ABSTRACT

**THE INTERCONNECTION OF THE VESTIBULAR AND OCULOMOTOR
SYSTEMS ANALYZED IN HEALTHY YOUNG ADULTS BY EXAMINING
POSTURAL SWAY**

by
Cassandra Martin

In order to study the human brain in a non-invasive way, the vestibular and oculomotor systems have been analyzed simultaneously. To achieve this, an eye movement and balance assessment was conducted for 29 (23 male; 21.6 ± 3.8 years) healthy participants with no history of concussions, brain injuries, vertigo, migraines, brain surgeries, eye surgeries, or amblyopia. The tasks consisted of eyes open, eyes closed, horizontal saccades, vertical saccades, vergence jumps, horizontal vestibulo-ocular reflex (VOR), and vertical VOR. Each task was completed in two stances: feet shoulder width apart and feet together. Distance, velocity, sway area, center of pressure (COP) frequency, and number of eye movements were of interest. The findings indicate that only VOR movements are strongly correlated with COP frequency ($p < 0.035$). The lowest peak COP frequency recorded, 0.5 Hz, was present across all tasks. These healthy participants exhibited a high endurance, which is the ability to perform at a consistent activity for some amount of time, in regard to the first half and second half of one task are statistically insignificant ($p > 0.112$). A wide stance has been found to positively effect postural stability compared to a narrow stance.

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Cassandra Martin

**A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Biomedical Engineering**

Department of Biomedical Engineering

May 2022

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I would like to dedicate this thesis to my family and friends.

ACKNOWLEDGEMENT

To my advisor, Dr. Yaramothu, thank you for giving me an opportunity to be involved with research for the first time and for guiding me whenever I needed it. To my committee members, Dr. Alvarez and Dr. Grasman, thank you for serving on my committee. To the members of SQRL Lab: Michaela, Rifath, AJ, Mitch, Itay, Sophia, and Stuti, thank you all for helping with data collection, teaching me on how to use the OMAT equipment, and for accepting me into your lab. To my parents, thank you for everything. To my sister, Ally, thank you for checking in to see how far I've come.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

Figure   **Page**

LIST OF TERMS

Amblyopia	Lazy eye.
Benign paroxysmal positional vertigo (BPPV)	Dizziness or spinning sensation.
Cutaneous Proprioception	Sensory receptors in the skin that sense movement, action, and location.
COP	Center of Pressure.
Force Plate	A device that measures pressure and movement.
HS	Horizontal Saccades.
HVOR	Horizontal VOR.
Hz*s	COP movements.
OMAT	OculoMotor Assessment Tool.
Saccade	Rapid eye movements in a singular plane between two points of visual fixation.
Vergence	Convergence and divergence eye movements.
VOR	Vestibulo-Ocular Reflex.
VJ	Vergence Jumps.
VS	Vertical Saccades.
VVOR	Vertical VOR.

CHAPTER 1

INTRODUCTION

The foundations by which the human brain processes signals, is not fully understood. Studying external mechanisms, such as the oculomotor and vestibular systems, provide such insight without invasive procedures. Here, postural stability and eye movements of healthy human participants were analyzed to determine the relationship between the vestibular and oculomotor systems, respectively.

1.1 Objectives

The objectives of this study are: (1) study the relationship between the oculomotor system and the vestibular system; (2) distinguish differences and similarities between Trial 1 and Trial 2; (3) study endurance by comparing the first 30s and second 30s of one task; (4) compare stance positions of feet shoulder width apart and feet together.

1.2 Hypotheses

It can be hypothesized that a longitudinal analysis between Trial 1 and Trial 2 will yield an increase in number of movements as well as center of pressure frequency, while also a decrease in mean distance, velocity, and sway area. Furthermore, the first 30s and second 30s of each task will not vary, showing the healthy population did not experience fatigue. In regard to stance position, a reduction in sway area and center of pressure frequency will be observed in a wider stance when compared to a narrower one.

Each hypothesis has been structured in said way because of the healthy participant population. It is believed healthy participants will present a high endurance in both stance stability and number of eye and head movements. Familiarity of the protocol may also influence the data from the second trial.

1.3 The Oculomotor System

Motion of the eyes is controlled by the oculomotor nerve; the third cranial nerve which originates from the midbrain of the brainstem (Leanage, 2019). There are six muscles which control movement of the eye and one muscle for the eyelid. A single eye has the ability to move horizontally, vertically, and torsionally (Eggert, 2007). The medial and lateral rectus are pairs which adduct and abduct the eye. The superior and inferior rectus elevate and depress the eye. The superior and inferior oblique provide torsional rotation and therefore the ability to look down and out or up and out, respectively. The final muscle is the levator palpebrae superioris, which provides motion to the eyelid.

As light enters the pupil, it passes through the body of the eye and lands on the retina. Within the retina are light sensitive cells called photoreceptors. There are two types: rods, which are activated in low light, and cones, which provide vision during daylight (Fu & Yau, 2007). There is an abundance of cone-shaped photoreceptors at the fovea, a small depressed region at the center of the retina (Kolb, 1995). As the muscles move the eye, the fovea becomes aligned with an object along the visual field. This object becomes in focus, while the surrounding regions are out of focus (Madrid & Hout, 2018). Thus, eye movements are necessary to view a clear environment.
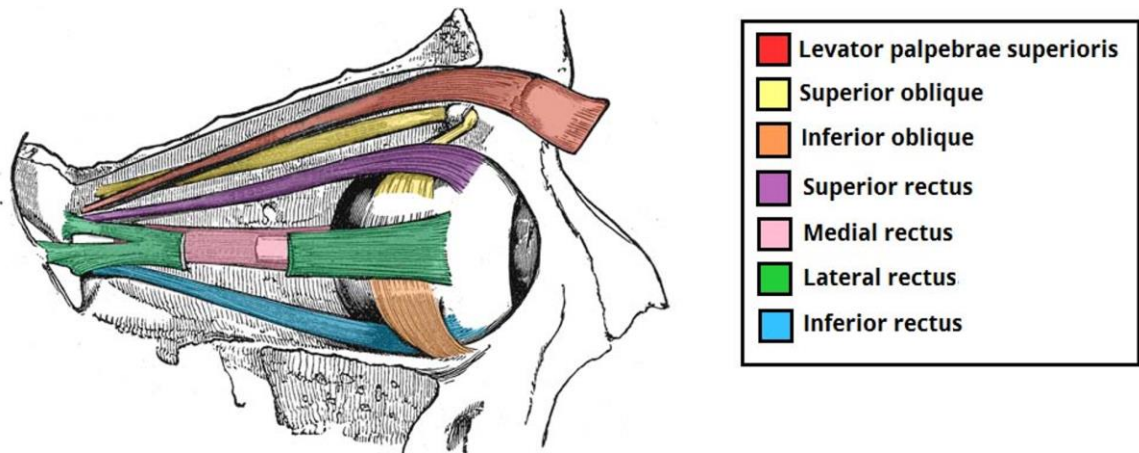
Figure 1.1 Lateral view of the extraocular muscles.

Source: (Leanage, 2019)
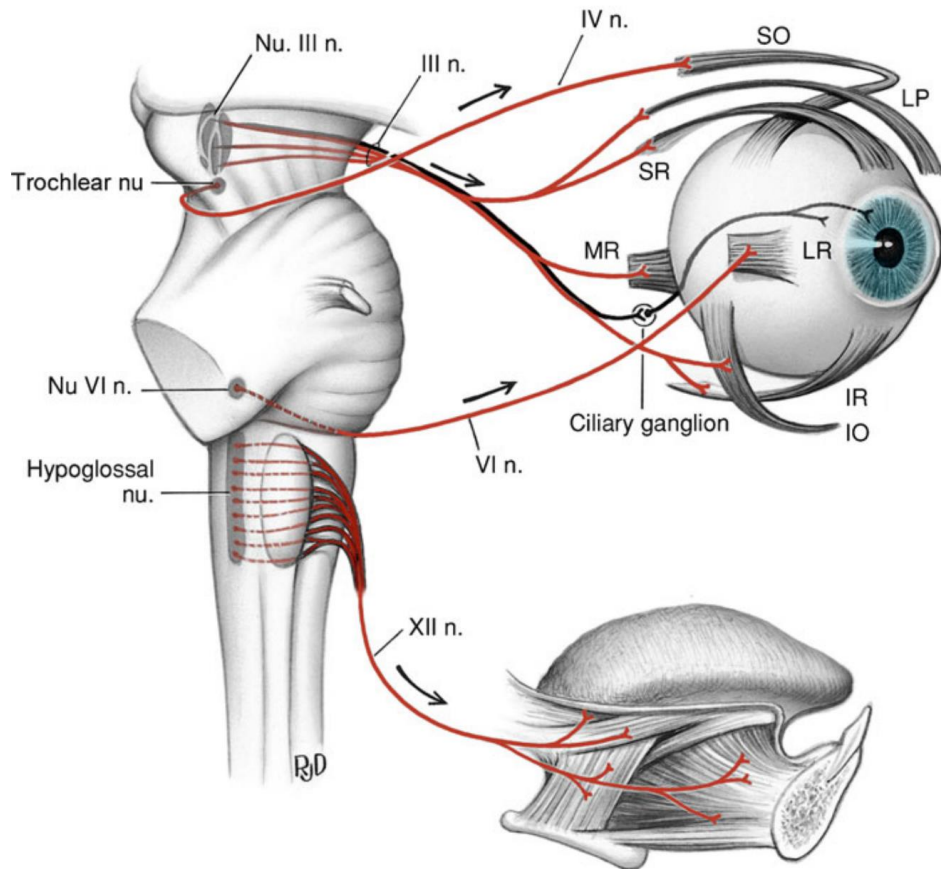
Figure 1.2 Somatic efferent cranial nerves: oculomotor (III), trochlear (IV), abducent (VI), and hypoglossal (XII) which enables tongue movement.

Source: (Strominger et al., 2012)
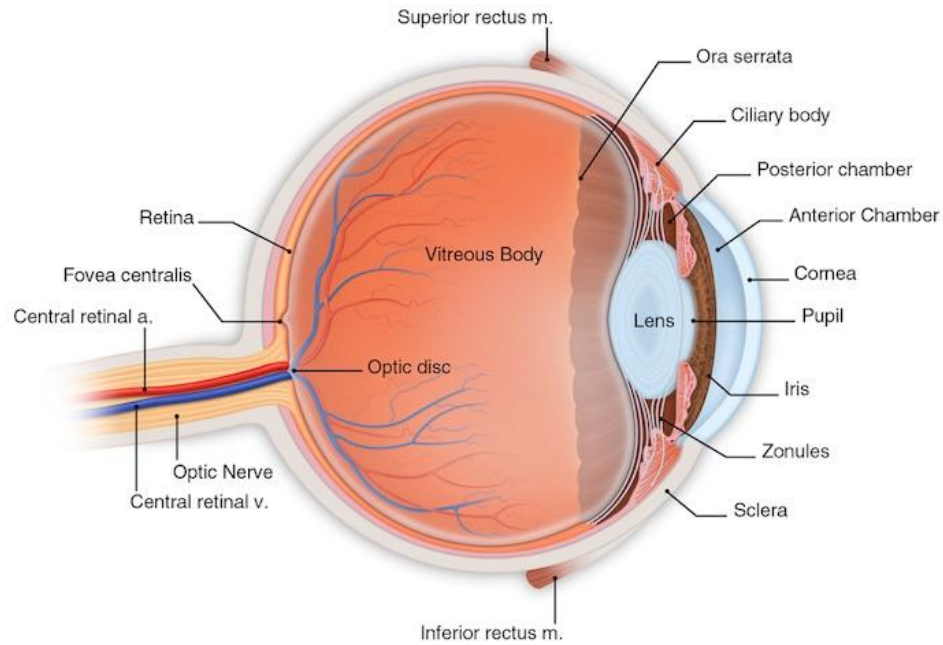
Figure 1.3 The human eye anatomy.

Source: (*How The Eye Works*, 2020)

1.4 The Vestibular System

The vestibular organs are housed within the inner ear and are responsible for detecting head rotations and movements via the semicircular canals or the otoliths, respectively (Day & Fitzpatrick, 2005). The vestibular labyrinth contains three semicircular canals, which are oriented perpendicular to each other. The canals are filled with a fluid that flows into the ampulla, a larger area at the base of the canal (Gray, 2020). Fine hairs are located within the ampulla and are activated when the fluid displaces, thus bending the hairs. Gravitational forces are detected by hair cells within the utricle and saccule, which are activated either by horizontal or vertical movements, respectively (Rabbitt et al., 2004). Crystal structures are suspended above these hair cells in a fluid that shift in response to movement. Benign paroxysmal positional vertigo (BPPV) is associated with the dislodgement of these crystals, causing the hair cells to send false signals to the brain.
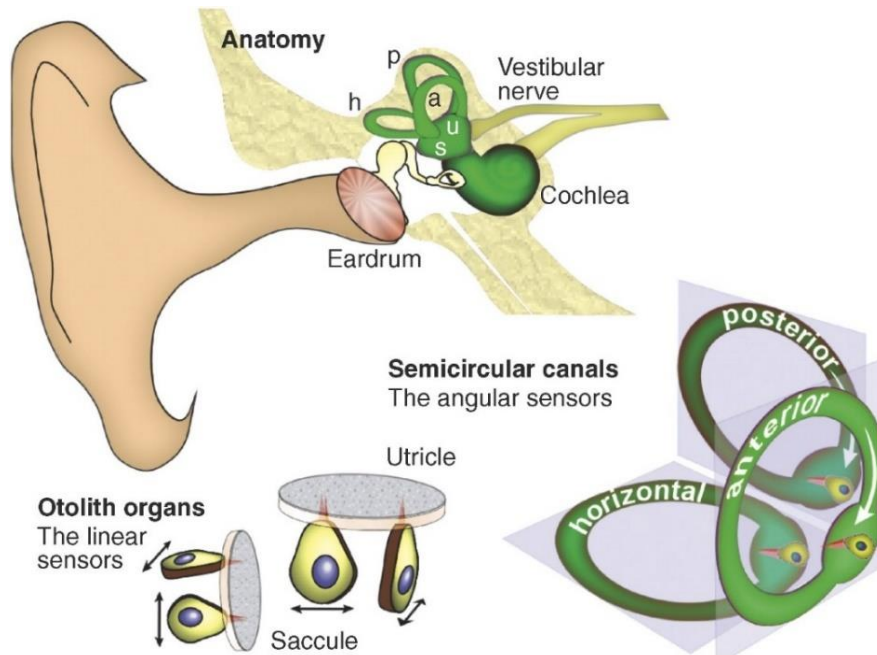
Figure 1.4 The vestibular organs.

Source: (Day & Fitzpatrick, 2005)
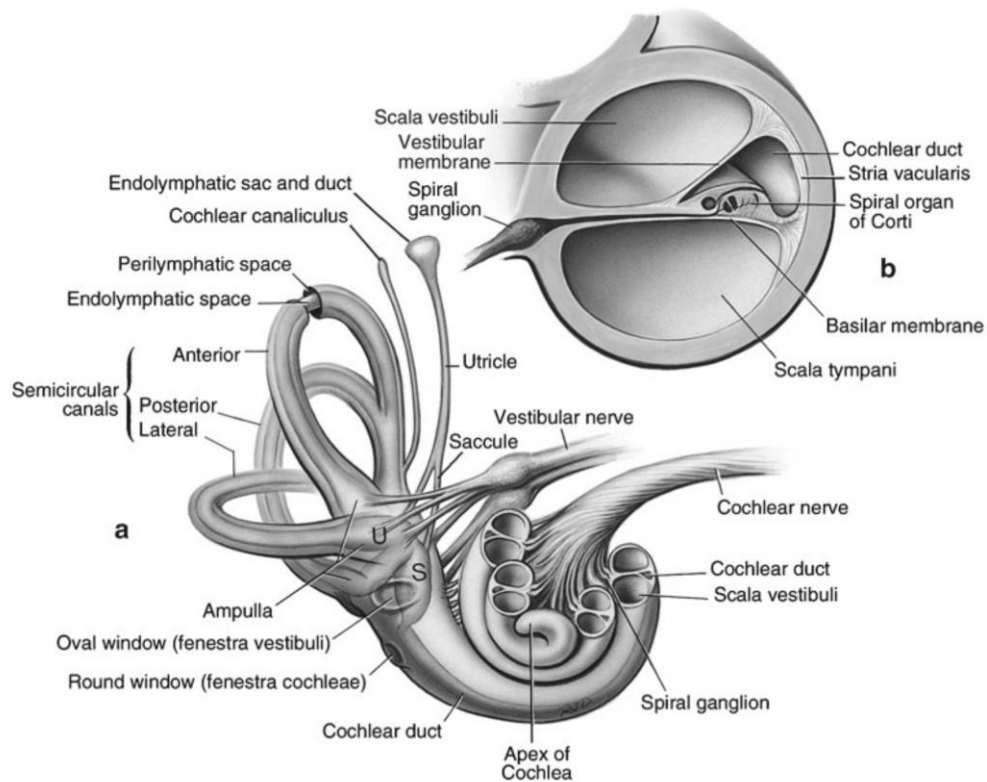
Figure 1.5 The labyrinth. (a) Right labyrinth, from the front. (b) Cross section through a half turn of the cochlea.

Source: (Strominger et al., 2012)

1.5 Types of Eye Movements

The human eye is capable of executing four basic types of movement: vergence, saccades, vestibulo-ocular reflex (VOR), and smooth pursuit (Purves & Williams, 2001).
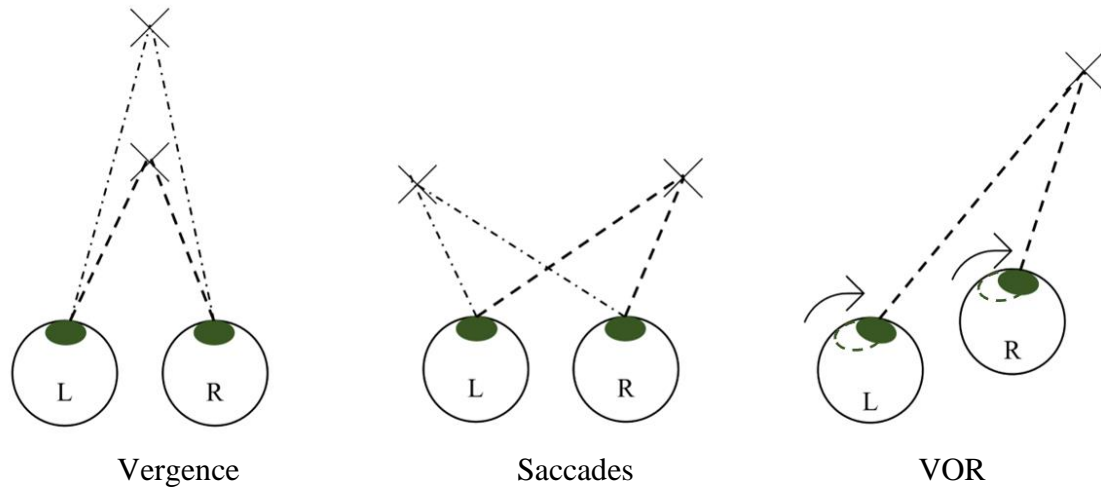
Figure 1.6 Three types of eye movements discussed in this paper.

1.5.1 The Vergence System

The purpose of vergence eye movements is to provide animals with binocular single vision the ability to fixate on targets within a depth of field (Mays, 1984). This type of eye movement involves fixating the eyes on a far object and transitioning them to a near object (Robinson, 1968). During this process, the eyes turn inwards or outwards equally, in opposite directions, in order for the image to focus on the fovea (Downey & Leigh, 1998). These movements can be further represented as divergence or convergence, respectively. Divergence is identified when the eyes rotate outwards, while convergence is represented as an inwards rotation. Due to the opposite rotations of the eyes, fast movement cannot be achieved, and thus, are the slowest type of eye movements (Robinson, 1968).

1.5.2 The Saccadic System

Saccades are rapid, conjugate eye movements used to isolate objects in different locations. The speed of the movement reduces time spent performing the saccades, which in turn allows the eyes to focus on numerous locations (Liversedge et al., 2012). As the eyes change fixation from one target to the next, a period of rest, referred to as a fixation, occurs which can last from 100 milliseconds to several seconds (Rayner, 1998). Saccades are even present while fixating on an object. These miniature movements, often unnoticeable, are referred to as 'microsaccades' and are necessary to prevent the image from fading (Martinez-Conde et al., 2004).

1.5.3 The VOR System

VOR movements are achieved by fixing the eyes on an object and turning the head back and forth. While in motion, it can be observed that not only the targeted object is clear, but objects within the peripheral vision can also be distinguished. This, therefore, explains that the purpose of this system is to stabilize the visual field while the head is in motion (Khojasteh & Galiana, 2007). In order for stability to be achieved, three elements that make up this system need to work concurrently: the vestibular organs, a central processing mechanism, and the ocular muscles (Szentagothai, 1950). The process begins within the inner ear where angular velocity and linear acceleration are perceived by the semicircular canals and the otoliths, respectively. This information is sent to the vestibular nucleus complex and the cerebellum, where the output is sent to and read by the ocular muscles (Fetter, 2007).
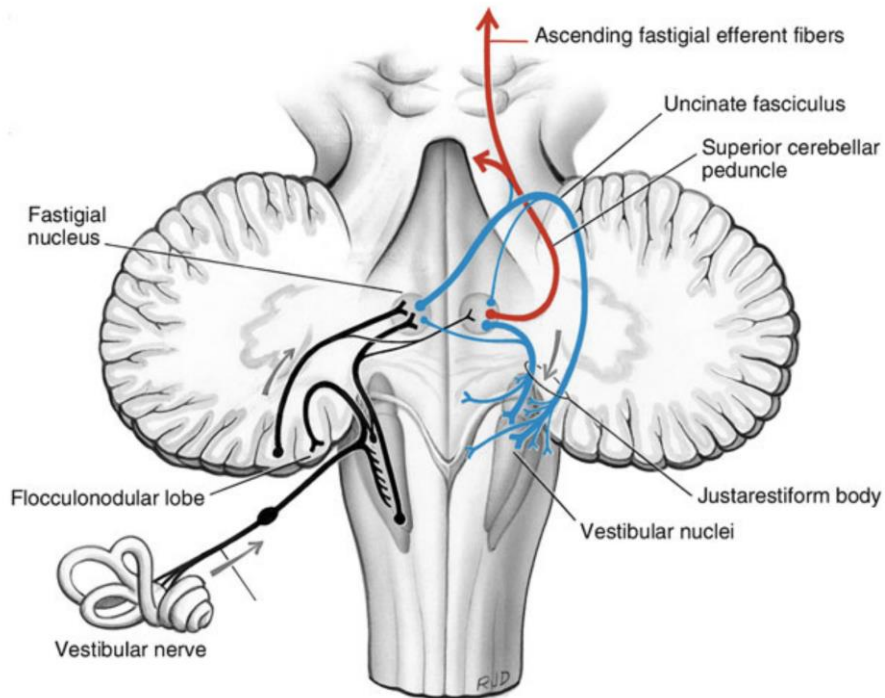
Figure 1.7 Vestibulocerebellar input/output pathways in the cerebellum and brainstem. Input to the vestibular nucleus complex and cerebellum (black). Output from the fastigial nuclei to the ascending fastigial efferent fibers (red).

Source: (Strominger et al., 2012)

1.6 Endurance

Endurance testing often relates to physical exercise and the ability to execute consistently for an extended period of time. It can be used to evaluate cardiovascular health (Lear et al., 1999) or muscular capabilities (Strand et al., 2014). Few studies have applied endurance testing to the oculomotor system, which are in the forms of saccadic, reading, and vergence testing (Greenspan, 2018; Ramulu et al., 2013; Yaramothu et al., 2019). The duration of these tests ranged from 18 minutes to 30 minutes. Each study demonstrated that healthy individuals did not express significant fatigue. Studying the endurance of the oculomotor system provides a different outlook on fatigue when compared to the generally accepted physical exertion form of endurance testing.

1.7   Stance Position

The purpose of increasing stance width is to provide stability. For example, healthy individuals may be unaffected by narrow or wide stances, but individuals with balance impairment may opt for a wider stance (Day et al., 1993). The idea is that by distributing one's body weight over a larger area, essentially creating a more stable base, reduces the chance of losing balance and therefore falling. When comparing narrow and wide stance widths, only postural control in the medial and lateral directions are effected (Scrivens et al., 2008). This is due to the muscular structure differences within the sagittal and frontal planes (Day et al., 1993). At a narrow stance, the COP sway area and the lower body torque increases, whereas a wide stance produces the opposite effects (Goodworth et al., 2014; Jacobs et al., 2015).

CHAPTER 2

METHODS

2.1 Participant Demographics

29 healthy participants with no history of concussions, brain injuries, vertigo, migraines, brain surgeries, eye surgeries, or amblyopia, were selected. The participants were recruited from the New Jersey Institute of Technology in Newark, NJ. All participants signed a written consent form approved by the New Jersey Institute of Technology Institutional Review Board, upon receiving oral explanations of the procedure. The mean age was 21.6 years, 79% were males, and 21 participants indicated the usage of corrective lenses.

2.2 Data Collection

Each participant performed seven tasks with both feet shoulder width apart and feet together, resulting in fourteen tasks. Shoes were not permitted during data collection, as they affect cutaneous proprioception (Hausselle et al., 2021). Those who indicated the usage of corrective lenses were instructed to wear them during the experiment. The participants were instructed to keep their arms at their sides, stand with good posture, and refrain from voluntary movement of the body unless instructed. Data was collected for 60 seconds for each task in the following order: (1) eyes open, (2) eyes closed, (3) horizontal saccades, (4) vertical saccades, (5) vergence jumps, (6) horizontal VOR, and (7) vertical VOR. The order of the starting stance positions were randomized for the population. Each participant returned for a second trial after at least two days. The second trial consisted of the same procedures in the identical, original order including stance positions.

2.2.1 Equipment and Software

Bertec Digital Acquire version 4.12 was used to collect data from Bertec force plates (Figure 2.2). The force plates were leveled on the floor. The OculoMotor Assessment Tool (OMAT) was used for the following procedures: horizontal saccades, vertical saccades, vergence jumps, horizontal VOR, and vertical VOR (Figure 2.1) (*OculoMotor Assessment Tool (OMAT)*, 2022). The protocols which use the OMAT instrument have been obtained from the standardized testing procedure and modified to adjust to the needs of this study (Yaramothu et al., 2021). The OMAT Companion App was used to manually count the number of eye and/or head movements associated with each task (Yaramothu et al., 2021). It displayed the number of movements in three categories, 1st 30s, 2nd 30s, and total 60s.

Figure 2.1 OMAT instrument.

Source: (*OculoMotor Assessment Tool (OMAT)*, 2022)
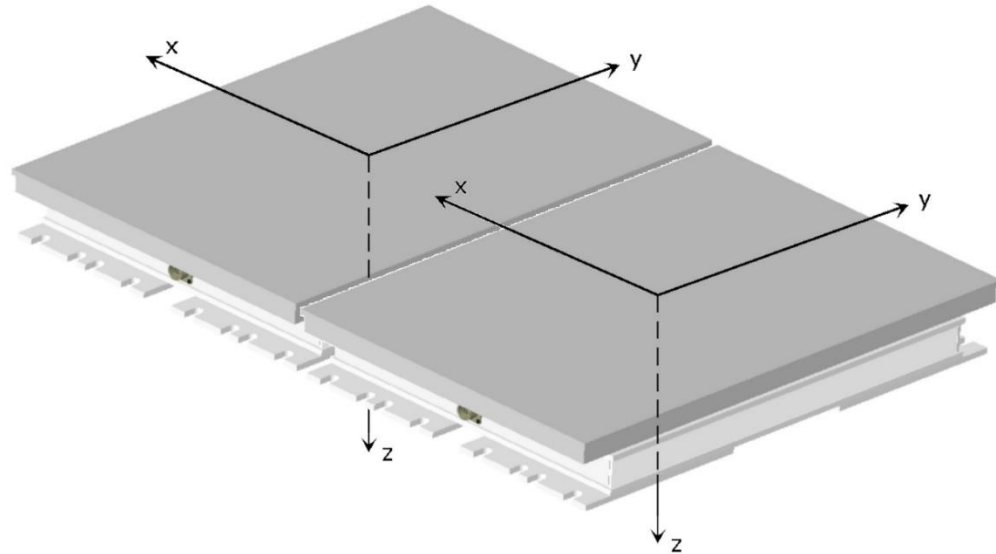
Figure 2.2 Force plate coordinate system and orientation where the participants' toes are oriented in the positive y-direction. Y-direction represents anterior/posterior (AP). X-direction represents medial/lateral (ML). Sampling rate was 1,000 Hz. Each force plate was pre-calibrated from the manufacturer; therefore the calibration matrix is stored digitally inside.

Source: (*Bertec Force Plates*, 2011)

2.2.2 Control

Two control tasks were conducted: eyes open and eyes closed. Eyes open incorporates both the vestibular and oculomotor systems, while eyes closed focuses on the vestibular system. In both tasks, the participant's orientation was as follows: barefoot, arms at their sides, and standing with good posture so that the head was level with the ground. In the case of eyes open, the participant was instructed to focus their gaze on an eye level target, selected as an uppercase "E", across the room 10 feet away.

2.2.3 Horizontal Saccades

The OMAT was oriented as predicted in Figure 2.1 with the narrow end resting on the bridge of the participant's nose so that the green marker was to their left. For the duration

of this exercise, the participant was instructed to move their eyes between the green and red markers, as fast as they could, without overshooting or undershooting, beginning on the green marker. Head motion was not permitted. The orientation of the participant remained the same.

2.2.4　Vertical Saccades

This exercise was conducted similarly to the horizontal saccades. The OMAT was oriented so that the green marker was positioned above their eyes. For the duration of this exercise, the participant was instructed to move their eyes between the green and red markers, as fast as they could, without overshooting or undershooting, beginning on the green marker. Head motion was not permitted. The orientation of the participant remained the same.

2.2.5　Vergence Jumps

The red and green attachments were removed from the OMAT as this test utilizes the sliders. The instrument was again positioned on the bridge of the nose. Two sliders were positioned on the bar, located 24 cm (far vergence demand of 13.7°) and 8.9 cm (near vergence demand of 33.7°) from the bridge of the nose (Yaramothu et al., 2021). The participant was instructed to begin on the slider furthest away from them and rapidly change their fixation between both sliders and only moving until a single vision was achieved. Head motion was not permitted. The orientation of the participant remained the same.

2.2.6 Horizontal VOR

A small target, selected as the large slider, was placed eye level at an arms distance from the participant, with the letters facing the participant, therefore eliminating the usage of the OMAT body. To conduct this exercise, the participant's eyes remained fixed on the target while their head moved in a horizontal direction, as if they were shaking their head 'no', as fast as they could. A full extension of rotation was desired. The orientation of the participant remained the same.

2.2.7 Vertical VOR

This exercise was conducted similarly to the horizontal VOR. The only difference is that the participant moved their head in the vertical direction, as if they were nodding their head 'yes'. The orientation of the participant remained the same.

2.3 Data Processing

MATLAB R2020a was used to process the raw COP force plate data. A 6th order lowpass Butterworth filter with a cutoff frequency of 3 Hz was applied. In the following equations, N, the number of data points, is 60,000; and T, the time for data collection, is 60 seconds. The COPx and COPy components was used to calculate the resultant distance, mean distance, mean velocity, and sway area. COPx relates to medial/lateral (ML) directions, while COPy relates to anterior/posterior (AP) directions. The COP frequency data utilized the force components in both the X and Y directions (Fx and Fy). Equations 2.1 through 2.4 were obtained from Prieto et al.

14

The resultant distance (RD) was calculated by finding the difference between the AP or ML coordinates from each of the plates. The Pythagorean theorem was then used to relate each ordered pair to the COP. The order by which the subtraction occurs does not affect the RD value, as it will always be positive.

$$RD = \sqrt{AP^2 + ML^2} \qquad (2.1)$$

The mean distance (MD) represents the average distance of the ordered pairs to the COP. It was calculated by the sum of the RD divided by the number of data points.

$$MD = \frac{1}{N} \sum_{i=1}^{N} RD \qquad (2.2)$$

The mean velocity (MV) represents the average velocity of the COP. It was calculated by the summation of the distances between consecutive ordered pairs.

$$MV = \frac{\sum_{i=1}^{N-1} \sqrt{(AP(i+1) - AP(i))^2 + (ML(i+1) - ML(i))^2}}{T} \qquad (2.3)$$

The sway area (SA) is the area of the COP path. It is calculated by, "summing the area of the triangles formed by two consecutive points on the COP path and the mean COP" (Prieto et al., 1996).

$$SA = \frac{1}{2T} \sum_{i=1}^{N-1} |AP(i+1) * ML(i) - AP(i) * ML(i+1)| \qquad (2.4)$$

The power spectrum of the COP frequency was determined by performing equations 2.5 through 2.9 in MATLAB in the present order. These equations are expressed in MATLAB syntax. Furthermore, A, B, and C expressed in the following equations, are

arbitrary variables represented to provide ease of readability between equations. A fast Fourier transform (FFT) was first performed to the difference of either Fx or Fy from each of the plates. It shall be noted that Fx in equation 2.5 can be represented as Fy.

$$A = \text{fft}(Fx_1 - Fx_2) \tag{2.5}$$

$$B = \text{abs}(A/N) \tag{2.6}$$

$$C = B(1{:}\,N/2 + 1) \tag{2.7}$$

$$C(2{:}\,\text{end} - 1) \ = \ 2 * C(2{:}\,\text{end} - 1) \tag{2.8}$$

$$\text{COP frequency} \ = \ 1000 * (0{:}\,(N/2))/N \tag{2.9}$$

Subsequent to equation 2.9, the peak COP frequency associated with the largest power spectrum intensity was isolated by omitting the DC component and surrounding frequencies of ± 0.15 Hz.

2.4 Statistics

IBM SPSS Statistics 28.0.0.0 was used to perform several statistical analyses. A repeated-measures ANOVA ($\alpha = 0.05$) with Bonferroni correction was first performed. The repeated-measures design was selected because it was applied to models which used the entire participant population. If $p < 0.05$, a secondary analysis, post-hoc t-test, was run.

CHAPTER 3

RESULTS

The participant population consisted of 29 individuals, and of that, 23 were male (79%) and 6 were female (21%). The age of the participants ranged from 18 years to 35 years (21.6 ± 3.8 years). Microsoft Excel (Version 2203 Build 16.0.15028.20178) was used to create several figures and tables.

3.1 Raw Data

The COP frequency spectrums, shown in Figure 3.1 (a) and (c), represent the intensity of the COP sway during horizontal VOR movements in a wide stance. The frequency associated with the largest power spectrum intensity was collected, 1.133 Hz and 0.3167 Hz, for (a) and (c), respectively. If the frequency is multiplied by 60 s, the results become similar to the number of total head movements: (a) 73 movements, 68 Hz*s; (c) 22 movements, 19 Hz*s. Figure 3.1 (b) and (d) represent the COP path and are expressions of the same data collection as in (a) and (c). The position of the COP path is related to weight distribution on the toes or heels, as wells as the left or right foot. A positive value along the anterior/posterior direction, indicates a COP shift towards the toes, while along the medial/lateral direction represents a shift towards the right foot. A clearer representation of this is expressed in Figure 3.2.
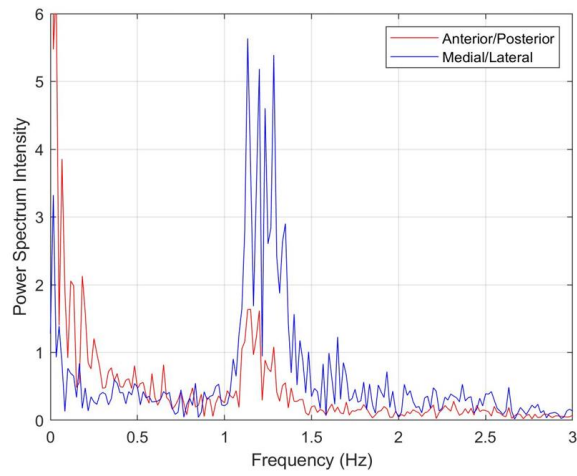
(a)
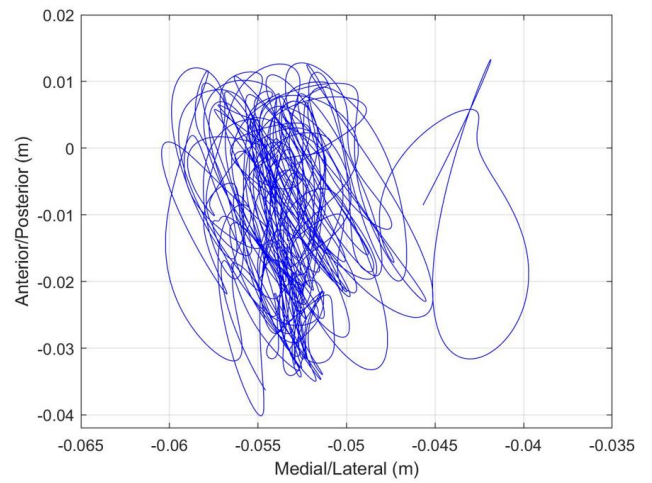
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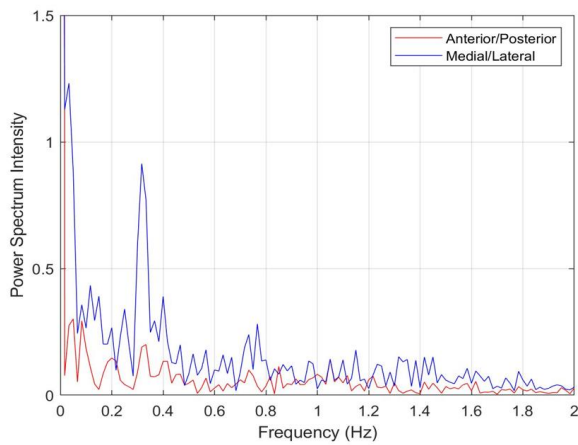
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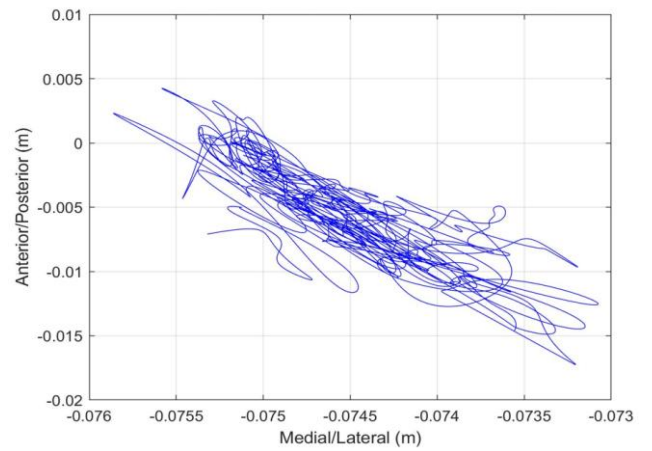
(d)

Figure 3.1 Raw COP data of trial 1, feet shoulder width apart, horizontal VOR. (a) participant 26 COP frequency spectrum; (b) participant 26 trajectory of COP; (c) participant 7 COP frequency spectrum; (d) participant 7 trajectory of COP.

Table 3.1 Average Number of Eye and Head Movements

		Trial 1: Feet Apart	Trial 2: Feet Apart	Trial 1: Feet Together	Trial 2: Feet Together
Horizontal Saccades	1st 30s	68.62 ± 17.79	74.69 ± 19.39	67.86 ± 14.99	73.17 ± 19.65
	2nd 30s	65.24 ± 14.76	66.97 ± 21.62	65.45 ± 14.56	66.76 ± 17.12
	Total 60s	133.86 ± 32.00	141.66 ± 38.89	133.31 ± 28.86	139.93 ± 36.39
Vertical Saccades	1st 30s	69.66 ± 15.59	73.24 ± 17.55	69.59 ± 15.15	72.55 ± 18.42
	2nd 30s	67.24 ± 15.53	69.93 ± 15.89	65.59 ± 13.55	68.00 ± 14.49
	Total 60s	136.90 ± 30.91	143.17 ± 33.00	135.17 ± 28.11	140.55 ± 32.09
Vergence Jumps	1st 30s	47.24 ± 9.45	55.59 ± 13.39	47.52 ± 12.99	52.76 ± 13.00
	2nd 30s	44.28 ± 9.36	52.07 ± 12.19	44.28 ± 10.18	49.45 ± 11.55
	Total 60s	91.52 ± 18.27	107.66 ± 25.33	91.79 ± 22.68	102.21 ± 23.96
Horizontal VOR	1st 30s	40.90 ± 15.69	47.79 ± 22.57	41.72 ± 18.94	48.14 ± 23.53
	2nd 30s	43.72 ± 16.25	49.17 ± 23.40	44.14 ± 19.13	49.38 ± 24.10
	Total 60s	84.62 ± 31.71	96.97 ± 45.85	85.86 ± 37.91	97.52 ± 47.55
Vertical VOR	1st 30s	43.31 ± 19.86	49.72 ± 25.44	45.52 ± 20.75	48.62 ± 24.01
	2nd 30s	45.10 ± 20.43	50.41 ± 24.54	46.34 ± 19.72	50.28 ± 23.36
	Total 60s	88.41 ± 40.05	100.14 ± 49.86	91.86 ± 40.36	98.90 ± 47.31
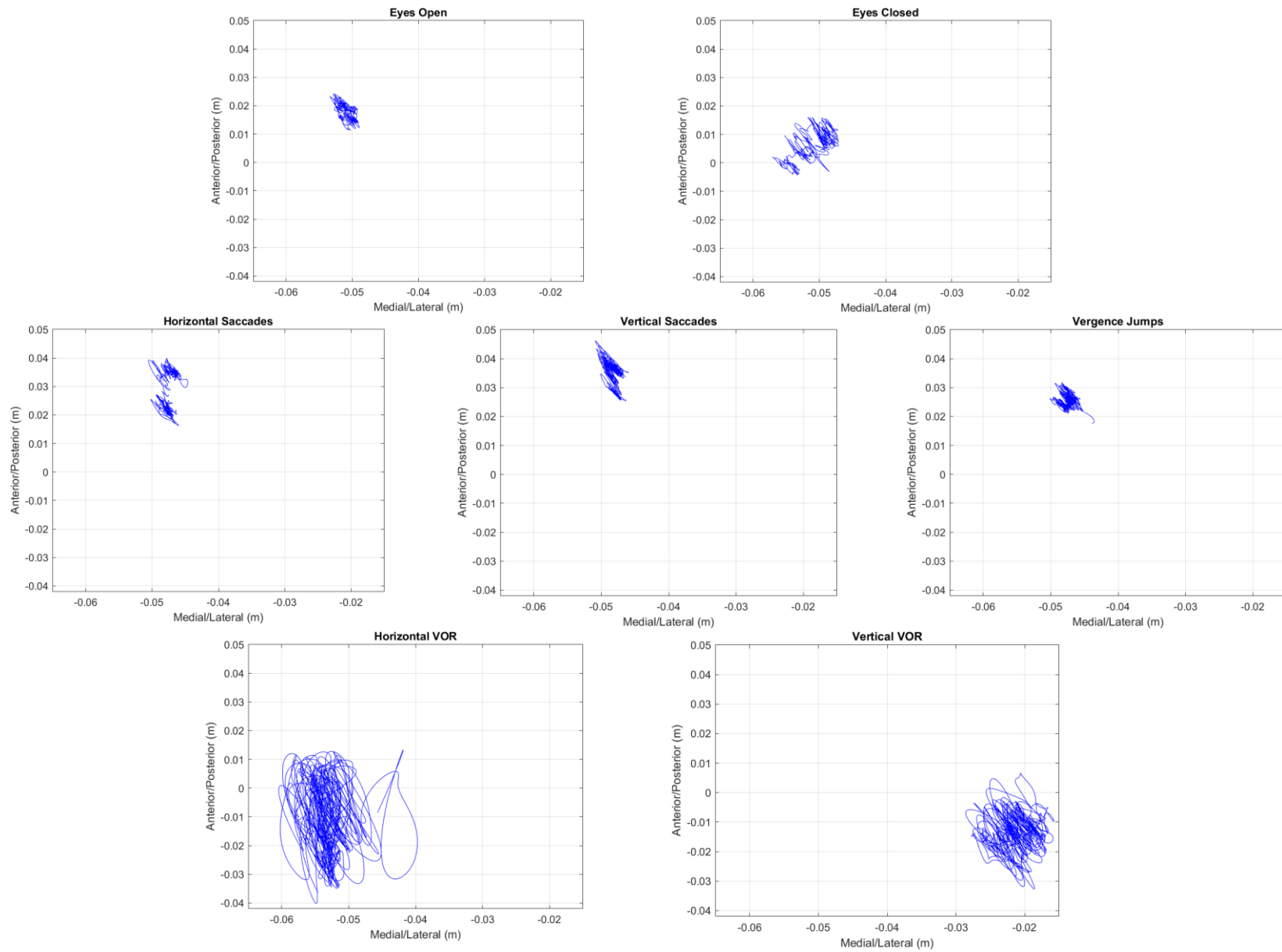
Figure 3.2 COP trajectory of Participant 26 for trial 1 with feet shoulder width apart.

Each of the plots in Figure 3.2 have the same limits for the axes so the COP distribution can be compared across all tasks. Large COP areas represent less postural control and in increase in sway area. Horizontal VOR and vertical VOR movements illustrate a COP concentration on the heels, while it is directed towards the toes for the other tasks. There is a slight shift towards the toes for horizontal saccades, vertical saccades, and vergence jumps, compared to the control groups. It is believed that the usage of the OMAT caused this participant to lean forwards unintentionally, in an attempt to better secure the OMAT to the bridge of the nose. In order to gather a pure form of these COP distributions, future studies should limit physical contact with the participants, so they are freely standing and uninfluenced to distribute their COP away from the natural locations. It shall be noted that the orientations of these COP paths are randomly distributed across the entire population and do not appear to favor directions for specific tasks as presented in Figure 3.2.

3.2 Oculomotor and Vestibular Systems

All figures and tables hereafter represent total participant population.

(a)

(b)

(c)

(d)
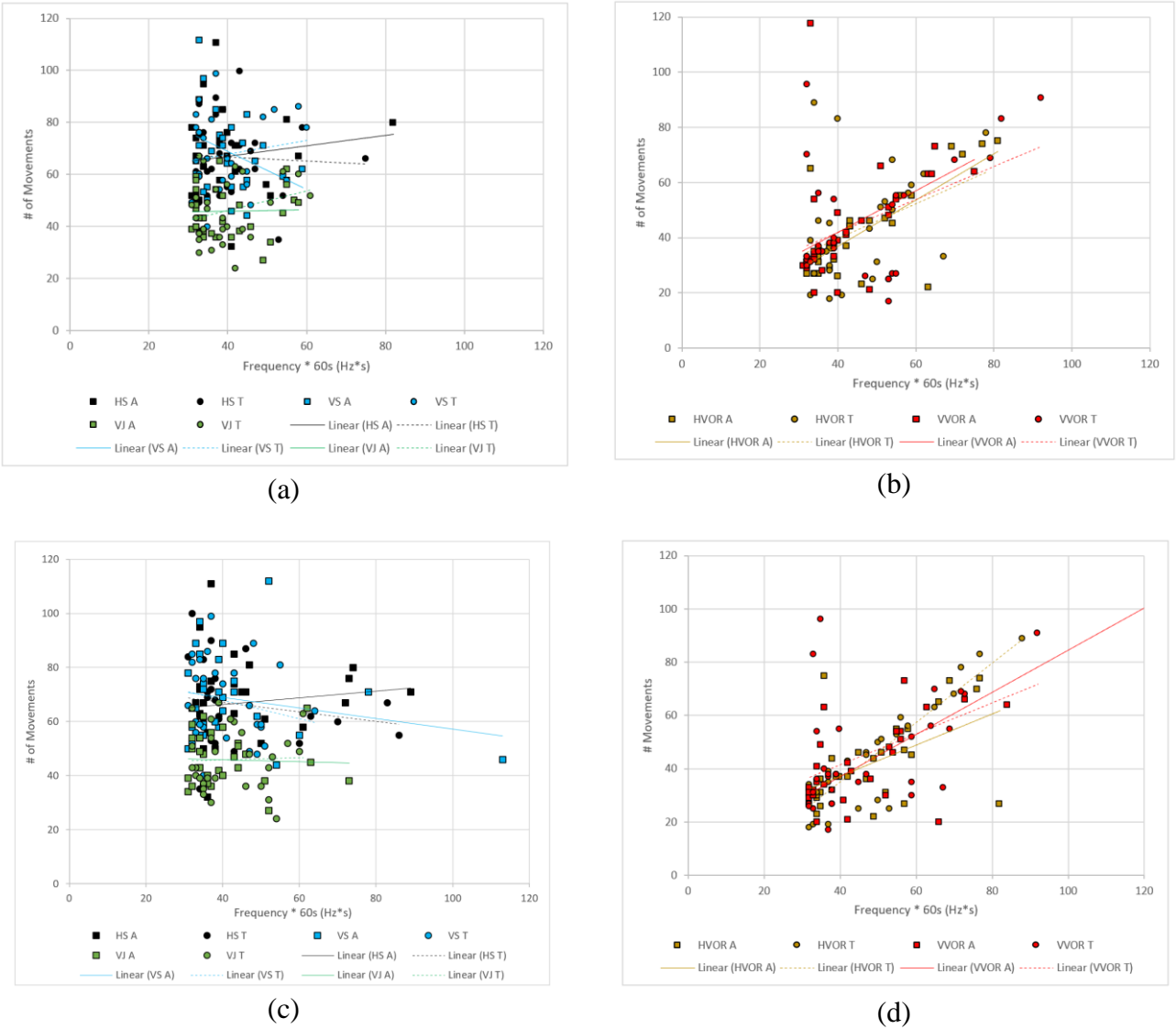
Figure 3.3 Correlation of COP frequency and number of movements for Trial 1. The frequency values were multiplied by 60 as the duration of each task was 60 seconds. The y-axis represents eye or head movements, and the x-axis represents COP movements. T represents feet together, whereas A represents feet apart. (a) medial/lateral frequencies for saccadic and vergence eye movements; (b) medial/lateral frequencies for VOR head movements; (c) anterior/posterior frequencies for saccadic and vergence eye movements; (d) anterior/posterior frequencies for VOR head movements.

Presented in Figure 3.3 is the correlation between COP frequency and number of eye or head movements in the medial/lateral and the anterior/posterior directions. The control tasks, eyes open and eyes closed, are not displayed as voluntary eye or head movements were not performed. Horizontal saccades, vertical saccades, and vergence jumps (Figure 3.3 (a) and (c)), do not display a correlation ($p > 0.177$). A correlation between COP frequency and number of head movements, however, is present for horizontal VOR and vertical VOR ($p < 0.035$). Despite these distinct differences, Figure 3.3 (a), (b), (c), and (d) commonly display a minimum frequency of about 0.5 Hz (30 Hz*s).

Table 3.2 Statistical Analysis Corresponding to Figure 3.3

Task	Stance Position	Medial/Lateral	Anterior/Posterior
Horizontal Saccades (HS)	Feet Apart	R=0.135, p=0.484	R=0.112, p=0.565
	Feet Together	R=-0.51, p=0.792	R=-0.177, p=0.357
Vertical Saccades (VS)	Feet Apart	R=-0.338, p=0.073	R=-0.211, p=0.273
	Feet Together	R=0.157, p=0.417	R=-0.205, p=0.287
Vergence Jumps (VJ)	Feet Apart	R=0.028, p=0.886	R=-0.038, p=0.843
	Feet Together	R=0.258, p=0.177	R=0.029, p=0.879
Horizontal VOR (HVOR)	Feet Apart	R=0.74, p<0.001	R=0.53, p=0.003
	Feet Together	R=0.393, p=0.035	R=0.897, p<0.001
Vertical VOR (VVOR)	Feet Apart	R=0.446, p=0.015	R=0.792, p<0.001
	Feet Together	R=0.476, p=0.009	R=0.463, p=0.011

3.3 Comparison of Trial 1 and Trial 2 as well as Stance Positions

Table 3.3 COP Averages of Eyes Open

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	9.3541 ± 4.4495	28.3645 ± 1.7620	10.3871 ± 4.9556	28.4417 ± 1.8251
Mean Velocity (cm/s)	0.6637 ± 0.2941	0.8455 ± 0.3301	0.7492 ± 0.3900	0.9129 ± 0.3458
Sway Area (cm^2/s)	0.0241 ± 0.0141	0.1106 ± 0.0486	0.0283 ± 0.0167	0.1197 ± 0.0487
ML Frequency (Hz)	0.6483 ± 0.1144	0.5948 ± 0.0642	0.6253 ± 0.1079	0.6230 ± 0.1028
AP Frequency (Hz)	0.6707 ± 0.1582	0.6535 ± 0.1365	0.6764 ± 0.1152	0.7086 ± 0.1585

Table 3.4 COP Averages of Eyes Closed

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	9.8830 ± 4.2575	28.2814 ± 1.5567	10.3148 ± 5.2305	28.2015 ± 1.8893
Mean Velocity (cm/s)	0.7346 ± 0.2770	1.0320 ± 0.3609	0.8000 ± 0.4782	1.0145 ± 0.4303
Sway Area (cm^2/s)	0.0284 ± 0.0147	0.1329 ± 0.0512	0.0294 ± 0.0191	0.1309 ± 0.0575
ML Frequency (Hz)	0.6121 ± 0.0767	0.6920 ± 0.1081	0.6960 ± 0.1200	0.6914 ± 0.1291
AP Frequency (Hz)	0.6253 ± 0.0968	0.7730 ± 0.2780	0.6535 ± 0.1614	0.7391 ± 0.1921

Table 3.5 COP Averages of Horizontal Saccades

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	10.1552 ± 4.6397	28.0851 ± 1.6773	10.3268 ± 5.0192	27.9553 ± 2.1012
Mean Velocity (cm/s)	0.5036 ± 0.2272	0.7089 ± 0.2999	0.5492 ± 0.3933	0.7620 ± 0.3533
Sway Area (cm^2/s)	0.0189 ± 0.0096	0.0894 ± 0.0392	0.0201 ± 0.0114	0.0955 ± 0.0453
ML Frequency (Hz)	0.6667 ± 0.1775	0.6862 ± 0.1559	0.6121 ± 0.0924	0.6219 ± 0.0834
AP Frequency (Hz)	0.7489 ± 0.2444	0.7161 ± 0.2422	0.8483 ± 0.3648	0.6466 ± 0.1765

Table 3.6 COP Averages of Vertical Saccades

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	10.1726 ± 4.4196	27.6743 ± 2.1476	10.3860 ± 4.9829	27.8071 ± 2.6028
Mean Velocity (cm/s)	0.5325 ± 0.3025	0.7146 ± 0.2945	0.5831 ± 0.4568	0.7819 ± 0.3677
Sway Area (cm²/s)	0.0181 ± 0.0098	0.0897 ± 0.0385	0.0220 ± 0.0147	0.0954 ± 0.0410
ML Frequency (Hz)	0.6742 ± 0.0000	0.6569 ± 0.1384	0.6604 ± 0.1552	0.6506 ± 0.1199
AP Frequency (Hz)	0.7086 ± 0.2785	0.6816 ± 0.1395	0.6632 ± 0.1114	0.7081 ± 0.2026

Table 3.7 COP Averages of Vergence Jumps

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	9.9688 ± 4.9041	27.4430 ± 2.4482	10.3313 ± 4.9155	27.8740 ± 2.2734
Mean Velocity (cm/s)	0.5104 ± 0.2893	0.7286 ± 0.2765	0.6306 ± 0.4405	0.7662 ± 0.3014
Sway Area (cm²/s)	0.0168 ± 0.0086	0.0895 ± 0.0345	0.0237 ± 0.0000	0.0953 ± 0.0376
ML Frequency (Hz)	0.6713 ± 0.1465	0.6592 ± 0.1304	0.6759 ± 0.1276	0.6408 ± 0.1033
AP Frequency (Hz)	0.6805 ± 0.1721	0.7040 ± 0.1489	0.7104 ± 0.1752	0.7035 ± 0.2702

Table 3.8 COP Averages of Horizontal VOR

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	10.3436 ± 4.8865	27.2612 ± 2.2799	10.4531 ± 5.2479	27.6811 ± 2.6056
Mean Velocity (cm/s)	1.4103 ± 1.0350	1.4360 ± 0.8265	1.5751 ± 1.2639	1.6499 ± 0.9284
Sway Area (cm²/s)	0.0556 ± 0.0391	0.1792 ± 0.1074	0.0617 ± 0.0453	0.2076 ± 0.1231
ML Frequency (Hz)	0.7747 ± 0.2332	0.7517 ± 0.1971	0.8167 ± 0.3665	0.6782 ± 0.2053
AP Frequency (Hz)	0.8138 ± 0.2397	0.7851 ± 0.2542	0.9276 ± 0.4208	0.8437 ± 0.3733

Table 3.9 COP Averages of Vertical VOR

	Trial 1		Trial 2	
	Feet Apart	Feet Together	Feet Apart	Feet Together
Mean Distance (cm)	10.4436 ± 4.7708	27.2764 ± 2.2099	10.4514 ± 5.1963	27.7260 ± 2.5959
Mean Velocity (cm/s)	1.4569 ± 0.7537	1.4629 ± 0.7577	1.4815 ± 0.8137	1.6041 ± 0.8608
Sway Area (cm^2/s)	0.0510 ± 0.0000	0.1719 ± 0.0886	0.0510 ± 0.0000	0.1914 ± 0.1046
ML Frequency (Hz)	0.7184 ± 0.1972	0.7799 ± 0.2687	0.7333 ± 0.2101	0.8690 ± 0.3528
AP Frequency (Hz)	0.8173 ± 0.3345	0.7920 ± 0.2686	0.8713 ± 0.4326	0.7856 ± 0.2349
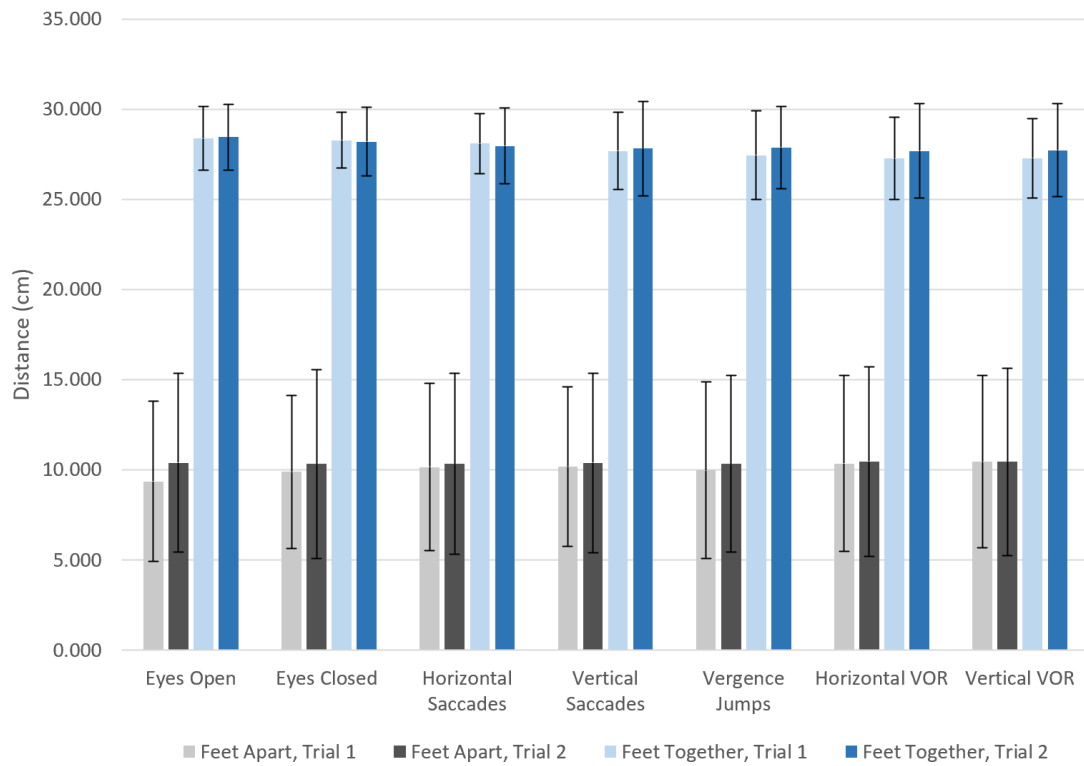
Figure 3.4 Mean distance traveled.

The average total distance traveled by the COP is represented in Figure 3.4. Consistency is present throughout each of the tasks and trials if the stance position remained constant (t = 1). Differences arise between feet apart and feet together (t < 0.001), where feet together produced a greater distance traveled. Statistics corresponding to Figure 3.4 are presented in Tables 3.10 and 3.11.

Table 3.10 Repeated-measures ANOVA Corresponding to Figure 3.4

Eyes Open	$f(3,84)=380.2, p<0.001$
Eyes Closed	$f(3,84)=372.416, p<0.001$
Horizontal Saccades	$f(3,84)=341.708, p<0.001$
Vertical Saccades	$f(3,84)=308.497, p<0.001$
Vergence Jumps	$f(3,84)=305.829, p<0.001$
Horizontal VOR	$f(3,84)=267.3, p<0.001$
Vertical VOR	$f(3,84)=266.342, p<0.001$

Table 3.11 Post-Hoc T-Test Corresponding to Figure 3.4

	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
Apart Trial 1 vs Apart Trial 2	1	1	1	1	1	1	1
Apart Trial 1 vs Together Trial 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 1 vs Together Trial 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 2 vs Together Trial 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 2 vs Together Trial 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Together Trial 1 vs Together Trial 2	1	1	1	1	1	1	1

Figure 3.5 Mean velocity.

The average COP velocity is represented in Figure 3.5. Stance was the factor that varied the results within eyes open, eyes closed, horizontal saccades, vertical saccades, and vergence jumps. However, the velocity did not vary between stance positions nor trials for horizontal VOR ($p = 0.078$) and vertical VOR ($p = 0.453$). Statistics corresponding to Figure 3.5 are presented in Tables 3.12 and 3.13.

Table 3.12 Repeated-Measures ANOVA Corresponding to Figure 3.5

Eyes Open	$f(3,84)=6.378$, $p<0.001$
Eyes Closed	$f(3,84)=9.121$, $p<0.001$
Horizontal Saccades	$f(3,84)=10.634$, $p<0.001$
Vertical Saccades	$f(3,84)=8.141$, $p<0.001$
Vergence Jumps	$f(3,84)=9.862$, $p<0.001$
Horizontal VOR	$f(3,84)=2.353$, $p=0.078$
Vertical VOR	$f(3,84)=0.884$, $p=0.453$

Table 3.13 Post-Hoc T-Test Corresponding to Figure 3.5

	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
Apart Trial 1 vs Apart Trial 2	0.7	1	1	1	0.112	-	-
Apart Trial 1 vs Together Trial 1	0.022	<0.001	<0.001	0.002	<0.001	-	-
Apart Trial 1 vs Together Trial 2	0.006	0.009	0.002	0.008	<0.001	-	-
Apart Trial 2 vs Together Trial 1	1	0.059	0.048	0.203	0.340	-	-
Apart Trial 2 vs Together Trial 2	0.058	0.009	0.009	0.043	0.297	-	-
Together Trial 1 vs Together Trial 2	1	1	1	1	1	-	-
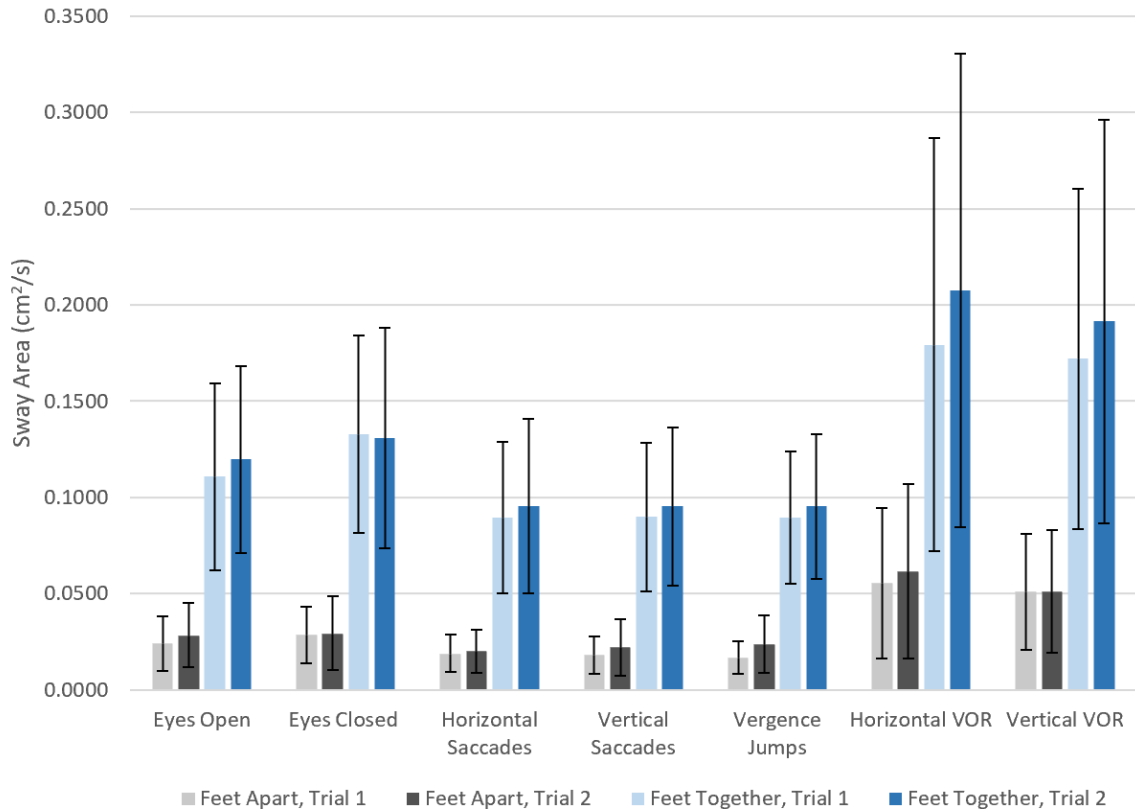
Figure 3.6 Sway area.

The average sway area created by the COP is represented in Figure 3.6. Similar to the average distance traveled (Figure 3.4), statistical differences between trials within each task are not present ($t > 0.114$). Differences occur between feet apart and feet together ($t < 0.001$). Statistics corresponding to Figure 3.5 are presented in Tables 3.14 and 3.15.

Table 3.14 Repeated-Measures ANOVA Corresponding to Figure 3.6

Eyes Open	f(3,84)=83.523, p<0.001
Eyes Closed	f(3,84)=93.671, p<0.001
Horizontal Saccades	f(3,84)=75.622, p<0.001
Vertical Saccades	f(3,84)=89.686, p<0.001
Vergence Jumps	f(3,84)=97.932, p<0.001
Horizontal VOR	f(3,84)=53.463, p<0.001
Vertical VOR	f(3,84)=54.035, p<0.001

Table 3.15 Post-Hoc T-Test Corresponding to Figure 3.6

	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
Apart Trial 1 vs Apart Trial 2	0.67	1	1	0.897	0.114	1	1
Apart Trial 1 vs Together Trial 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 1 vs Together Trial 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 2 vs Together Trial 1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Apart Trial 2 vs Together Trial 2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Together Trial 1 vs Together Trial 2	1	1	1	1	1	0.171	0.496
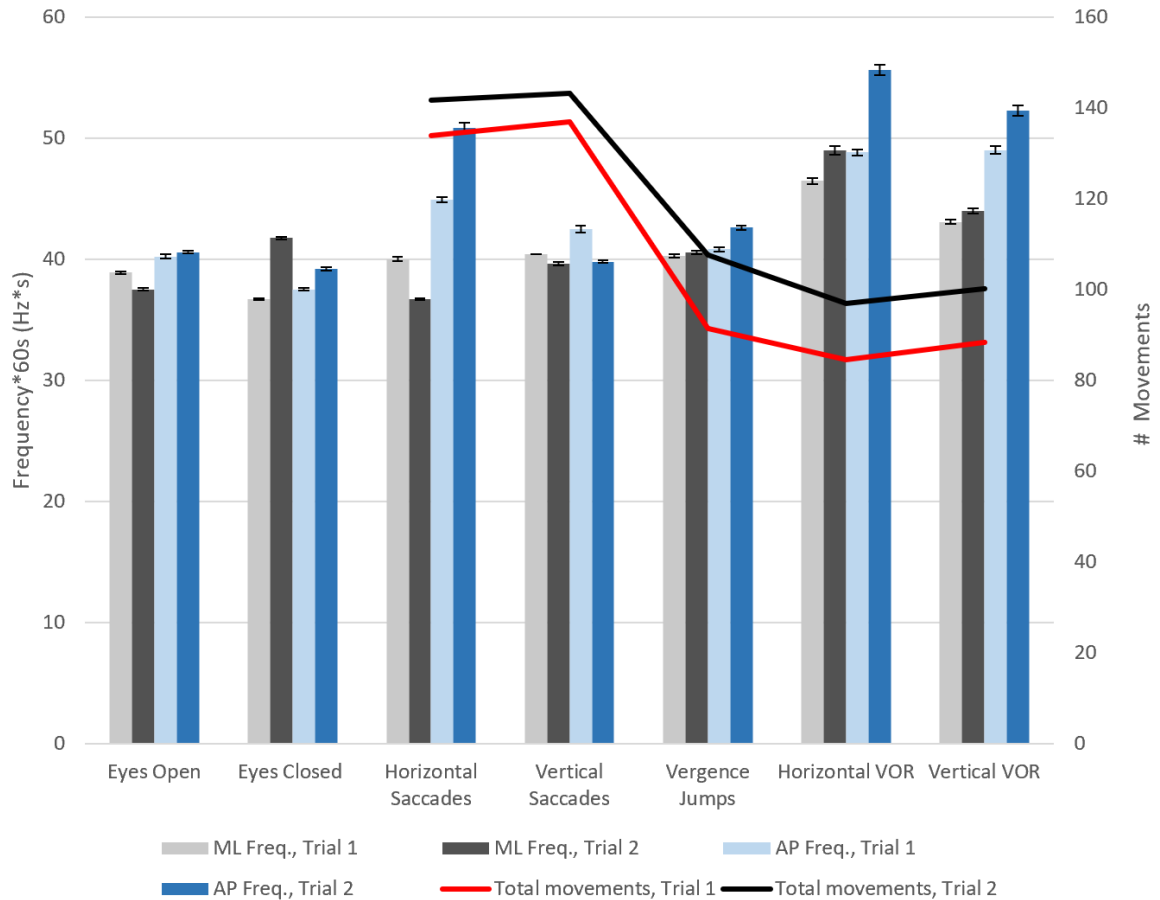
Figure 3.7 Number of movements corresponding to COP frequency for feet apart. The frequency values were multiplied by 60 as the duration of each task was 60 seconds. The right axis represents the average value of total number of eye or head movements, while the left axis represents the average COP movements.

When feet are positioned to be shoulder width apart, the COP frequency is generally unaffected when comparing the anterior/posterior direction to the medial/lateral direction, as represented in Figure 3.7. Variation is represented in horizontal saccades, horizontal VOR, and vertical VOR. Furthermore, the total number of movements are greatest during horizontal saccades and vertical saccades, but decrease greatly for vergence jumps, horizontal VOR, and vertical VOR.
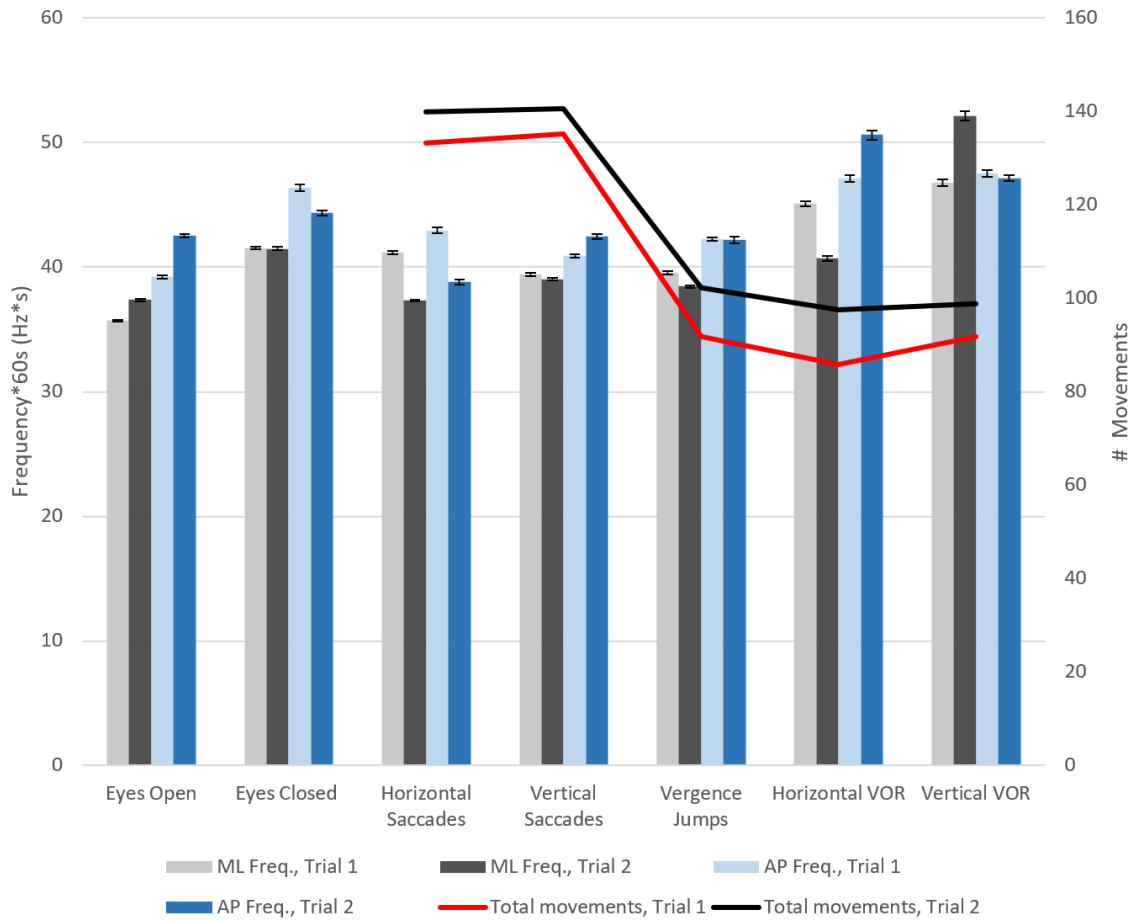
Figure 3.8 Number of movements corresponding to COP frequency for feet together. The frequency values were multiplied by 60 as the duration of each task was 60 seconds. The right axis represents the average value of total number of eye or head movements, while the left axis represents the average COP movements.

Similar to Figure 3.7, the COP frequency is often unaffected while the feet are positioned together, as shown in Figure 3.8. The medial/lateral and anterior/posterior frequencies are rather consistent between eyes open, eyes closed, horizontal saccades, vertical saccades, and vergence jumps. A slight increase in total COP frequency is seen during horizontal VOR and vertical VOR movements. The total number of eye or head movements follows the same trend as represented during feet apart.

		Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
Feet Apart	Eyes Open	1													
	Eyes Closed	0.908	1												
	Horizontal Saccades	0.894	0.946	1											
	Vertical Saccades	0.849	0.897	0.933	1										
	Vergence Jumps	0.848	0.904	0.942	0.946	1									
	Horizontal VOR	0.788	0.895	0.926	0.935	0.957	1								
	Vertical VOR	0.793	0.901	0.919	0.925	0.959	0.979	1							
Feet Together	Eyes Open	0.359	0.468	0.441	0.374	0.382	0.468	0.3760	1						
	Eyes Closed	0.264	0.398	0.335	0.269	0.260	0.342	0.2450	0.891	1					
	Horizontal Saccades	0.225	0.367	0.309	0.268	0.261	0.336	0.2400	0.869	0.972	1				
	Vertical Saccades	0.248	0.331	0.322	0.127	0.169	0.234	0.1500	0.787	0.881	0.861	1			
	Vergence Jumps	0.358	0.433	0.382	0.233	0.262	0.262	0.2140	0.759	0.824	0.787	0.832	1		
	Horizontal VOR	0.230	0.273	0.243	0.097	0.108	0.175	0.0920	0.741	0.846	0.841	0.925	0.847	1	
	Vertical VOR	0.237	0.282	0.280	0.136	0.152	0.210	0.1280	0.809	0.860	0.839	0.926	0.868	0.937	1
		Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
		Feet Apart							Feet Together						

Figure 3.9 Pearson correlation of the mean distance traveled by the COP for Trial 1.

		Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
Feet Apart	Eyes Open	1													
	Eyes Closed	0.778	1												
	Horizontal Saccades	0.638	0.702	1											
	Vertical Saccades	0.651	0.657	0.665	1										
	Vergence Jumps	0.703	0.624	0.762	0.778	1									
	Horizontal VOR	0.205	0.456	0.435	0.444	0.429	1								
	Vertical VOR	0.430	0.418	0.547	0.551	0.516	0.530	1							
Feet Together	Eyes Open	0.244	0.411	0.186	0.273	0.124	0.379	0.2040	1						
	Eyes Closed	0.155	0.42	0.269	0.314	0.109	0.486	0.1900	0.803	1					
	Horizontal Saccades	0.262	0.403	0.382	0.359	0.237	0.294	0.056	0.646	0.829	1				
	Vertical Saccades	0.171	0.274	0.343	0.292	0.160	0.173	-0.031	0.622	0.735	0.878	1			
	Vergence Jumps	0.136	0.245	0.246	0.234	0.041	0.140	-0.010	0.671	0.732	0.825	0.847	1		
	Horizontal VOR	-0.099	0.088	0.096	0.170	0.015	0.751	0.115	0.489	0.652	0.479	0.443	0.47	1	
	Vertical VOR	0.009	0.122	0.176	0.236	0.134	0.704	0.303	0.57	0.666	0.553	0.511	0.509	0.887	1
		Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR	Eyes Open	Eyes Closed	Horizontal Saccades	Vertical Saccades	Vergence Jumps	Horizontal VOR	Vertical VOR
		Feet Apart							Feet Together						

Figure 3.10 Pearson correlation of the COP sway area for Trial 1.

The Pearson correlation heat charts in Figures 3.9 and 3.10, represent the mean distance and sway area associated with the COP for Trial 1, respectively. Feet apart and feet together are uncorrelated, as represented by the red regions, but it is more pronounced for the mean distance (Figure 3.9). Likewise, similar stance positions are correlated amongst the seven tasks performed.

In Figure 3.9, the feet apart stance is more correlated with itself than the feet together stance is. This indicates the mean distance has more variability during a wide stance. Furthermore, eyes open feet apart is the only task which does not present as strong of a correlation ($p > 0.788$), whereas the other tasks are closely related to each other ($p > 0.895$). The correlations between the tasks while the feet were positioned together is evenly distributed.

Similar findings are present for the sway area, however, the strong correlation between the feet apart tasks is not present, as shown in Figure 3.10. In this case, the feet together stance is more directly correlated with itself, opposite of what is presented for the mean distance. When comparing like stance positions, horizontal VOR and vertical VOR are not correlated to the remainder of the tasks but are similar amongst themselves. It can also be seen that a strong correlation is present between horizontal VOR during feet apart and both VOR tasks during feet together ($p > 0.704$).

3.4 Comparison of 1ˢᵗ 30s and 2ⁿᵈ 30s

The COP frequencies for both horizontal VOR (Figure 3.11) and vertical VOR (Figure 3.12) are statistically similar (p > 0.130), except for the feet apart, Trial 2, horizontal VOR (p = 0.014). Stance nor Trial influenced the intensity of the frequency.

Figure 3.11 Horizontal VOR COP frequency comparison between time periods.

Table 3.16 Repeated-Measures ANOVA Corresponding to Figure 3.11

Feet Apart, Trial 1	f(3,84)=2.071, p=0.130
Feet Apart, Trial 2	f(3,84)=4.276, p=0.014
Feet Together, Trial 1	f(3,84)=1.337, p=0.269
Feet Together, Trial 2	f(3,84)=1.383, p=0.259

Table 3.17 Post-Hoc T-Test Corresponding to Figure 3.11

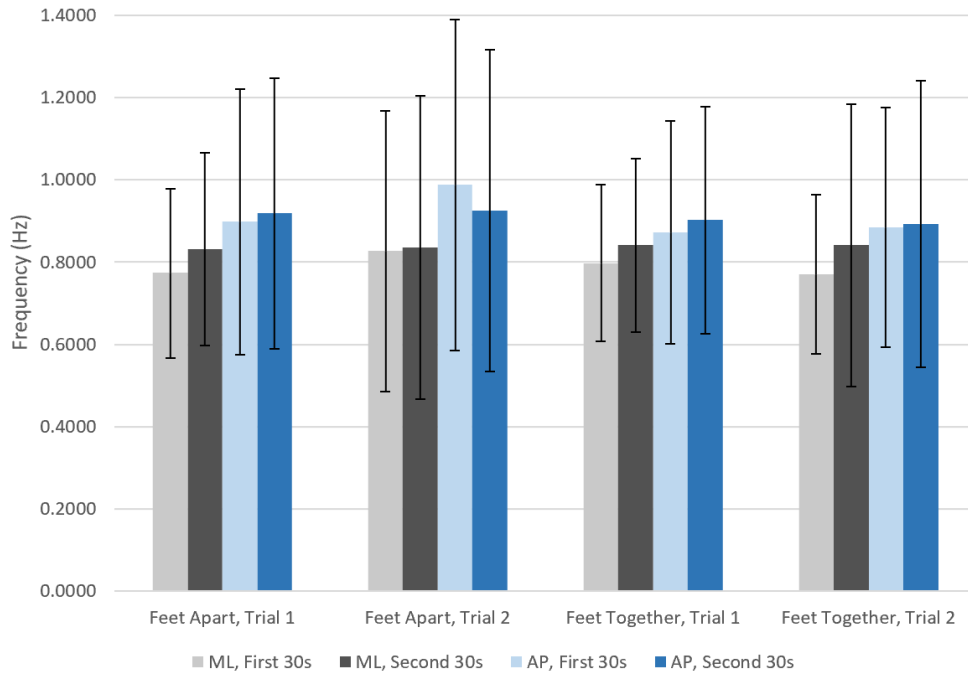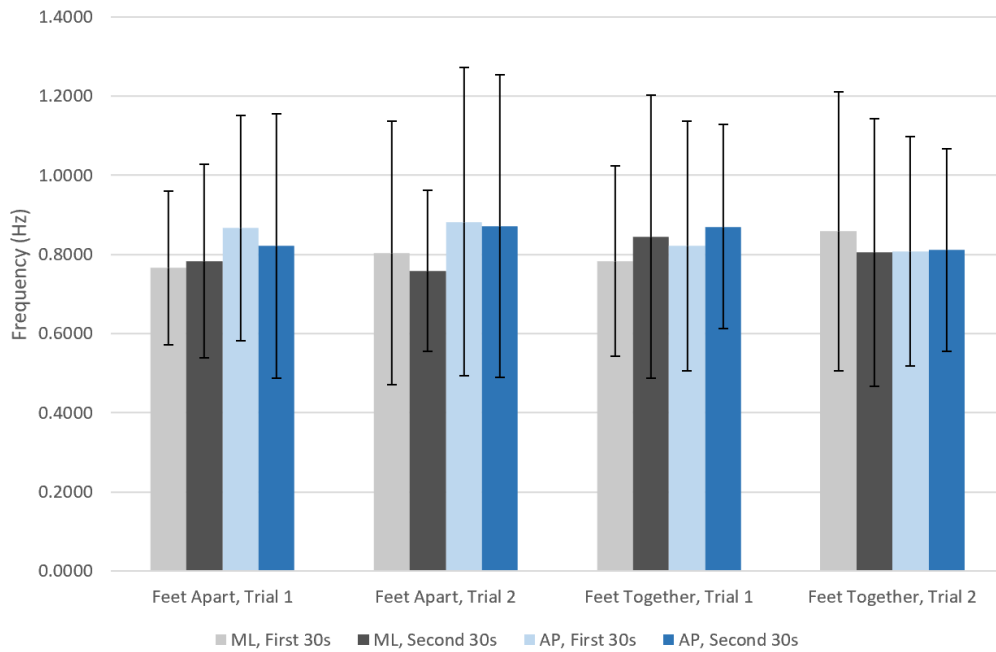|	Feet Apart, Trial 1	Feet Apart, Trial 2	Feet Together, Trial 1	Feet Together, Trial 2
ML First 30s vs ML Second 30s	-	1	-	-
ML First 30s vs AP First 30s	-	0.014	-	-
ML First 30s vs AP Second 30s	-	0.498	-	-
ML Second 30s vs AP First 30s	-	0.130	-	-
ML Second 30s vs AP Second 30s	-	0.740	-	-
AP First 30s vs AP Second 30s	-	1	-	-

Figure 3.12 Vertical VOR COP frequency comparison between time periods.

Table 3.18 Repeated-Measures ANOVA Corresponding to Figure 3.112

Feet Apart, Trial 1	$f(3,84)=1.025, p=0.368$
Feet Apart, Trial 2	$f(3,84)=1.288, p=0.285$
Feet Together, Trial 1	$f(3,84)=0.558, p=0.635$
Feet Together, Trial 2	$f(3,84)=0.302, p=0.729$

CHAPTER 4

DISCUSSION AND FUTURE OUTLOOK

4.1 Discussion

The aim of the study, first and foremost, was to determine how the oculomotor and vestibular systems relate to each other. Secondary objectives were to compare trials, time periods within one trial, and stance positions. This was achieved by collecting COP data from the force plates in conjunction with the number of eye or head movements in healthy young adults.

The results indicate saccades and vergence eye movements improve postural stability when compared to the control tests, eyes open and eyes closed, as shown in Figures 3.5 and 3.6. These findings are concurrent with previous studies (Ajrezo et al., 2013; Kapoula & Bucci, 2007; Matheron et al., 2016; Rougier & Garin, 2007; Stoffregen et al., 2006; Uchida et al., 1979).

An increase in distance traveled, sway area, velocity, and COP frequency were observed during a narrow stance when compared to a wide stance (Figures 3.4, 3.5, 3.6, 3.11, and 3.12). Several studies have also found a narrow stance negatively effects postural stability (Aguiar et al., 2015; Roh et al., 2021). Aguiar et al., has also noted that as age increases, postural stability is unaffected by stance position for older adults. A study that focused on children determined as age increased, stability increased (Riach & Hayes, 1987). To create a versatile protocol for future works, it can be suggested to focus solely on a wider stance as it would accept meaningful results from all age groups. By selecting the stance with more stability, the relationship of how balance disorders effect COP could

also be studied as this may reduce the risk of falling. The purpose of selecting one stance for future studies is to increase the likelihood of non-healthy participants finishing the experiment.

A statistically significant correlation between the oculomotor and vestibular system has only been expressed during VOR movements ($p < 0.035$) (Figure 3.3, Table 3.2). Horizontal saccades ($p > 0.357$), vertical saccades ($p > 0.073$), and vergence jumps ($p > 0.177$), are not statistically similar to the COP frequency. These differences most likely have occurred since VOR movements require oscillations of the head whereas the other tasks require the head to be stationary. It is to be noted that this correlation was only revealed after the COP frequencies were multiplied by 60 seconds, which has been selected as it relates to the time for data collection. This manipulation of the COP frequency units was intentional, as it allows for easier interpretation of the data. Additionally, the lowest peak COP frequency recorded, 0.5 Hz (30 Hz*s), is present across all tasks (Figure 3.3). Previous studies have determined humans experience a natural frequency at 1hz or less (Duarte & Zatsiorsky, 2000; Funato et al., 2016; Loram et al., 2005; Maurer & Peterka, 2005). This correlation observed between the oculomotor and vestibular systems for VOR movements indicate a stabilization in the visual field. If they were out of phase, the visual field would appear to oscillate, making it difficult for the ocular system to focus on finer details due to the hindrance of unnecessary noise.

The average number of eye or head movements did not substantially vary over the course of the entire study. They remained similar for the first 30 seconds and the second 30 seconds, stance position, and between the trials (Table 3.1). Excluding the total number of movements, the values ranged from 40 to about 70, with the greatest values occurring

during saccades. These values correlate with a previous study which collected about 65 movements for the saccades (Yaramothu et al., 2021). Both populations contained healthy participants and similar age ranges. Additionally, a decrease in number of movements for vergence jumps is expressed in previous literature as well due to it being the slowest type of eye movement (Robinson, 1968). The sustained values further validate healthy participants do not experience fatigue in 60 second increments. In addition to no expression of eye or head movement fatigue, COP fatigue was absent as well. The statistical differences between trial one and trial two ($p > 0.112$), as well as the first 30 seconds and the second 30 seconds ($p > 0.13$), have been calculated to be statistically insignificant.

When comparing the two control tests, eyes open and eyes closed, the effects of both systems as well as isolating the vestibular system could be studied in their natural states. While the eyes are closed, the body relies solely on the vestibular system. A slight decrease in postural stability, in terms of distance, velocity and sway area was observed. Several prior studies have also observed this phenomenon (Fitzgerald et al., 1994; Prieto et al., 1996; Santos et al., 2008). The distances are statistically insignificant, however tables 3.3and 3.4 verify this trend is indeed present.

4.2 Study Limitations

This study did not account for the following postural stability inhibitors: substance usage (drugs or alcohol), high or low blood pressure, medications, or extracurricular activities, such as sports and hobbies. Furthermore, body structure and attributes were not recorded. This study took place in a laboratory where other experiments occurred, so visual or audio stimulations could have influenced the participants' focus. The OMAT usage

during horizontal saccades, vertical saccades, and vergence jumps were the only tests where contact was made with the participants. Leaning into or away from the OMAT could have occurred randomly throughout the experiments.

4.2 Future Outlook

The current findings have created a foundation for future research. This protocol can be implemented on concussed individuals, which could then be compared to this healthy data. By comparing the brain in two separate states, the overall disconnection between the oculomotor and vestibular systems could be analyzed. Additionally, the healing progression could be identified depending on the severity of the concussion. Aside from concussed individuals, testing can be conducted on those who experience BPPV. Perhaps similarities could be identified, or distinct differences will be present between concussions and BPPV. In either case, these studies certainly will add to this area of research.

MATLAB CODE: MATHEMATICS FILE

```matlab
% %Un-comment this to run this file without using the other file
% cd('C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject 8\trial 1\apart')
% data = load('a_vvor.mat');
% data = data.a_vvor;

N = length(data.x1_COPx); %number of data points
T = 60; %seconds

%% Filter
Fs = 1000; %Hz
t = linspace(0,N/Fs,N); %time vector
cutoff = 3;
[b,a] = butter(6,cutoff/(Fs/2),'low');
data.x1_COPx = filtfilt(b,a,data.x1_COPx);
data.x2_COPx = filtfilt(b,a,data.x2_COPx);
data.x1_COPy = filtfilt(b,a,data.x1_COPy);
data.x2_COPy = filtfilt(b,a,data.x2_COPy);
data.x1_Fx = filtfilt(b,a,data.x1_Fx);
data.x1_Fy = filtfilt(b,a,data.x1_Fy);
data.x2_Fx = filtfilt(b,a,data.x2_Fx);
data.x2_Fy = filtfilt(b,a,data.x2_Fy);
%% RD
tic
fprintf("RD:       ")
%resultant distance (RD)
Rx = data.x2_COPx-data.x1_COPx;
Ry = data.x2_COPy-data.x1_COPy;
RD = sqrt(Rx.^2+Ry.^2);
toc

%% DIST
tic
fprintf("Distance:  ")
%Calculate mean distances
mean_distance = (1/N)*sum(RD); %m
sd_distance = 0;
toc

%% VEL
tic
fprintf("Velocity:  ")
%Calculate mean velocity
```

```matlab
distance = 0;
for i = 1:N-1
    distance(i) = sqrt((Rx(i+1) - Rx(i))^2 + (Ry(i+1) - Ry(i))^2);
    slope(i) = (Ry(i+1) - Ry(i))/(Rx(i+1) - Rx(i));
    if slope(i) > 20
        slope(i) = 0;
    elseif slope(i) < -20
        slope(i) = 0;
    end
end

total_distance = sum(distance);   %m
avg_slope = sum(slope)/T;
mean_velocity = total_distance/T;   %m/s
sd_velocity = 0;
toc

%% SWAY
tic
fprintf("Sway:     ")
%Calculate Sway
sway = 0;
for i = 1:N-1
    sway_area_sum(i) = abs(Rx(i+1)*Ry(i) - Rx(i)*Ry(i+1));
end
sway_area = (1/(2*T))*sum(sway_area_sum); %m^2/s
sd_sway_area = 0;
toc


%% Frequency x
%(c), 2022, Cassandra Martin, All Rights Reserved

%fft
Y = fft(data.x1_Fx - data.x2_Fx);
P2 = abs(Y/N);
P1_x = P2(1:N/2+1);
P1_x(2:end-1) = 2*P1_x(2:end-1);
freq_x = Fs*(0:(N/2))/N;

idx_x = find(freq_x>0.5);
[pks_x,locs_x] = findpeaks(P1_x(idx_x));
adjlocs_x = locs_x + idx_x(1)-1;


[peak_frequency_x_val,peak_frequency_x_loc] = max(pks_x);
```

```matlab
peak_frequency_x = freq_x(adjlocs_x(peak_frequency_x_loc));

%% Frequency y
%fft
Y = fft(data.x1_Fy - data.x2_Fy);
P2 = abs(Y/N);
P1 = P2(1:N/2+1);
P1(2:end-1) = 2*P1(2:end-1);
freq = Fs*(0:(N/2))/N;


idx_y = find(freq>0.5);
[pks_y,locs_y] = findpeaks(P1(idx_y));
adjlocs_y = locs_x + idx_y(1)-1;

 [peak_frequency_y_val,peak_frequency_y_loc] = max(pks_y);
peak_frequency_y = freq(adjlocs_y(peak_frequency_y_loc));

% %% Freq. Plot
% figure(1)
% plot(freq_x,P1_x,'r')%x direction
% hold on
% plot(freq,P1,'b') %y direction
% grid on
% legend('Anterior/Posterior','Medial/Lateral');
% xlabel('Frequency (Hz)');
% ylabel('Power Spectrum Intensity');
% title('Frequency Spectrum');
% xlim([0 3])
% ylim([0 6])
% hold off

% %% COP Plot
% Rx = data.x2_COPx-data.x1_COPx;
% Ry = data.x2_COPy-data.x1_COPy;
% RD = sqrt(Rx.^2+Ry.^2);

% figure(2)
% plot(Rx,Ry,'b');
% grid on
% xlabel('Medial/Lateral (m)');
% ylabel('Anterior/Posterior (m)');
% title('Trajectory of COP');
% xlim([-0.065 -0.035])
% ylim([-0.042 0.02])
% (c), 2022, Cassandra Martin, All Rights Reserved
```

```
%%
subjects = [mean_distance sd_distance mean_velocity sd_velocity sway_area
sd_sway_area peak_frequency_x peak_frequency_y];
```

MATLAB CODE: ALL PARTICIPANTS TOTAL TIME

```matlab
clc;
clear all;
close all;
tic
%% Closing Excel
try
   Excel = actxGetRunningServer('Excel.Application');
   Excel.Quit;
catch
end
%%
n_folder = 29;

%% Eyes Open, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Eyes Open Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
   trialType = 1;
   feetPosition = ['apart'];
   movementType = ['a_eo'];

   cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
      num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

   matFileName = sprintf('a_eo.mat');
   if isfile(matFileName)
      data = load(matFileName);
   else
      continue; % Skip this file but continue with loop
   end
   data = data.a_eo;
   addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
   savepath
   fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
   run('Master_File')

   %Creating matrix A to send to excel
   A(subjectNumber,:)= subjects;  %8 columns 30 rows
   A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
```

```matlab
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',1,'Range','B3:I32')

%% Eyes Open, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Eyes Open Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_eo'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_eo.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_eo;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',1,'Range','P3:W32')

%% Eyes Open, Feet Together, Trial 1
A = [];
fprintf("Now Processing Eyes Open Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_eo'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_eo.mat');
```

```matlab
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_eo;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',1,'Range','B43:I72')
%% Eyes Open, Feet Together, Trial 2
A = [];
fprintf("Now Processing Eyes Open Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_eo'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_eo.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_eo;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
```

```matlab
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',1,'Range','P43:W72')
%% Eyes Closed, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Eyes closed Feet apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_ec'];
    %(c), 2022, Cassandra Martin, All Rights Reserved
    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_ec.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_ec;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',2,'Range','B3:I32')

%% Eyes Closed, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Eyes closed Feet apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_ec'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
```

```matlab
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_ec.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_ec;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')


    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',2,'Range','P3:W32')

%% Eyes Closed, Feet Together, Trial 1
A = [];
fprintf("Now Processing Eyes closed Feet together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_ec'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_ec.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_ec;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')
```

```matlab
    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',2,'Range','B43:I72')
%% Eyes Closed, Feet Together, Trial 2
A = [];
fprintf("Now Processing Eyes closed Feet together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_ec'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_ec.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_ec;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',2,'Range','P43:W72')
%% Horizontal Saccades, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Horizontal Saccades, Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_hs'];
```

```matlab
cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
    num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

matFileName = sprintf('a_hs.mat');
if isfile(matFileName)
    data = load(matFileName);
else
    continue; % Skip this file but continue with loop
end
data = data.a_hs;
addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
savepath
fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

run('Master_File')

%Creating matrix A to send to excel
A(subjectNumber,:)= subjects;  %8 columns 30 rows
A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',3,'Range','B3:I32')

%% Horizontal Saccades, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Horizontal Saccades, Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_hs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hs.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hs;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
```

```matlab
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',3,'Range','P3:W32')

%% Horizontal Saccades, Feet Together, Trial 1
A = [];
fprintf("Now Processing Horizontal Saccades, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_hs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hs.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hs;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',3,'Range','B43:I72')
%% Horizontal Saccades, Feet Together, Trial 2
A = [];
fprintf("Now Processing Horizontal Saccades, Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
```

```matlab
trialType = 2;
feetPosition = ['together'];
movementType = ['t_hs'];

cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
    num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

matFileName = sprintf('t_hs.mat');
if isfile(matFileName)
    data = load(matFileName);
else
    continue; % Skip this file but continue with loop
end
data = data.t_hs;
addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
savepath
fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

run('Master_File')

%Creating matrix A to send to excel
A(subjectNumber,:)= subjects;  %8 columns 30 rows
A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',3,'Range','P43:W72')

%% Vertical Saccades, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Vertical Saccades, Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_vs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vs.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vs;
```

```matlab
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',4,'Range','B3:I32')

%% Vertical Saccades, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Vertical Saccades, Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_vs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vs.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vs;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',4,'Range','P3:W32')
```

```matlab
%% Vertical Saccades, Feet Together, Trial 1
A = [];
fprintf("Now Processing Vertical Saccades, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_vs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vs.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vs;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder) %(c), 2022,
Cassandra Martin, All Rights Reserved

    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',4,'Range','B43:I72')
%% Vertical Saccades, Feet Together, Trial 2
A = [];
fprintf("Now Processing Vertical Saccades, Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_vs'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vs.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

```matlab
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vs;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',4,'Range','P43:W72')
%% Vergence Jumps, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Vergence Jumps, Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_vj'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vj.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vj;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',5,'Range','B3:I32')
```

```matlab
%% Vergence Jumps, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Vergence Jumps, Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_vj'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vj.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vj;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',5,'Range','P3:W32')

%% Vergence Jumps, Feet Together, Trial 1
A = [];
fprintf("Now Processing Vergence Jumps, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_vj'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vj.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

```matlab
    else
       continue; % Skip this file but continue with loop
    end
    data = data.t_vj;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',5,'Range','B43:I72')
%% Vergence Jumps, Feet Together, Trial 2
A = [];
fprintf("Now Processing Vergence Jumps, Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_vj'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
       num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vj.mat');
    if isfile(matFileName)
       data = load(matFileName);
    else
       continue; % Skip this file but continue with loop
    end
    data = data.t_vj;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',5,'Range','P43:W72')
```

```matlab
%% Horizontal VOR, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','B3:I32')

%% Horizontal VOR, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
```

```matlab
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','P3:W32')

%% Horizontal VOR, Feet Together, Trial 1
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','B43:I72')
```

```matlab
%% Horizontal VOR, Feet Together, Trial 2
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','P43:W72')

%% Vertical VOR, Feet Apart, Trial 1
A = [];
fprintf("Now Processing Vertical VOR, Feet Apart 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
```

```matlab
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','B3:I32')

%% Vertical VOR, Feet Apart, Trial 2
A = [];
fprintf("Now Processing Vertical VOR, Feet Apart 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','P3:W32')
```

```matlab
%% Vertical VOR, Feet Together, Trial 1
A = [];
fprintf("Now Processing Vertical VOR, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','B43:I72')
%% Vertical VOR, Feet Together, Trial 2
A = [];
fprintf("Now Processing Vertical VOR, Feet Together 2\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
```

```matlab
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_File')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','P43:W72')

%% Horizontal VOR, Feet Apart, Trial 1 First 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart, Trial 1 First 30 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','AE3:AL32')
```

```matlab
%% Horizontal VOR, Feet Apart, Trial 2 First 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart, Trial 2 First 30 \n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','AS3:AZ32')

%% Horizontal VOR, Feet Together, Trial 1 First 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together, Trial 1 First 30 \n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

```matlab
        else
            continue; % Skip this file but continue with loop
        end
        data = data.t_hvor;
        addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
        savepath
        fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
        run('Master_first_30')

        %Creating matrix A to send to excel
        A(subjectNumber,:)= subjects;  %8 columns 30 rows
        A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','AE43:AL72')
%% Horizontal VOR, Feet Together, Trial 2 First 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together, Trial 2 First 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','AS43:AZ72')
```

```matlab
%% Horizontal VOR, Feet Apart, Trial 1 second 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart 1 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','BG3:BN32')

%% Horizontal VOR, Feet Apart, Trial 2 second 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Apart, Trial 2 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

68

```matlab
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','BU3:CB32')

%% Horizontal VOR, Feet Together, Trial 1 second 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together, Trial 1 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data %(c), 2022, Cassandra Martin, All Rights Reserved
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
```

```matlab
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','BG43:BN72')
%% Horizontal VOR, Feet Together, Trial 2 second 30
A = [];
fprintf("Now Processing Horizontal VOR, Feet Together, Trial 2 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_hvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_hvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_hvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',6,'Range','BU43:CB72')

%% vertical VOR, Feet Apart, Trial 1 First 30
A = [];
fprintf("Now Processing vertical VOR, Feet Apart, Trial 1 First 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

```matlab
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','AE3:AL32')

%% vertical VOR, Feet Apart, Trial 2 First 30
A = [];
fprintf("Now Processing vertical VOR, Feet Apart, Trial 2 First 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
```

```matlab
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','AS3:AZ32')

%% vertical VOR, Feet Together, Trial 1 First 30
A = [];
fprintf("Now Processing vertical VOR, Feet Together 1\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','AE43:AL72')
%% vertical VOR, Feet Together, Trial 2 First 30
A = [];
fprintf("Now Processing vertical VOR, Feet Together, Trial 2 First 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
```

```matlab
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_first_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','AS43:AZ72')

%% vertical VOR, Feet Apart, Trial 1 second 30
A = [];
fprintf("Now Processing vertical VOR, Feet Apart, Trial 1 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
```

```matlab
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','BG3:BN32')

%% vertical VOR, Feet Apart, Trial 2 second 30
A = [];
fprintf("Now Processing vertical VOR, Feet Apart, Trial 2 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['apart'];
    movementType = ['a_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('a_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.a_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder) %(c), 2022,
Cassandra Martin, All Rights Reserved
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','BU3:CB32')

%% vertical VOR, Feet Together, Trial 1 second 30
A = [];
fprintf("Now Processing vertical VOR, Feet Together, Trial 1 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 1;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
```

```matlab
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','BG43:BN72')
%% vertical VOR, Feet Together, Trial 2 second 30
A = [];
fprintf("Now Processing vertical VOR, Feet Together, Trial 2 second 30\n")
for subjectNumber = 1:n_folder %loop over subjects
    trialType = 2;
    feetPosition = ['together'];
    movementType = ['t_vvor'];

    cd(['C:\Users\cassi\Documents\1 NJIT\Thesis\Participant Data\Subject ',...
        num2str(subjectNumber),'\trial ',num2str(trialType),'\',num2str(feetPosition)])

    matFileName = sprintf('t_vvor.mat');
    if isfile(matFileName)
        data = load(matFileName);
    else
        continue; % Skip this file but continue with loop
    end
    data = data.t_vvor;
    addpath('C:\Users\cassi\Documents\1 NJIT\Thesis')
    savepath
    fprintf("Processing %d/%d subjects\n",subjectNumber,n_folder)
    run('Master_second_30')

    %Creating matrix A to send to excel
    A(subjectNumber,:)= subjects;  %8 columns 30 rows
    A = [A; subjects-subjects]; %subtract subjects to get 0 0 0 0 0 0 0 0 in the last row for
the last subject's repeated data
end
```

```matlab
cd('C:\Users\cassi\Documents\1 NJIT\Thesis')
writematrix(A,'Matlab to Excel Subject Data.xlsx','Sheet',7,'Range','BU43:CB72')
%}
toc
%% Opening Excel
winopen('Matlab to Excel Subject Data.xlsx')
```

MATLAB CODE: ALL PARTICIPANTS FIRST 30S

```matlab
N = length(data.x1_COPx); %number of data points
N = N/2;
T = 30; %seconds

%% Filter
Fs = 1000; %Hz
t = linspace(0,N/Fs,N); %time vector
cutoff = 3;
[b,a] = butter(6,cutoff/(Fs/2),'low');
data.x1_COPx = filtfilt(b,a,data.x1_COPx);
data.x2_COPx = filtfilt(b,a,data.x2_COPx);
data.x1_COPy = filtfilt(b,a,data.x1_COPy);
data.x2_COPy = filtfilt(b,a,data.x2_COPy);
data.x1_Fx = filtfilt(b,a,data.x1_Fx);
data.x1_Fy = filtfilt(b,a,data.x1_Fy);
data.x2_Fx = filtfilt(b,a,data.x2_Fx);
data.x2_Fy = filtfilt(b,a,data.x2_Fy);
%% Naming

%First 30s
first_x1_COPx = data.x1_COPx(1:round(end/2));
first_x2_COPx = data.x2_COPx(1:round(end/2));
first_x1_COPy = data.x1_COPy(1:round(end/2));
first_x2_COPy = data.x2_COPy(1:round(end/2));
first_x1_Fx = data.x1_Fx(1:round(end/2));
first_x1_Fy = data.x1_Fy(1:round(end/2));
first_x2_Fx = data.x2_Fx(1:round(end/2));
first_x2_Fy = data.x2_Fy(1:round(end/2));

%% RD
tic
fprintf("RD:        ")
%resultant distance (RD)
Rx = first_x2_COPx-first_x1_COPx;
Ry = first_x2_COPy-first_x1_COPy;
RD = sqrt(Rx.^2+Ry.^2);
toc

%% DIST
tic
fprintf("Distance:  ")
%Calculate mean distances
```

```matlab
mean_distance = (1/N)*sum(RD); %m
sd_distance = 0;
toc

%% VEL
tic
fprintf("Velocity:  ")
%Calculate mean velocity
distance = 0;
for i = 1:N-1
    distance(i) = sqrt((Rx(i+1) - Rx(i))^2 + (Ry(i+1) - Ry(i))^2);
    slope(i) = (Ry(i+1) - Ry(i))/(Rx(i+1) - Rx(i));
    if slope(i) > 20
        slope(i) = 0;
    elseif slope(i) < -20
        slope(i) = 0;
    end
end

total_distance = sum(distance);   %m
avg_slope = sum(slope)/T;
mean_velocity = total_distance/T;   %m/s
sd_velocity = 0;
toc
%(c), 2022, Cassandra Martin, All Rights Reserved
%% SWAY
tic
fprintf("Sway:      ")
%Calculate Sway
sway = 0;
for i = 1:N-1
    sway_area_sum(i) = abs(Rx(i+1)*Ry(i) - Rx(i)*Ry(i+1));
end
sway_area = (1/(2*T))*sum(sway_area_sum); %m^2/s
sd_sway_area = 0;
toc

%% Frequency x
%fft
Y = fft(first_x1_Fx - first_x2_Fx);
P2 = abs(Y/N);
P1_x = P2(1:N/2+1);
P1_x(2:end-1) = 2*P1_x(2:end-1);
freq_x = Fs*(0:(N/2))/N;

idx_x = find(freq_x>0.5);
```

78

```
[pks_x,locs_x] = findpeaks(P1_x(idx_x));
adjlocs_x = locs_x + idx_x(1)-1;



[peak_frequency_x_val,peak_frequency_x_loc] = max(pks_x);
peak_frequency_x = freq_x(adjlocs_x(peak_frequency_x_loc));

%% Frequency y
%fft
Y = fft(first_x1_Fy - first_x2_Fy);
P2 = abs(Y/N);
P1 = P2(1:N/2+1);
P1(2:end-1) = 2*P1(2:end-1);
freq = Fs*(0:(N/2))/N;



idx_y = find(freq>0.5);
[pks_y,locs_y] = findpeaks(P1(idx_y));
adjlocs_y = locs_x + idx_y(1)-1;



[peak_frequency_y_val,peak_frequency_y_loc] = max(pks_y);
peak_frequency_y = freq(adjlocs_y(peak_frequency_y_loc));

%%
subjects = [mean_distance sd_distance mean_velocity sd_velocity sway_area
sd_sway_area peak_frequency_x peak_frequency_y];
```

MATLAB CODE: ALL PARTICIPANTS SECOND 30S

```
N = length(data.x1_COPx); %number of data points
N = N/2;
T = 30; %seconds

%% Filter
Fs = 1000; %Hz
t = linspace(0,N/Fs,N); %time vector
cutoff = 3;
[b,a] = butter(6,cutoff/(Fs/2),'low');
data.x1_COPx = filtfilt(b,a,data.x1_COPx);
data.x2_COPx = filtfilt(b,a,data.x2_COPx);
data.x1_COPy = filtfilt(b,a,data.x1_COPy);
data.x2_COPy = filtfilt(b,a,data.x2_COPy);
data.x1_Fx = filtfilt(b,a,data.x1_Fx);
data.x1_Fy = filtfilt(b,a,data.x1_Fy);
data.x2_Fx = filtfilt(b,a,data.x2_Fx);
data.x2_Fy = filtfilt(b,a,data.x2_Fy);

%% Naming
%Second 30s
second_x1_COPx = data.x1_COPx(round(end/2):end);
second_x2_COPx = data.x2_COPx(round(end/2):end);
second_x1_COPy = data.x1_COPy(round(end/2):end);
second_x2_COPy = data.x2_COPy(round(end/2):end);
second_x1_Fx = data.x1_Fx(round(end/2):end);
second_x1_Fy = data.x1_Fy(round(end/2):end);
second_x2_Fx = data.x2_Fx(round(end/2):end);
second_x2_Fy = data.x2_Fy(round(end/2):end);
%% RD
tic
fprintf("RD:        ")
%resultant distance (RD)
Rx = second_x2_COPx-second_x1_COPx;
Ry = second_x2_COPy-second_x1_COPy;
RD = sqrt(Rx.^2+Ry.^2);
toc

%% DIST
tic
fprintf("Distance:  ")
%Calculate mean distances
mean_distance = (1/N)*sum(RD); %m
```

```matlab
sd_distance = 0;
toc

%% VEL
tic
fprintf("Velocity:  ")
%Calculate mean velocity
distance = 0;
for i = 1:N-1
    distance(i) = sqrt((Rx(i+1) - Rx(i))^2 + (Ry(i+1) - Ry(i))^2);
    slope(i) = (Ry(i+1) - Ry(i))/(Rx(i+1) - Rx(i));
    if slope(i) > 20
        slope(i) = 0;
    elseif slope(i) < -20
        slope(i) = 0;
    end
end

total_distance = sum(distance);   %m
avg_slope = sum(slope)/T;
mean_velocity = total_distance/T;   %m/s
sd_velocity = 0;
toc

%% SWAY
tic
fprintf("Sway:      ")
%Calculate Sway
sway = 0;
for i = 1:N-1
    sway_area_sum(i) = abs(Rx(i+1)*Ry(i) - Rx(i)*Ry(i+1));
end
sway_area = (1/(2*T))*sum(sway_area_sum); %m^2/s
sd_sway_area = 0;
toc

%% Frequency x
%fft
Y = fft(second_x1_Fx - second_x2_Fx);
P2 = abs(Y/N);
P1_x = P2(1:N/2+1);
P1_x(2:end-1) = 2*P1_x(2:end-1);
freq_x = Fs*(0:(N/2))/N;

idx_x = find(freq_x>0.5);
[pks_x,locs_x] = findpeaks(P1_x(idx_x));
```

```matlab
adjlocs_x = locs_x + idx_x(1)-1;


[peak_frequency_x_val,peak_frequency_x_loc] = max(pks_x);
peak_frequency_x = freq_x(adjlocs_x(peak_frequency_x_loc));

%% Frequency y
%fft
Y = fft(second_x1_Fy - second_x2_Fy);
P2 = abs(Y/N);
P1 = P2(1:N/2+1);
P1(2:end-1) = 2*P1(2:end-1);
freq = Fs*(0:(N/2))/N;
%(c), 2022, Cassandra Martin, All Rights Reserved

idx_y = find(freq>0.5);
[pks_y,locs_y] = findpeaks(P1(idx_y));
adjlocs_y = locs_x + idx_y(1)-1;


[peak_frequency_y_val,peak_frequency_y_loc] = max(pks_y);
peak_frequency_y = freq(adjlocs_y(peak_frequency_y_loc));
%%
subjects = [mean_distance sd_distance mean_velocity sd_velocity sway_area
sd_sway_area peak_frequency_x peak_frequency_y];
```

REFERENCES

Aguiar, S., Polastri, P., Godoi, D., Moraes, R., Barela, J., & Rodrigues, S. (2015). Effects of saccadic eye movements on postural control in older adults. *Psychology & Neuroscience*, *8*, 19-27. https://doi.org/10.1037/h0100352

Ajrezo, L., Wiener-Vacher, S., & Bucci, M. P. (2013). Saccades improve postural control: a developmental study in normal children. *PLoS One*, *8*(11), e81066. https://doi.org/10.1371/journal.pone.0081066

Bertec Force Plates. (2011). (B. Corporation, Ed.) https://www.bertec.com/s/Type-2001-Force-Plate-User-Manual.pdf

Day, B. L., & Fitzpatrick, R. C. (2005). The vestibular system. *Curr Biol*, *15*(15), R583-586. https://doi.org/10.1016/j.cub.2005.07.053

Day, B. L., Steiger, M., Thompson, P. D., & Marsden, C. D. (1993). Effect of vision and stance width on human body motion when standing: implications for afferent control of lateral sway. *The Journal of Physiology*, *469*.

Downey, D. L., & Leigh, R. J. (1998). Eye movements: pathophysiology, examination and clinical importance. *J Neurosci Nurs*, *30*(1), 15-22; quiz 23-14. https://doi.org/10.1097/01376517-199802000-00003

Duarte, M., & Zatsiorsky, V. M. (2000). On the fractal properties of natural human standing. *Neurosci Lett*, *283*(3), 173-176. https://doi.org/10.1016/s0304-3940(00)00960-5

Eggert, T. (2007). Eye movement recordings: methods. *Dev Ophthalmol*, *40*, 15-34. https://doi.org/10.1159/000100347

Fetter, M. (2007). Vestibulo-ocular reflex. *Dev Ophthalmol*, *40*, 35-51. https://doi.org/10.1159/000100348

Fitzgerald, J. E., Murray, A., Elliott, C., & Birchall, J. P. (1994). Comparison of body sway analysis techniques. Assessment with subjects standing on a stable surface. *Acta Otolaryngol*, *114*(2), 115-119. https://doi.org/10.3109/00016489409126028

Fu, Y., & Yau, K.-W. (2007). Phototransduction in mouse rods and cones. *Pflügers Archiv - European Journal of Physiology*, *454*(5), 805-819. https://doi.org/10.1007/s00424-006-0194-y

Funato, T., Aoi, S., Tomita, N., & Tsuchiya, K. (2016). Smooth enlargement of human standing sway by instability due to weak reaction floor and noise. *R Soc Open Sci*, *3*(1), 150570. https://doi.org/10.1098/rsos.150570

Goodworth, A. D., Mellodge, P., & Peterka, R. J. (2014). Stance width changes how sensory feedback is used for multisegmental balance control. *Journal of Neurophysiology*, *112*(3), 525-542. https://doi.org/10.1152/jn.00490.2013

Gray, L. (2020). *Chapter 10: Vestibular System: Structure and Function*. McGovern Medical School at UTHealth. https://nba.uth.tmc.edu/neuroscience/m/s2/chapter10.html

Greenspan, L. (2018). Saccadic Eye Movement Endurance as an Indicator of Symptomatic Lingering Post-Concussion Impairment. *Archives of Physical Medicine and Rehabilitation*, *99*, e176. https://doi.org/10.1016/j.apmr.2018.08.149

Hausselle, J., Haddox, A. G., Kasitz, J., & Azoug, A. (2021). An interventional exploratory study to assess the effect of footwear on postural stability and strategy during quiet standing. *Int Biomech*, *8*(1), 63-74. https://doi.org/10.1080/23335432.2021.1985610

How The Eye Works. (2020). https://socialeyesoptical.net/how-the-eye-works/

Jacobs, J. V., Wu, G., & Kelly, K. M. (2015). Evidence for beta corticomuscular coherence during human standing balance: Effects of stance width, vision, and support surface. *Neuroscience*, *298*, 1-11. https://doi.org/10.1016/j.neuroscience.2015.04.009

Kapoula, Z., & Bucci, M. P. (2007). Postural control in dyslexic and non-dyslexic children. *J Neurol*, *254*(9), 1174-1183. https://doi.org/10.1007/s00415-006-0460-0

Khojasteh, E., & Galiana, H. L. (2007). Modulation of vergence during the vestibulo-ocular reflex. *Annu Int Conf IEEE Eng Med Biol Soc*, *2007*, 5377-5380. https://doi.org/10.1109/iembs.2007.4353557

Kolb, H. (1995). The Organization of the Retina and Visual System. In E. Fernandez & R. Nelson (Eds.). University of Utah Health Sciences Center Copyright: © 2022 Webvision .

Leanage, N. (2019). *The Oculomotor Nerve (CN III)*. https://teachmeanatomy.info/head/cranial-nerves/oculomotor/

Lear, S. A., Brozic, A., Myers, J. N., & Ignaszewski, A. (1999). Exercise Stress Testing. *Sports Medicine*, *27*(5), 285-312. https://doi.org/10.2165/00007256-199927050-00002

Liversedge, S., Gilchrist, I., & Everling, S. (2012). *The Oxford Handbook of Eye Movements*. https://doi.org/10.1093/oxfordhb/9780199539789.001.0001

Loram, I. D., Maganaris, C. N., & Lakie, M. (2005). Human postural sway results from frequent, ballistic bias impulses by soleus and gastrocnemius. *J Physiol*, *564*(Pt 1), 295-311. https://doi.org/10.1113/jphysiol.2004.076307

Madrid, J., & Hout, M. C. (2018). Eye spy: why we need to move our eyes to gather information about the world. *Front. Young Minds*, *6*, 71.

Martinez-Conde, S., Macknik, S. L., & Hubel, D. H. (2004). The role of fixational eye movements in visual perception. *Nat Rev Neurosci*, *5*(3), 229-240. https://doi.org/10.1038/nrn1348

Matheron, E., Yang, Q., Delpit-Baraut, V., Dailly, O., & Kapoula, Z. (2016). Active ocular vergence improves postural control in elderly as close viewing distance with or without a single cognitive task. *Neurosci Lett*, *610*, 24-29. https://doi.org/10.1016/j.neulet.2015.10.065

Maurer, C., & Peterka, R. J. (2005). A new interpretation of spontaneous sway measures based on a simple model of human postural control. *J Neurophysiol*, *93*(1), 189-200. https://doi.org/10.1152/jn.00221.2004

Mays, L. E. (1984). Neural control of vergence eye movements: convergence and divergence neurons in midbrain. *J Neurophysiol*, *51*(5), 1091-1108. https://doi.org/10.1152/jn.1984.51.5.1091

OculoMotor Assessment Tool (OMAT). (2022). Gluden Ophthalmics. https://guldenophthalmics.com/product/oculomotor-assessment-tool-omat/

Prieto, T. E., Myklebust, J. B., Hoffmann, R. G., Lovett, E. G., & Myklebust, B. M. (1996). Measures of postural steadiness: differences between healthy young and elderly adults. *IEEE Trans Biomed Eng*, *43*(9), 956-966. https://doi.org/10.1109/10.532130

Purves, D., & Williams, S. M. (2001). *Neuroscience. 2nd edition*. Sinauer Associates 2001. http://lib.ugent.be/catalog/ebk01:3450000000002013

Rabbitt, R. D., Damiano, E., & Grant, J. W. (2004). Biomechanics of the Semicircular Canals and Otolith Organs.

Ramulu, P. Y., Swenor, B. K., Jefferys, J. L., & Rubin, G. S. (2013). Description and Validation of a Test to Evaluate Sustained Silent Reading. *Investigative Ophthalmology & Visual Science*, *54*(1), 673-680. https://doi.org/10.1167/iovs.12-10617

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychol Bull*, *124*(3), 372-422. https://doi.org/10.1037/0033-2909.124.3.372

Riach, C. L., & Hayes, K. C. (1987). Maturation of postural sway in young children. *Dev Med Child Neurol*, *29*(5), 650-658. https://doi.org/10.1111/j.1469-8749.1987.tb08507.x

Robinson, D. A. (1968). The oculomotor control system: A review. *Proceedings of the IEEE*, *56*(6), 1032-1049. https://doi.org/10.1109/PROC.1968.6455

Roh, M., Shin, E., & Lee, S. (2021). Relations between postural sway and cognitive workload during various gaze tasks in healthy young and old people. *J Exerc Rehabil*, *17*(2), 131-137. https://doi.org/10.12965/jer.2142154.077

Rougier, P., & Garin, M. (2007). Performing saccadic eye movements or blinking improves postural control. *Motor Control*, *11*(3), 213-223. https://doi.org/10.1123/mcj.11.3.213

Santos, B. R., Delisle, A., Lariviere, C., Plamondon, A., & Imbeau, D. (2008). Reliability of centre of pressure summary measures of postural steadiness in healthy young adults. *Gait Posture*, *27*(3), 408-415. https://doi.org/10.1016/j.gaitpost.2007.05.008

Scrivens, J. E., DeWeerth, S. P., & Ting, L. H. (2008). A robotic device for understanding neuromechanical interactions during standing balance control. *Bioinspiration & Biomimetics*, *3*(2), 026002. https://doi.org/10.1088/1748-3182/3/2/026002

Stoffregen, T. A., Bardy, B. G., Bonnet, C. T., & Pagulayan, R. J. (2006). Postural Stabilization of Visually Guided Eye Movements. *Ecological Psychology*, *18*(3), 191-222. https://doi.org/10.1207/s15326969eco1803_3

Strand, S. L., Hjelm, J., Shoepe, T. C., & Fajardo, M. A. (2014). Norms for an isometric muscle endurance test. *J Hum Kinet*, *40*, 93-102. https://doi.org/10.2478/hukin-2014-0011

Strominger, N. L., Demarest, R. J., & Laemle, L. B. (2012). Cerebellum. In N. L. Strominger, R. J. Demarest, & L. B. Laemle (Eds.), *Noback's Human Nervous System, Seventh Edition: Structure and Function* (pp. 307-320). Humana Press. https://doi.org/10.1007/978-1-61779-779-8_18

Szentagothai, J. (1950). The elementary vestibulo-ocular reflex arc. *J Neurophysiol*, *13*(6), 395-407. https://doi.org/10.1152/jn.1950.13.6.395

Uchida, T., Hashimoto, M., Suzuki, N., Takegami, T., & Iwase, Y. (1979). Effects of periodic saccades on the body sway in human subjects. *Neurosci Lett*, *13*(3), 253-258. https://doi.org/10.1016/0304-3940(79)91503-9

Yaramothu, C., Greenspan, L. D., Scheiman, M., & Alvarez, T. L. (2019). Vergence Endurance Test: A Pilot Study for a Concussion Biomarker. *J Neurotrauma*, *36*(14), 2200-2212. https://doi.org/10.1089/neu.2018.6075

Yaramothu, C., Morris, C. J., d'Antonio-Bertagnolli, J. V., & Alvarez, T. L. (2021). OculoMotor Assessment Tool Test Procedure and Normative Data. *Optom Vis Sci*, *98*(6), 636-643. https://doi.org/10.1097/OPX.0000000000001698