5-2023

Gaze During Turning in Older Adults

Kalina Mavrov

Gaze During Turning in Older Adults

Thesis by

Kalina Mavrov

In Fulfillment of the Requirements for the

University Honors Program Thesis/Capstone/Creative Project

Department of Biomechanics

University of Nebraska at Omaha

Advisor: Dr. Carolin Curtze

May 2023

Abstract

To navigate complex environments, our gaze needs to attenuate to locomotor tasks, such as walking and turning. Shifting gaze (i.e., rotation of the eyes and head), is important when moving through different environments. The aim of this study was to compare gaze anticipation during clinical tests and complex real-world locomotion. I hypothesized that older adults would shift their gaze in a new heading direction in anticipation of turns. I further predicted increased gaze anticipation in tasks that have a high demand for spatial orientation. Participants were asked to complete clinical tasks consisting of a 2-minute walk, figure-8, and 360-turning in place, and to navigate along a hallway consisting of a variety of turns to the left and right. Eye-tracking glasses were worn by the participant to collect horizontal head and eye movements. My findings highlight the importance of eye and head coordination for locomotion. Moreover, gaze attenuation was highly task specific. Real-world situations required increased spatial orientation, and in turn increased eye and head movements to complete the task. This suggests different tasks require different levels of spatial orientation and clinical tests should be adequately complex to produce ecologically valid results.

Introduction

To navigate real-world environments, eye and head movements need to attune to the locomotor task (Franchak et al., 2021; Matthis et al., 2018). Gaze anticipation during walking and turning is critical for motor anticipation when reorienting towards a new heading direction (Grasso et al., 1998). Gaze is defined as the combination of eye movements plus head movements (Franchak et al., 2021; Kandel et al., 2000).

Any locomotion task requires some form of turning for the completion of an activity. Glaister and colleagues reported about 35-45% of the steps taken during daily activities such as going to the store, navigating through a cafeteria, from one office to another, and from an office to a car are non-straight steps (Glaister et al., 2007). This study also found that there are architectural constraints that play a role in the amount of turning that occurs during daily activities. When the space is more constrained, such as a cafeteria or an office space, more turning will be required to get from one point to the next, whereas walking from an office to a car has more opportunity for straight walking (Glaister et al., 2007). Consequently, turning and gaze behavior are important factors in the navigation of these everyday environments.

Turning is a complex task that requires spatial orientation which is achieved by integrating inputs from the visual, vestibular, and proprioceptive systems (Authié et al., 2015; Hicheur & Berthoz, 2005). Turning follows a top-down sequence of segmental reorientation, beginning with the eyes and head, followed by the reorientation of the body into the new heading direction (Bernardin et al., 2012; Cocks et al., 2021; Imai et al., 2001; Lamontagne et al., 2007). This segmental coordination can become altered in people with stroke and Parkinson’s disease leading to a more ‘en-bloc’ turning behavior (Earhart, 2013; Lamontagne et al., 2007).

Authié and colleagues set out to determine if anticipatory gaze shifts persist during walking in the dark without vision (Authié et al., 2015). Their study showed that gaze anticipation occurs when navigating in darkness or in light. Thus, highlighting the fundamental role of gaze and head anticipation for spatial orientation.

The predominant paradigm of the above-described studies is clinical and in-laboratory turning tasks. Building on technological advances, this project aimed to compare gaze anticipation during clinical tests and complex real-world locomotion in natural environments. I hypothesized that older adults would shift their gaze in a new heading direction in anticipation of turns. Moreover, I predicted a stronger gaze anticipation in tasks that have an increased demand of spatial orientation/navigation.

Methods

Participants

Five healthy female subjects ranging in age from 50-64 years old (M=58.6 years, SD=5.639) participated in this study (Table 1). All participants had normal or corrected to normal vision which was verified using a Snellen chart. The experimental protocol was approved by the University of Nebraska at Omaha institutional review board. All participants gave their informed consent prior to the data collection.

Table 1. Demographics of participants

Subject	Age (years)	Height (m)	Weight (kg)
1	61	1.737	77.1
2	62	1.737	92.9
3	56	1.676	81.7
4	50	1.676	79.4
5	64	2.012	68.0
Mean (SD)	58.6 (5.639)	1.768 (0.140)	79.82 (8.971)

Data Acquisition

Tobii-Pro eye-tracking glasses were used to collect data on the eye movements of each participant. Visual correction lenses were fitted to the eye-tracking glasses for participants who needed correction to normal (20/20) vision. The system recorded eye movements using infrared light and head movements using a gyroscope and accelerometer at a sampling frequency of 100 Hz. The data allows for the reconstruction of the gaze (i.e., the combination of eye and head movements) for further analysis. The Tobii-Pro system shows videos of the inner and outer view of the left and right eye along with a live-streamed video of the environment through the glasses (Fig. 1.) Each recording requires a calibration of the glasses. Participants are asked to look straight ahead at a single-point calibration card. As part of a larger study, participants wore 9 inertial measurement units (IMUs) to record full-body kinematics (APDM Wearable Technologies., Portland, OR). Only the data from the Tobii-Pro eye-tracking glasses will be presented in this thesis.

A **B** **C**

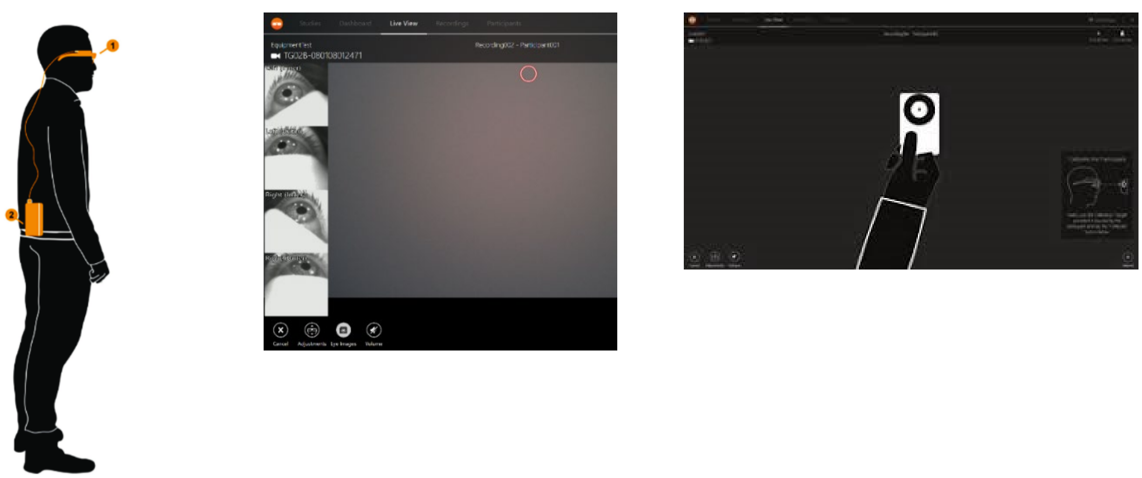

Fig.1. Tobii-Pro eye-tracking system. **A)** Tobii-Pro eyeglasses (1) and recording unit (2) as worn by participants (Tobii Pro n.d.). **B)** Software brings up view of left and right eye. Video is streamed from glasses with the red circle illustrating gaze point. **C)** Calibration card held up at eye level to ensure eyes are visible.

Tasks

Participants were instructed to complete four separate tasks (Fig.2). 1) A 2-minute walk comprised of 180-degree turns in the clinical space. Two tape marks, placed on opposite sides of the room, were used as distance markers for stopping and turning. 2) Figure-8. Two cones were placed 5 feet apart and participants were instructed to walk in figures of eight around them for the time allotted. 3) 360-turning in place. Participants stood in place and completed alternating 360-degree turns. For example, if the participant turned towards the left first, the next turn was to be to the right. 4) Hallway walk. Participants followed a known trajectory through a hallway in the building.

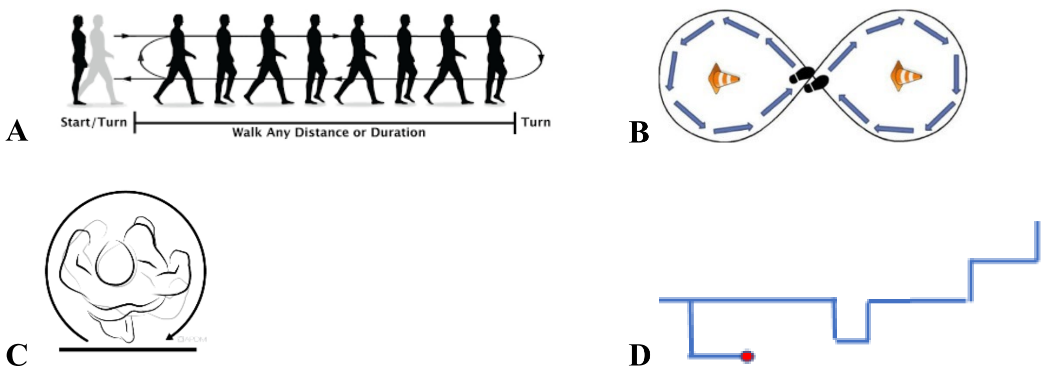

Fig. 2. Walking and turning tasks. A) 2-minute walk, **B)** Figure-8, **C)** 360-turning in place, and **D)** Hallway walk. Schematic trajectory of the hallway with 90- and 180-degree turns. The red dot illustrates start and end position.

Data Processing and Statistical Analysis

Raw data from the Tobii-Pro eye-tracking glasses were exported and further processed using an open-software package for MATLAB (Niehorster et al., 2020) to extract horizontal head and eye movements. Finally, those outputs were further processed using custom MATLAB scripts. To describe changes in heading angle and eye movements as a function of the different tasks, I extracted the following primary outcomes: Pearson correlations were calculated to assess the strength of the linear relationship between head and eye movement. Pearson correlation values can range from -1 to 1, where correlation coefficients between -0.5 and -1 are defined as a moderate negative correlation. Linear regression coefficients were calculated to describe the linear relationship. The slope describes the rate of change between head and eye movements.

Results

Horizontal Eye and Head Movements (Raw Data)

Exemplary time series data of the horizontal eye and head movements for Participants 1 and 3 during the 2-minute walking task are shown in Fig. 3. The top graphs illustrate the left and right eye horizontal movements throughout the task and the bottom graphs illustrate the head movement. The red spikes indicate horizontal head movements to the left and right. The spikes in the positive direction indicate a left turn and the spikes in the negative direction indicate a right turn. Participants shown appeared to favor turning to the left, as all the spikes are in the positive direction. Note that Participant 3 turned to the right at the beginning of the trial and then proceeded to turn left for the remainder of the walk. Participant 1 turned right at about 30 seconds of the walking trial.

2-minute walk

Participant 1 Participant 3

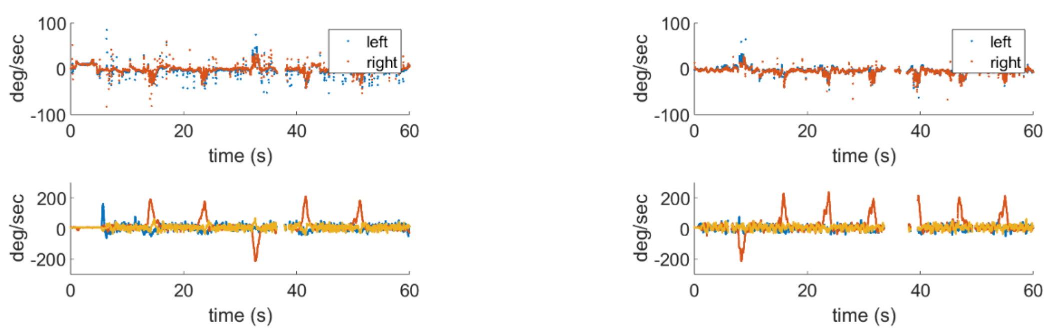

Fig. 3. Example data of horizontal eye (top) and head movements (bottom) in the 2-minute walking task for Participants 1 and 3. Head movements are indicated as follows: horizontal (red), vertical (blue), and roll (yellow).

In the figure-8 task, participants are required to take alternating turns to the left and right (Fig. 4). Due to the alternating nature of the task, the data appears in a rhythmic pattern from one direction to the next. Participant 1 showed an increase in head roll (yellow) while performing the turns of this task. Participant 1 completed 14 turns and Participant 3 completed 18 turns in the first minute of the task. Participant 3 moved in figures of eight faster than Participant 1.

Figure-8

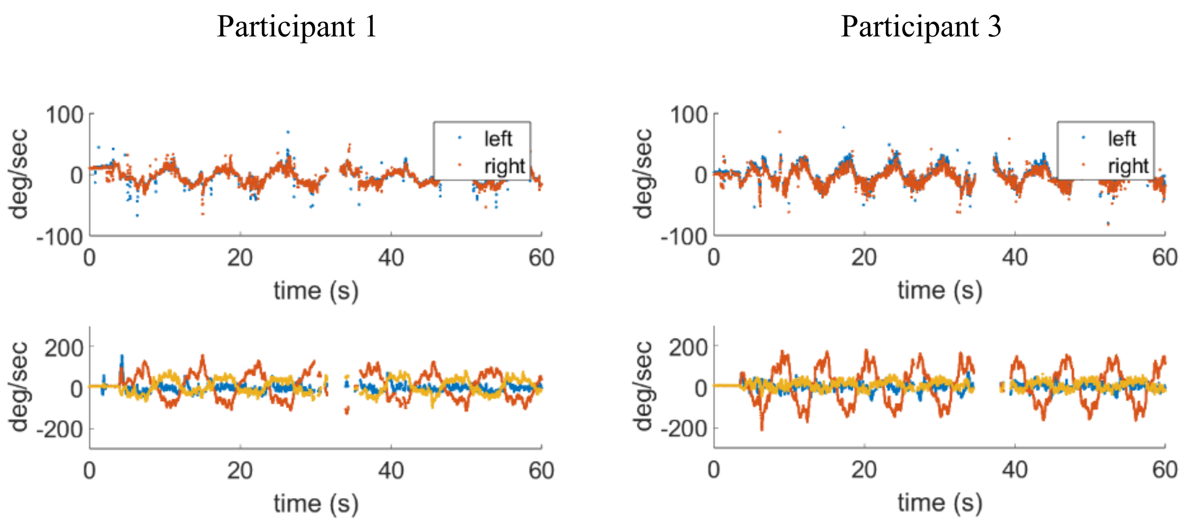

Fig. 4. Example data of horizontal eye (top) and head movements (bottom) in the figure-8 task for Participants 1 and 3. Head movements are indicated as follows: horizontal (red), vertical (blue), and roll (yellow).

The 360-turning in place task appeared like the figure-8 task, with alternating turns as seen in Fig. 5. Participant 3 had faster turns whereas Participant 1 had slower turns. Participant 3 has twice the amplitude at 500 deg/sec than Participant 1 who was at 250 deg/sec. This indicates a faster horizontal movement of the head as each turn was completed. More horizontal eye movements were collected for Participant 1, with the slower turns as they moved through the turns and the program was able to pick up the visual feedback from the glasses. Participant 3 had sparce horizontal eye movements due to their faster movements.

360-turning in place

Participant 1 Participant 3

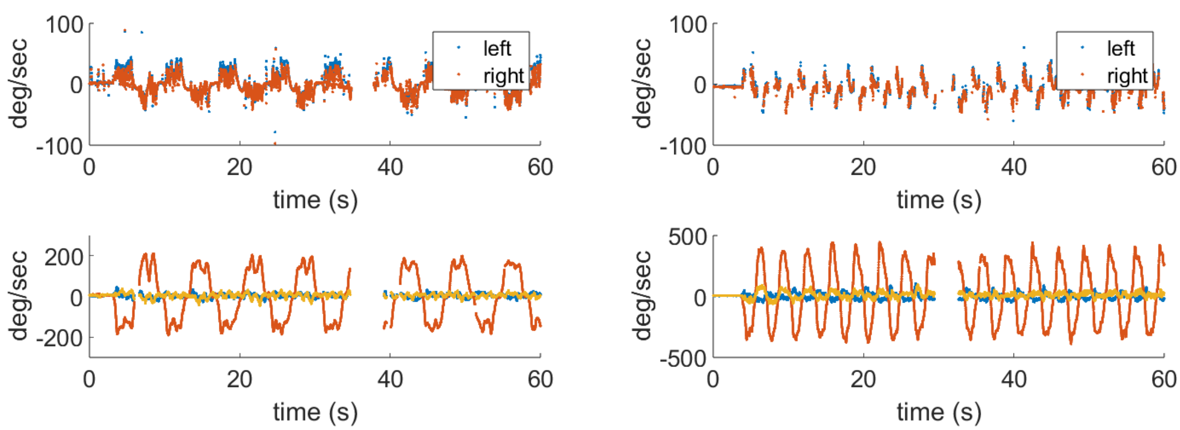

Fig. 5. Example data of horizontal eye (top) and head movements (bottom) in the turning in place task for Participants 1 and 3. Head movements are indicated as follows: horizontal (red), vertical (blue), and roll (yellow).

During the hallway walk, less structured 90- and 180-degree turns were not as prominent. The large spike at around 15 seconds shows that Participant 1 looked to the left and then immediately and quickly redirected their head and gaze to the right to continue their walk down the hallway which is not seen in other participants. Note that Participant 1 had more prominent horizontal head movements as the red lines spike left and right, but Participant 3 does not have the same spikes to the right even though the same hallway was used in all trials.

Hallway Walk

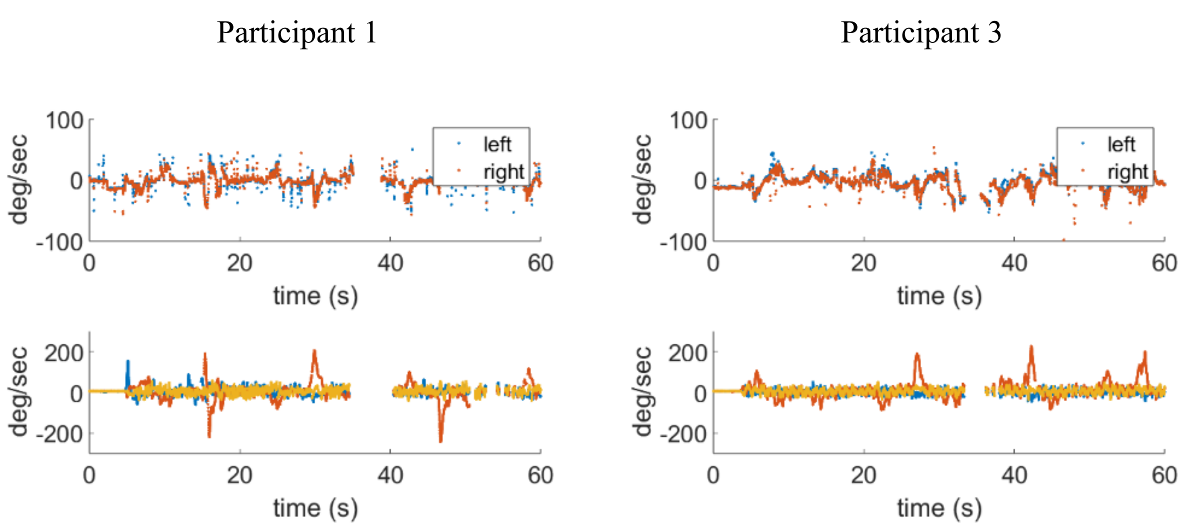

Fig. 6. Example data of horizontal eye (top) and head movements (bottom) in the hallway walk for Participants 1 and 3. Head movements are indicated as follows: horizontal (red), vertical (blue), and roll (yellow).

Gaze Shifts: Horizontal Head-Eye Movements

The coordination of gaze and head movement during turning is shown in Fig. 7. The participant leads with their gaze, which is the combination of horizontal eye and head movements into each of the turns. The separation between gaze and head movements was the greatest at about the peak of each turn suggesting an increase in horizontal eye movements into the new heading direction at around this phase. This was a consistent finding in all participants and tasks.

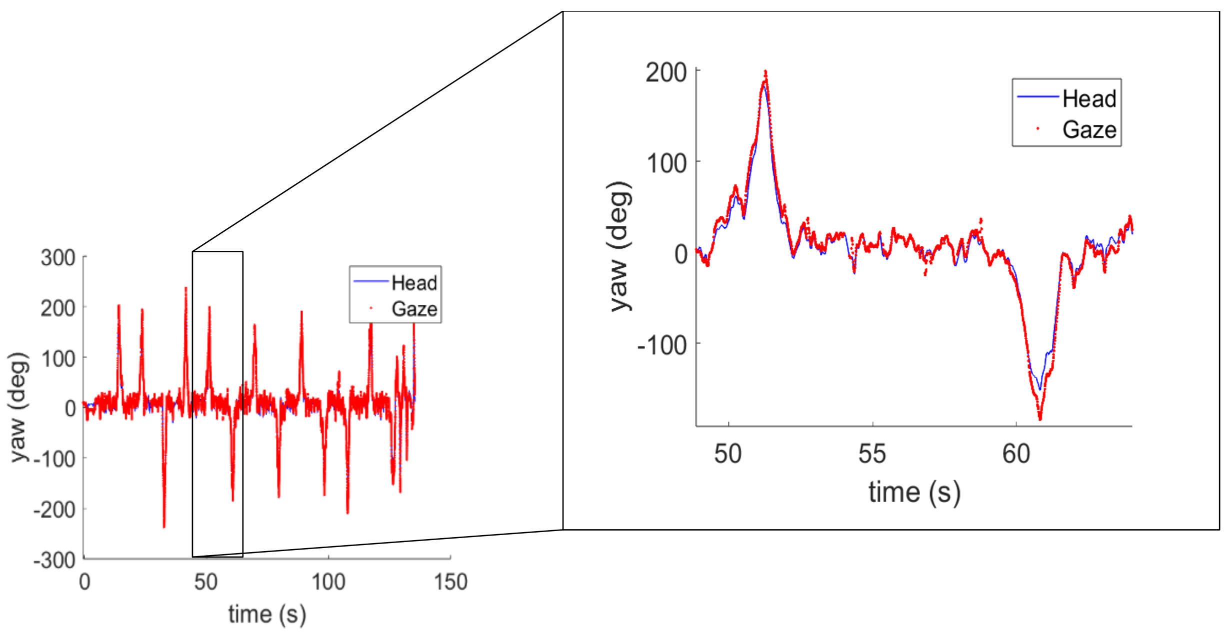

Fig. 7. Example of the movement of the head and gaze in the horizontal direction. (2-minute task)

Association between Head and Eye Movements

The next step was to investigate the association between eye movement and turn angle for each task (Fig. 8). Visual inspection of the correlation between eye and head movements across the four tasks showed marked differences in the strength and rate with which these are coupled.

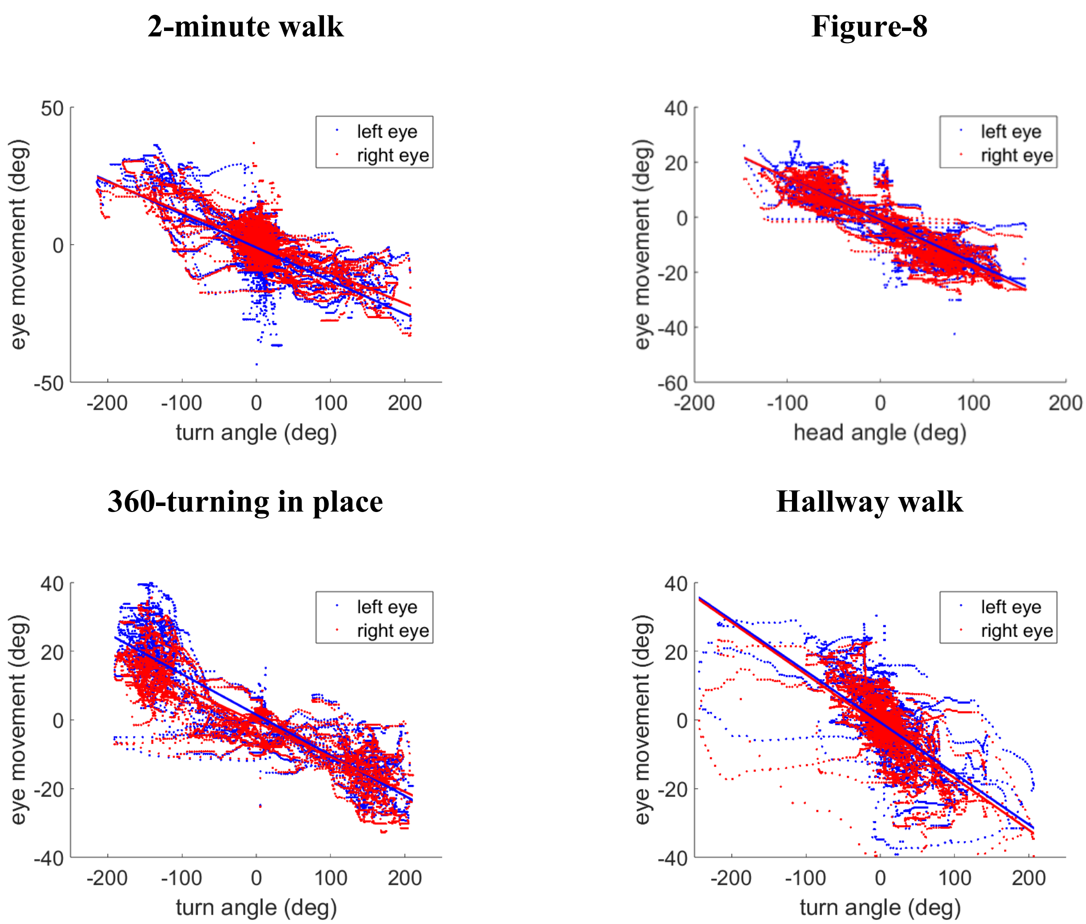

Fig. 8. Association between horizontal head angle and eye movement for the different walking tasks. Blue and red lines represent the linear regression line between head and eye movement in the horizontal plane.

Pearson Correlation and Regression Coefficient

Pearson correlations between eye and head movements revealed a strong negative association for all tasks (Fig. 9). Specifically, the 360-degree turning in place and figure-8 had a strong linear relationship as calculated by the Pearson correlation. Moreover, the figure-8 and the hallway walk had a similar rate of change between eye and head movements as calculated by the regression coefficient.

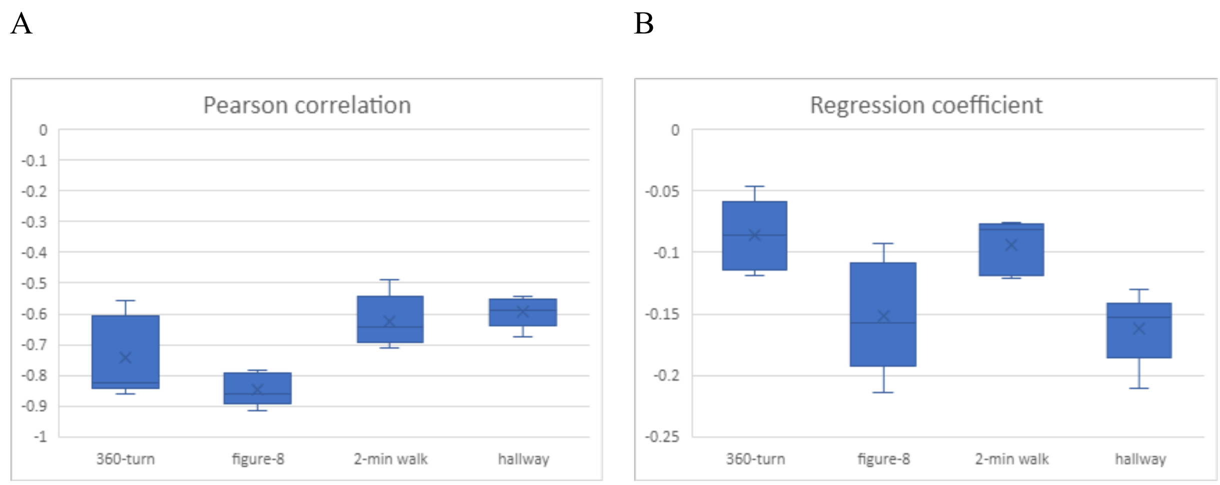

Fig. 9. Association between eye and head movements. **A)** Pearson correlation. **B)** Regression Coefficient.

Discussion

In this study, I characterized gaze in the context of turning in older adults performing clinical laboratory tasks and real-world everyday walking. Overall, four different walking and turning tasks were completed. The clinical tasks consisted of a 2-minute walk, figure-8, and 360-turning in place; the real-world walking task was the hallway walk.

The aim of my study was to investigate the coordination between head and eye movements when performing each of the tasks to advance our understanding of visual control and steering during locomotor tasks. In this study, I observed a strong association between the eye and head movements in all participants. Participants attenuated their gaze more during the figure-8 and hallway walk than during the 2-minute walk and the 360-turning in place. This suggests that there may be less spatial orientation needed to complete these tasks. The relatively low level of gaze anticipation in the 360-turning in place suggests that the participants did not need to attenuate their gaze to complete this task. The same applies to the 2-min walk, as the participants are walking back and forth in the same space. Here, visual control appears to be mainly used to provide intermittent updates on spatial orientation to not drift in space while walking. When navigating the real-world hallway, participants needed to spatially orient and thus attenuated their gaze to complete the spectrum of turns and straight-ahead sections.

Both clinical tests and real-world walking produced data that showed participants lead with their gaze into the turn, suggesting the importance of eye and head coordination for locomotion. This confirms previous findings that the eyes assist in the reorientation of the head when a change in direction occurs (Authié et al., 2015; Bernardin et al., 2012). Specifically, in real-world situations, individuals will attune their gaze as their walking direction changes and orient themselves to the trajectory they want to follow. In the hallway task, individuals had to plan out their path as it was an unfamiliar, variable environment. The 360-turning in place is more of a balance task than one that requires spatial orientation. Matthis et al studied the gaze strategies for foot placement control when navigating terrains of different complexity (Matthis et al., 2018). They found that individuals tune the distance at which they look ahead to plan their next step to the complexity of the locomotor task (Matthis et al., 2018). That is when walking on flat terrain, participants would look further ahead than when walking on rough terrain.

My study confirms previous findings that the participants lead with their gaze as they move into each turn (Imai et al., 2001). Linear regression analysis revealed distinct differences in the level of gaze anticipation between tasks, that is participants lead with their gaze less during the 360-turning in place and the 2-minute walk; and increased gaze anticipation in the figure-8 and hallway walk.

Conclusion

I found gaze attenuation to be highly task specific. Tasks that required more spatial orientation also required more eye and head movements for navigation. The outcomes of this study should be considered in future research that aims to investigate deficits in the visual control of locomotion. Real-world locomotion requires an increased gaze anticipation for spatial orientation and navigation. Clinical tests need to be sufficiently complex to be considered ecologically valid.

Funding

This research was supported by the FUSE Award UNO and the NIH P20 GM 109090.

References

Authié, C. N., Hilt, P. M., N'Guyen, S., Berthoz, A., & Bennequin, D. (2015). Differences in gaze anticipation for locomotion with and without vision. *Frontiers in Human Neuroscience*, *9*. https://doi.org/10.3389/fnhum.2015.00312

Bernardin, D., Kadone, H., Bennequin, D., Sugar, T., Zaoui, M., & Berthoz, A. (2012). Gaze anticipation during human locomotion. *Experimental Brain Research*, *223*(1), 65–78. https://doi.org/10.1007/s00221-012-3241-2

Cocks, A. J., Young, W. R., Ellmers, T. J., Jackson, R. C., & Williams, A. M. (2021). Concern about falling is associated with segmental control when turning in older adults. *Gait & Posture*, *88*, 105–108. https://doi.org/10.1016/j.gaitpost.2021.05.011

Earhart, G. M. (2013). Dynamic control of posture across locomotor tasks: Posture Control Across Locomotor Tasks. *Movement Disorders*, *28*(11), 1501–1508. https://doi.org/10.1002/mds.25592

Franchak, J. M., McGee, B., & Blanch, G. (2021). Adapting the coordination of eyes and head to differences in task and environment during fully-mobile visual exploration. *PLOS ONE*, *16*(8), e0256463. https://doi.org/10.1371/journal.pone.0256463

Glaister, B. C., Bernatz, G. C., Klute, G. K., & Orendurff, M. S. (2007). Video task analysis of turning during activities of daily living. *Gait & Posture*, *25*(2), 289–294. https://doi.org/10.1016/j.gaitpost.2006.04.003

Grasso, R., Prévost, P., Ivanenko, Y. P., & Berthoz, A. (1998). Eye-head coordination for the steering of locomotion in humans: An anticipatory synergy. *Neuroscience Letters*, *253*(2), 115–118. https://doi.org/10.1016/S0304-3940(98)00625-9

Hicheur, H., & Berthoz, A. (2005). How do humans turn? Head and body movements for the steering of locomotion. *5th IEEE-RAS International Conference on Humanoid Robots, 2005.*, 265–270. https://doi.org/10.1109/ICHR.2005.1573578

Imai, T., Moore, S. T., Raphan, T., & Cohen, B. (2001). Interaction of the body, head, and eyes during walking and turning. *Experimental Brain Research*, *136*(1), 1–18. https://doi.org/10.1007/s002210000533

Kandel, E. R., Schwartz, J. H., & Jessell, T. M. (2000). The Control of Gaze. In *Principles of Neural Science* (Fourth Edition, p. 40). McGraw-Hill.

Lamontagne, A., Paquette, C., & Fung, J. (2007). Stroke Affects the Coordination of Gaze and Posture During Preplanned Turns While Walking. *Neurorehabilitation and Neural Repair*, *21*(1), 62–67. https://doi.org/10.1177/1545968306290822

Matthis, J. S., Yates, J. L., & Hayhoe, M. M. (2018). Gaze and the Control of Foot Placement When Walking in Natural Terrain. *Current Biology*, *28*(8), 1224-1233.e5. https://doi.org/10.1016/j.cub.2018.03.008

Niehorster, D. C., Hessels, R. S., & Benjamins, J. S. (2020). GlassesViewer: Open-source software for viewing and analyzing data from the Tobii Pro Glasses 2 eye tracker. *Behavior Research Methods*, *52*(3), 1244–1253. https://doi.org/10.3758/s13428-019-01314-1

Tobii Pro. (n.d.). Tobii Pro Glasses 2 QuickStart Guide. Retrieved May 2, 2023, from http://andrewd.ces.clemson.edu/courses/cpsc881/manuals/Tobii/Tobii-Pro-Gasses-2-Quick-Start-Quide.pdf.