the OH adults. There were no significant findings with baseline testing correlations when walking on the HCWD path. With the LCWD path we observed that OH participants made more stepping errors than YH participants. When looking at correlations between baseline tests and completions of the walking tasks only FSST was seen as a good predictor of the number of stepping errors on the LCWD path. Out of this study we can see that as the paths increase in difficulty the OH participants struggled more. Interestingly the natural log of the FrACT percentages were not statistically significant predictors, in this study, of the average stepping error on the LCWD path. This suggests that perhaps there could be a different (e.g., more sensitive, or more comprehensive, etc.) visual contrast test that may be a better predictor. Since the only difference between LCWD and HCWD was path contrast sensitivity.

4.2 Implications

Walking is crucial to humanity. Walking provides a great deal of freedom to each individual. From taking strolls on the beach to wandering up and down the aisle at the grocery store, maintaining mobility is important to maintaining a healthy life. It was found that when older adults participated in physical activity in the LIFE Study, they would have a higher likelihood of still being able to complete a 400 meter walk over the 2.6-year clinical trial (Pahor et al., 2014). Seeing if we can use baseline clinical tests to predict walking success can help screen older adults who are at risk of losing the ability to have mobility. Mobility is key due to the fact it has been shown to predict life span. Nine separate cohort studies were examined to examine the health of an individual and how fast they could walk a distance between 8 feet and 6 meters (Studenski et al., 2011). It was found that there was a relationship between speed ($^{m}/_{s}$) and the predicted time a person had to live. There is a clear need to assess our older population to make sure they remain active throughout their later years of life.

Clinicians are proactive with testing patient's A1C levels for diabetes to testing lipid levels and prescribing statins to prevent heart disease. What is unclear in the literature is how we can use a combination of different baseline tests to pre-screen and prescribe to a patient a regiment to reduce the risk of falling. The CDC found that in 2021 38,000 people 65 and older died due to a fall (Centers for Disease Control and Prevention, 2024). The question that therefore needs to be looked at is how can we intervene before a fall occurs? From the basics of just moving to possibly paying for a personal trainer or physical therapist, the healthcare field may need to include these kinds of interventions to reduce the risk of falling.

4.3 Limitations of the Present Study

The Vicon camera system we used normally uses ten cameras. Due to technological difficulties our study only utilized nine out of the ten different cameras. The missing camera introduced some uncertainty in tracking the marker movements like marker dropouts that would require gaps to be filled after data collection. Then because stepping errors were identified from the marker trajectories, false positives/negatives in stepping errors were created. This led to the exclusion of 23 data points between the

YH and OH groups on either the HCWD or LCWD path for this paper. The additional data may have aided in finding more statistically significant correlations between the groups.

Another limitation that may affect the study could be the shoes that the participants wore. The study allowed participants to wear comfortable walking shoes. But it is known that a worn-down shoe can cause an increase in slipping (Sundaram et al., 2020). So if participants wore older shoes, it could lead to increased instability while walking, which might affect the outcome of the treadmill task and clinical baseline tests like the FSST.

There is a debate in the literature about the reliability of walking on a treadmill and how it correlates to walking in the real world (Schmitt et al., 2021). For this study, we wanted to limit confounding variables: weather, brightness of the room, walking speed, and the surface participants would walk on. One way to do this is to have people walk on a treadmill in a climate-controlled room.

Lastly, though not looked at for this paper, there was no eye tracking while participants walked on the treadmill. In future studies this could be used to see if older participants or people with glasses looked down more, looked around more, or scanned the paths and/or environment differently.

4.4 Suggestions for Future Studies

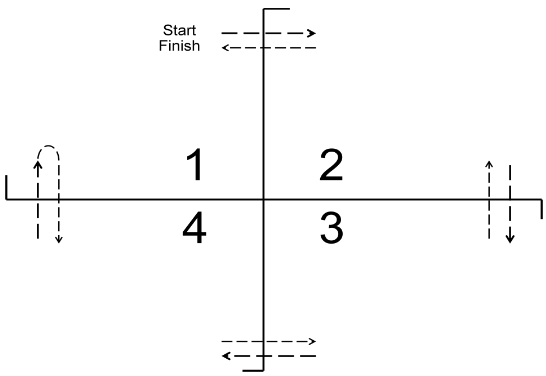
To expand on this study, it could be beneficial to recruit middle-aged adults. It would be interesting to explore whether this age range would align closer to YH groups, OH groups, or somewhere in between the two. It could depend on factors other than age like baseline test results. Another area to explore is the addition of adding screening questions based on the physical activity levels of all the participants. It is helpful to see if more active participants in the older age group would complete the tasks with less stepping errors than participants that are less active. Along with looking at the physical components, it may be beneficial to track the cognitive exercises that people participate in during their spare time. It may be possible that if someone participates in reading, completing sudoku puzzles, or doing Connections on The New York Times that the individual can complete the walking task with less stepping errors.

4.5 Conclusion

In this study we investigated whether to see if baseline tests would be good predictors of how adults would complete walking on a treadmill with different path conditions. 20 OH and 20 YH adults were tested after exclusion and obtaining 57 average stepping error data points on both HCWD and LCWD paths, we found that the FSST times were statistically significant in predicting the average amount of stepping errors participants would make while walking on the LCWD path. With this we can start to investigate other predictors of stepping errors made while on these paths, with the goal of finding trends that are clinically relevant to allow clinicians to help their patients reduce the chances of falling.

Appendix A

Baseline Testing Images

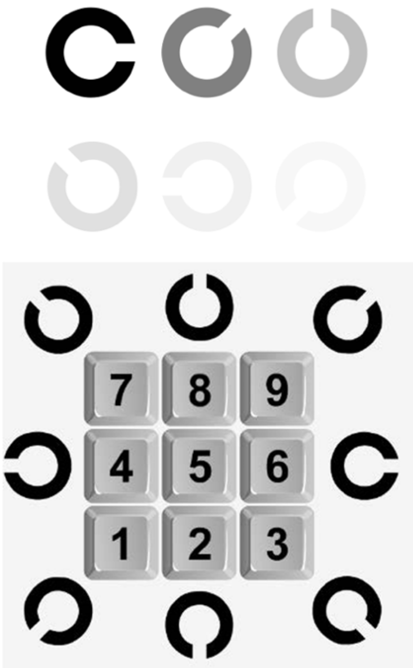


This is the four square step test set-up. The four dashed arrow goes first clockwise 1-4, then after reaching box 1 again you go back to box 4 going counterclockwise and follow the six dashed arrow until reaching box 1 again. Make sure that the participant is directed to have both feet in the box before moving on to the next one

Dite, W., & Temple, V. (2003). *FSST Set-Up* [Digital]. https://doi.org/10.1053/apmr.2002.35469

This an example image of one of the icon-FES tasks that a participant would be asked to rate on a 1-4 scale based on fear of falling during the task.

NeuRA. (n.d.). *Example of icon-FES Activity* [Digital]. Retrieved April 3, 2025, from https://neura.edu.au/resources-tools/apps/iconfes



This is the set-up for the FrACT test. Participants would press the number where they see the Landolt C. The contrasts would range from high (the dark C) to low (the very light grey).

Bach, M. (n.d.). Example of the Landolt C and How the People Would Complete the FrACT Test [Digital]. Retrieved April 3, 2025, from *https://michaelbach.de/fract/*.

Appendix B

Example Photos of the Different Paths


Low Contrast Straight Path (LCST)


Low Contrast Windy Path (LCWD)

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