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Vestibular Perceptual Thresholds in Pitch Tilt

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VESTIBULAR PERCEPTUAL THRESHOLDS IN PITCH TILT

by

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Suri, Kadambari (M.S., Aerospace Engineering Sciences)

Vestibular Perceptual Thresholds in Pitch Tilt

Thesis directed by Assistant Professor Torin K. Clark

Vestibular perceptual thresholds quantify how small of a self-motion a human is able to perceive as one direction versus the other reliably. A sensitive measure of vestibular function, thresholds have direct functional relevance.

While thresholds in translation and rotation have been extensively characterized and variation in thresholds between different axes (e.g., up/down vs. left/right) established there had been limited investigation of tilt thresholds in different axes using modern psychophysical techniques. Therefore, in phase 1 of this study, we quantify pitch tilt thresholds and compare to those in roll tilt in the same group of subjects, across a range of stimulus frequencies (i.e., 1/motion duration). In phase 2 of this study, we hypothesize anatomical asymmetries in pitch tilt may lead to directional asymmetries (i.e., differing sensitivity for tilts forward versus backward), which we investigate at one frequency using modern threshold approaches (assuming no asymmetry) and comparing resulting fits with those obtained from the hybrid dual sigma (asymmetry) model proposed by Roditi and Crane (Roditi and Crane 2012).

Our Tilt-Translation Sled device (without the translation activated) was used to create whole-body tilt motions to a seated subject in the dark, assessing pitch tilt and roll tilt thresholds in separate sessions. Subjects reported motion direction (left or right for roll tilt; forward or backward for pitch tilt) in a forced-choice, direction-recognition task and confidence level of their selection (between 50 and 100% at increments of 5).

In phase 1, ten subjects performed blocks of 200 trials for each tilt axis (roll or pitch) and stimulus frequency (0.15, 0.2, 0.5 or 1 Hz) presented in a counterbalanced order. As previously

observed for roll, tilt angle thresholds increased at lower frequencies but stabilized around 0.15-0.2 Hz. Pitch tilt thresholds, across each of the frequencies we tested, were observed to be similar to, but slightly higher than, roll tilt thresholds. Specifically, the geometric mean threshold for pitch tilt (versus roll tilt) was 1.66° (1.50°) for 0.15 Hz, 1.61° (1.46°) for 0.2 Hz, 0.99° (0.96°) for 0.5 Hz, and 0.51° (0.47°) for 1 Hz. In phase 2, four subjects performed a total of 2000 trials for pitch tilt at 1 Hz. Substantial directional asymmetries were identified in one of four subjects (with better sensitivity for backward tilts), while two were highly symmetric and one less so.

To our knowledge this is the first study to quantify pitch tilt thresholds across a range of frequencies, providing a comparative baseline of healthy subjects as well as reporting the presence of directional asymmetries in pitch tilt at 1 Hz. Understanding tilt thresholds across directions and frequencies, as well as the possibility for asymmetries, is essential for those with clinical balance impairments (e.g., elderly) and healthy individuals in unique balance environments (e.g., astronauts), alike.

DEDICATION

To my parents and my brother for helping me realize my outlandish dreams.

To my friends for their unyielding support as I make efforts to achieve these outlandish dreams.

ACKNOWLEDGEMENTS

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CHAPTER I | INTRODUCTION

Vestibular perceptual thresholds quantify how small of a self-motion an individual can reliably perceive (D. M. Merfeld 2011) and are therefore of keen interest. Thresholds are a useful mechanism as, on an experimental level, testing for thresholds involves implementation of small motions that are typically well tolerated and do not demonstrate adaptive changes (Hartmann et al. 2013). On a clinical and operational level, vestibular thresholds are significantly higher in people without vestibular systems, therefore, suggesting that it is mostly dependent on the vestibular system (Valko et al. 2012). Furthermore, thresholds are a measure of sensory noise (Nouri and Karmali 2018) associated with self-motion perception and therefore have direct functional relevance for tasks requiring vestibular sensory precision, such as standing balance (Bermúdez Rey et al. 2016).

For instance, thresholds are sensitive to disease or impairments in the vestibular system as well as systems broadly responsible for sensorimotor perception. Asymptomatic vestibular migraine patients have reduced roll tilt thresholds as compared to the average health baseline (Lewis et al. 2011b, 2011a). Individuals that have previously had total bilateral vestibular ablation have substantially elevated vestibular perceptual thresholds (Valko et al. 2012). The authors found that thresholds increased by 5.4 to 15.7 times in yaw rotation, 8.3 to 56.8 times in y-translation, and 1.3 to 3.0 times in roll tilt. Similarly, individuals with visual impairments were found to have improved vestibular thresholds (Hartmann et al. 2014), specifically at 0.33 Hz in roll tilt (Moser et al. 2015), suggesting sensory compensation.

Further, thresholds are shown to be impacted by other factors such as age and medication. After the age of 40 years, normal, healthy individuals have increasingly higher thresholds across several motion types, with no significant differences between males and females (Bermúdez Rey et al. 2016). The authors found that thresholds increased per decade after the cutoff of 40 as follows: 15% in yaw rotation, 32% in roll tilt at 0.2 Hz, 46% in y-translation, 56% in roll tilt in 1 Hz, and 83% in z-translation. Moreover, promethazine, an anti-motion sickness drug, often taken by astronauts results in a 31% increase in roll tilt thresholds from the healthy baseline (Diaz-Artiles et al. 2017).

Finally, thresholds are correlated to performance in balance and manual controlling nulling tasks. Even when accounting for age, in normal, healthy individuals there is substantial inter-individual variation in vestibular perceptual thresholds. Thresholds have consistently been observed to have a log-normal distribution across subjects (Benson, Spencer, and Stott 1986; Benson, Hutt, and Brown 1989). These individual differences seem to have a functional impact on the ability to perform sensorimotor tasks. For example, individuals with higher roll tilt thresholds at 0.2 Hz have an increased likelihood of failing a standard balance test (Bermúdez Rey et al. 2016; Karmali et al. 2017). Additionally, an individual's roll tilt threshold correlates ($p < 0.001$) with their ability to actively null their chair in roll tilt using a joystick in response to a random disturbance (Rosenberg et al. 2018), suggesting thresholds are an operationally limiting factor.

Given this clinical and operational importance, vestibular perceptual thresholds have been well-quantified for a range of motions. These investigations have quantified differences in thresholds for different axes of translation, as well as different axes of rotation. For example, translation thresholds in the Z-axis (superior-inferior, or up/down) are significantly higher than thresholds in X (fore-aft) and Y (interaural, or left/right) translation (Bermúdez Rey et al. 2016; Karmali et al. 2017; Benson, Spencer, and Stott 1986). Analogously, yaw rotation thresholds about an Earth-vertical axis have been observed to be lower than pitch (subject lying lateral recumbent) and roll (subject laying supine) rotation (Benson et al., 1989). Additionally, thresholds in various motions and axes (yaw and roll rotation; roll tilt; X, Y, and Z translation) have been found to vary with frequency; as the frequency of the single-cycle sinusoid in acceleration motion decreases (i.e., the duration of motion increases), thresholds tend to increase. For roll tilt, this increase in threshold (in terms of angle) continues with decreasing frequency until ~0.15 – 0.2 Hz where thresholds level off (Lim et al. 2017). Tilts include canal and otolith stimulation, but at lower frequencies, the canal cue becomes smaller and less reliable while the otolith cue becomes dominant. After ~0.15 Hz, the cue remains the same such that it does not change between say 0.15 Hz and 0.0001 Hz.

While thresholds in translation and rotation have been extensively characterized and variation in thresholds between different axes established there has been limited investigation of tilt thresholds using modern psychophysical techniques. In particular, while roll tilt thresholds have been well quantified (Lim et al. 2017; Valko et al. 2012), pitch tilt thresholds are not as well studied. For example, previous tests have primarily implemented motion-detection tasks rather than direction-recognition tasks (Bisdorff et al. 2018; Bringoux 2002; Bronstein 1999). Motion detection tasks, as their name suggests, require identification of change from the reference. Two-alternative, forced-choice, motion "direction-recognition" tasks require identification of the direction of the motion (e.g., did I move forward vs. backward?) after motion completion. The latter has advantages over the former, mainly when using one-interval presentations (D. M. Merfeld 2011), as it can distinguish perceptual thresholds from the subject's [arbitrary] selection of a decision boundary.

To our knowledge, two published studies *have* quantified pitch tilt thresholds using the standard direction-recognition task (Teasdale et al. 1999; Hartmann et al. 2014). However, the study by Teasdale did not implement standard experimentation and the study Hartmann did not draw any conclusions on pitch tilt thresholds in a health baseline, as detailed further in the discussion. This motivates our first objective of quantifying pitch tilt thresholds across a range of frequencies, using modern psychophysical approaches in normal, healthy adults. Our second objective is to statistically compare pitch tilt and roll tilt thresholds, in the same cohort of subjects, across these frequencies as differences in axes have been observed for rotation and translation motions. Specifically, we hypothesize that the pitch tilt thresholds would be higher than (i.e., less sensitive than) roll tilt thresholds. We believe that this may be because human gait is primarily in the sagittal plane with minimal movement in the coronal plane; the latter may suggest the need for active reduction of movement and therefore lower thresholds in roll tilt (movements within the coronal plane).

Investigation of pitch tilt thresholds and anatomical asymmetries motivate this concept of directional asymmetries in vestibular perceptual thresholds within pitch tilt or whether there is a difference between direction-recognition of forward tilts and backward tilts.

To our knowledge, one published study by Roditi and Crane *has* investigated directional asymmetries in vestibular perceptual thresholds, studying X-axis (referred to as surge), Y-axis (sway), and Z-axis translation (heave), as well as yaw rotation thresholds at 0.5 and 1 Hz using a forced-choice, direction-recognition task in a group of healthy subjects. The results are a bit ambiguous, as detailed in the discussion, therefore motivating our third objective of investigating directional asymmetries for pitch tilt using methods that control for false positive conclusions. Specifically, we hypothesize that the asymmetric nature of pitch tilt (forwards versus backward) will yield a directional asymmetry in pitch thresholds or the sensitivity in detecting forwards versus backward motions.

In summary, the purpose of this study can be broken down into the following objectives:

Objective 1 | To investigate pitch tilt thresholds, as pitch tilt thresholds have never been rigorously quantified using modern psychophysical techniques (certainly not across frequencies).

Objective 2 | To compare pitch tilt and roll tilt thresholds, because differences in axes have been observed for rotation and translation, with the hypothesis that pitch tilt thresholds will be higher than roll tilt thresholds.

Objective 3 | To investigate for the presence of directional asymmetries within pitch tilt, because of the presence of anatomical asymmetries, with the hypothesis that there will be a presence of directional asymmetries

CHAPTER II | MATERIALS AND METHODS

Motion Device

The Tilt Translation Sled (TTS) was used to deliver whole-body tilts, without the translation feature activated. The tilt motion profiles were single-cycle sinusoids in acceleration in order to resemble profiles of common head tilts (Bermúdez Rey et al. 2016; Grabherr et al. 2008; Karmali et al. 2016). The frequency of motion was blocked by session and set to 0.15, 0.2, 0.5, or 1.0 Hz (yielding motion durations of 7.5, 5, 2, and 1 second, respectively). The direction of the tilt stimuli (e.g., forward or backward for pitch tilt) on each trial was determined randomly. The magnitude of the tilt stimuli was determined using a standard three-down-one-up adaptive staircase (Leek 2001; Taylor and Creelman 1967; Karmali et al. 2016; Grabherr et al. 2008; Bermúdez Rey et al. 2016).

The subjects were seated in an upright position and secured with a five-point harness. Subjects' heads were fixed to relative to the chair using a cushioned grip in order to stimulate controlled motion to the vestibular system. Motions were delivered in a light-tight dark room while subjects listened to white noise through noise-canceling headphones to minimize non-vestibular cues. Two-way auditory communication was maintained between the subject and operator and the operator monitored the subject with an infrared video feed.

Procedure

The start of a trial was indicated by the lights turning off. A fraction of a second later, the chair passively tilted the subject. Upon reaching the desired angle, subjects were haptically cued (i.e., a light buzz to a handheld device) to report their perceived motion direction. This was done in a forced-choice, direction-recognition task (Grabherr et al. 2008; Chaudhuri and Merfeld 2013; Daniel M. Merfeld 2011). For example, subjects could report left or right for roll tilt; forward or backward for pitch tilt. Next, subjects reported the confidence level of their selection between 50% and 100%, in 5% increments; in this case, 50% means guessing, and 100% means certain. Subjects were encouraged to report a trial as a "lapse" if he or she was sleepy, daydreaming, fatigued, or distracted during the motion and the trial was repeated. However, if they were paying attention and were simply unsure of the motion direction, then they were asked to report with their best guess. The subjects identified there were very rarely lapses (<5%). After reporting, the subject was brought back to the upright position in preparation for the next trial, which began after at least a three-second pause with the lights on.

Confidence – Signal Detection Model

The confidence-signal detection model was proposed by Yi and Merfeld (2016). The authors applied the model to human data obtained from testing four individuals in yaw rotation about an earth-vertical rotation axis at one frequency, under standard procedures, 3for a hundred trials. They conclude that this model, which utilizes a subjects' confidence probability judgments per trial, can "yield psychometric parameter estimates that match the precision of those obtained from 100 trials using conventional analyses" in just 20 trials (Yi and Merfeld 2016). Details on the model are provided in the methods section. Given the limited human data analyzed using the model, this experiment aims to provide further quantification of confidence thresholds, as a secondary objective.

Training

Before beginning testing, subjects were given 10 to 20 practice trials where they were given instructions on things to focus on during testing. They were encouraged to report motion directions with respect to which direction their head tilts in rather than what direction their feet were moving, which all subjects appeared to be able to follow. They were also given feedback on whether they were reporting motion directions correctly at large angles to verify that they understood the task appropriately. Additionally, they were instructed on translating their internal feelings of certainty and uncertainty into probability judgment such that their confidence would be well-calibrated for the experiment. The operator checklists with exact quotes of what was said to subjects are included in the appendix for reference.

<u>Phase I of the Study</u>

Subjects

A total of ten subjects (nine males and one female; 25 ± 3 years old) were recruited to participate in phase I of this study. All subjects were pre-screened for self-reported vestibular dysfunction and motion sickness.

Experimental Set-Up

Each subject completed blocks of 200 trials for each tilt axis and stimulus frequency presented in a counterbalanced order. Before testing, subjects were notified of the axis and frequency of tilt motion for each session and were provided practice trials until they felt comfortable (typically 5-10).

Data Analysis

Psychometric curves were fit in two manners. First, a standard Gaussian cumulative distribution psychometric function defined by σ and μ was fit to the binary data (e.g., forward vs. backward responses). Here, μ corresponds to the “vestibular bias” or the stimulus at which the subject reports 50% and σ is the “1-sigma” threshold or the slope of the curve (Daniel M. Merfeld 2011). This can be mathematically represented as follows:

$$\frac{1}{2}\quad[1 + erf(\frac{x-\mu}{\sqrt{2\sigma^2}})]$$

(Roditi and Crane 2012)

A subjective probability density function or decision variable for each stimulus is generated by adding neural noise to the objective probability density function for a "well-controlled" stimulus (Yi and Merfeld 2016), and a psychometric function is derived by constructing the subjective probability density function for various stimuli. 95% confidence intervals were calculated using a parametric bootstrap approach. A bias-reduced bias-generalized linear model was used with a probit link function to properly account for the adaptive staircase (Chaudhuri and Merfeld 2013). We refer to this model, as the "single sigma" (SS) model.

To capture the effect of roll vs. pitch tilt, and the effect of frequency across subjects, thresholds were then evaluated using the following general linear model:

$$log(\sigma_{ijk}) = \quad \rho_i \quad + \quad \beta_j f_j + \quad \beta_k RP_k + \quad \varepsilon_{ijk}$$

where the first term characterizes random subject effects, the second and third terms are fixed effects of the frequency and roll vs. pitch, respectively, the last term characterizes the error and the individual variables as follows:

ρ_i: Subject Effects

β_j: Frequency Effects

f_j: Frequency (0.15, 0.2, 0.5, 1 Hz)

β_k: Axis Effects

RP_k: Axis (Roll, Pitch)

ε_{ijk}: Error

Since the frequency effects have previously been established for roll tilt and are known to be non-linear, here, the frequency effects are treated as categorical predictors without incorporating any interactions with the axis (pitch vs. roll). Conceptually, this assumes that pitch versus roll effects are constant over frequencies. The lowest frequency (0.15 Hz) is used as the reference level such that its indicator (β_j) was set to 0. The axis effects are the factor of primary interest. And, so, for a total of 80 threshold data points (10 subjects * 2 axes * 4 frequencies), this model allows 75 degrees of freedom (DOF). The number of frequencies take up 4 DOFs (4 frequencies – 1 + 1 y-intercept), and the axis takes up 1 DOF (2 axes – 1) The statistical significance of the axes effect of whether pitch tilt thresholds are higher than roll tilt thresholds, across all frequencies, is analyzed via a one-tailed t-test, as we hypothesized pitch tilt thresholds would be higher than roll. This effect is further analyzed at each frequency such that the normality of log-transformed thresholds is verified via a Shapiro-Wilkes test, after which a one-tailed paired t-test is performed.

Secondly, we fit the confidence-signal detection (CSD) model which integrates the subject's confidence reports. Broadly speaking, this is done by finding the maximum likelihood fit for the data using the following parameters: σ, μ, and K. K is the confidence scale factor where values < 1 correspond to overconfident, > 1 is underconfident, and = 1 is well-calibrated. An average confidence function is fit as a Gaussian cumulative distribution function and scaled by K. The confidence ratings provided by a subject for a stimulus are binned as upper and lower limits on this confidence function which, in turn, provide upper and lower limits to the subjective probability density function for that stimulus (Yi and Merfeld 2016). A psychometric function is derived by constructing the subjective probability density function for various stimuli. As a result, the CSD model theoretically yields similar, but more precise, estimates of the threshold as the SS model (Yi and Merfeld 2016).

As vestibular perceptual thresholds are lognormally distributed across subjects, we report geometric means and compute 95% confidence intervals in the log-transformed domain (Bermúdez Rey et al. 2016).

Phase II of the Study

Subjects

A total of five subjects (four males and one female; 23 ± 5 years old) were recruited to participate in phase II of this study. One subject overlapped between phase I and phase II of this study. After completing ~700 trials, a different subject decided not to complete the 2,000 trials of testing. This individual was excluded from data analysis since, as will be seen in the next section, it would be difficult to identify an underlying directional asymmetry with the reduced number of trials. Once again, all subjects were pre-screened for self-reported vestibular dysfunction and motion sickness.

Simulations

The number of trials required to uncover an individuals' underlying asymmetry (if it exists), was determined via simulations. For a particular number of trials, 50 simulations were run with an assigned underlying asymmetry (or dual sigma: σ_P and σ_N) and an underlying vestibular bias; this was repeated for a variety of combinations of underlying asymmetry and underlying vestibular bias. These values were then used to simulate subjects' responses for blocks of trials. The magnitude and direction of the stimuli for each trial were determined the same way as in testing (i.e., with a 3 down 1 up staircase, and randomly, respectively).

The resulting data was then fit in two ways. First, a standard Gaussian cumulative distribution psychometric function defined by a σ and μ was fit to the binary data (e.g., forward vs. backward responses) in accordance to the "single sigma" (SS) model detailed previously. Second, directional asymmetries within pitch tilt were investigated using the hybrid dual sigma (DS) model initially proposed by Roditi and Crane (Roditi and Crane

2012). In this model, a psychometric function was fit with an independent σ_p and σ_n on either side of μ to provide a maximum likelihood estimate with the following parameters: σ_p, σ_n, and μ. This can be mathematically represented as follows:

$$for\ x > \mu: \quad \frac{1}{2} \quad [1 + erf(\frac{x-\mu}{\sqrt{2\sigma_P{}^2}})]$$

$$for\ x < \mu: \quad \frac{1}{2} \quad [1 + erf(\frac{x-\mu}{\sqrt{2\sigma_N{}^2}})]$$

(Roditi and Crane 2012)

The quality of the fits from the DS model was compared to those from the SS model using the Bayesian Information Criterion (BIC) to establish which model performed better:

$$BIC = \quad -2 * n * ln(\hat{L}) + k * ln\,(n)$$

where the first term characterizes the goodness of fit, the second term provides a penalty for adding additional parameters and the individual variables as follows:

n: number of data points

$\hat{L}$: maximum likelihood function of the model

k: number of parameters

The parameter penalty, specifically the number of parameters, is of importance as the symmetric model has two (one σ, one μ) and the asymmetric has three (two σ, one μ). Therefore, the asymmetric BIC's goodness of fit needs to be better in comparison to the symmetric BIC to compensate for the parameter penalty. The model with the lower BIC is the better fit of the data; if the BICs of the two models are within about +/- 2 of each other than typically both are considered roughly equally good at fitting the data (Jeffreys 1998).

The results are detailed in ***Table 9*** of the appendix. From the simulations it was determined that 100 trials were not enough to calculate for a directional asymmetry as the chances for a false positive (i.e., asymmetric model is a better fit of the data even when there is not an asymmetry present) and false negative (i.e., symmetric model is a better fit of the data even when there is an asymmetry present) were substantial. Chances of both for their respective cases decreased with an increasing number of trials. Furthermore, while large asymmetries were reasonably identifiable with a data set of 500 trials and even more so for a data set of 1000 trials, the chances of correctly detecting significantly decreased if there were smaller underlying asymmetries. While chances of correctly identifying increased with an increasing number of trials for all cases, it was found that this increase was not substantial enough to outweigh the experimentation time it would require. As a result, 2000 trials were determined as a reasonable number of trials to collect with each subject.

Experimental Set-Up

Each subject completed a total of 2000 trials in pitch tilt at 1.0 Hz. This frequency was selected to reduce the time required for each subject's data collection. Before testing, subjects were notified of the axis and frequency of tilt motion and provided practice trials until they felt comfortable (typically 5-10 trials). The 2000 trials were split into sessions of typically 200 trials each, with one session per day and sessions scheduled at the subject's convenience.

Data Analysis

Psychometric curves were fit similar to the simulations. First, a standard Gaussian cumulative distribution psychometric function defined by σ and μ was fit to the binary data (e.g., forward vs. backward responses) in accordance to the "single sigma" (SS) model detailed previously. Second, directional asymmetries within pitch tilt were investigated using the hybrid dual sigma (DS) model initially proposed by Roditi and Crane (Roditi and Crane 2012). In this model, a psychometric function was fit with an independent σ_p and σ_n

on either side of μ to provide a maximum likelihood estimate. The quality of the fits from the DS model was once again compared to those from the SS model using the Bayesian Information Criterion (BIC).

<u>Phase I of the Study</u>

Fitting psychometric curves to the data, pitch tilt thresholds for each subject at each frequency were calculated as shown in ***Figure 1*** and as detailed in ***Table 4*** to ***Table 8*** in the appendix. While there is quite a bit of inter-subject variability, the general trend resembles that established for roll tilt -- thresholds increase as frequency decreases and stabilizes around 0.15-0.2 Hz.

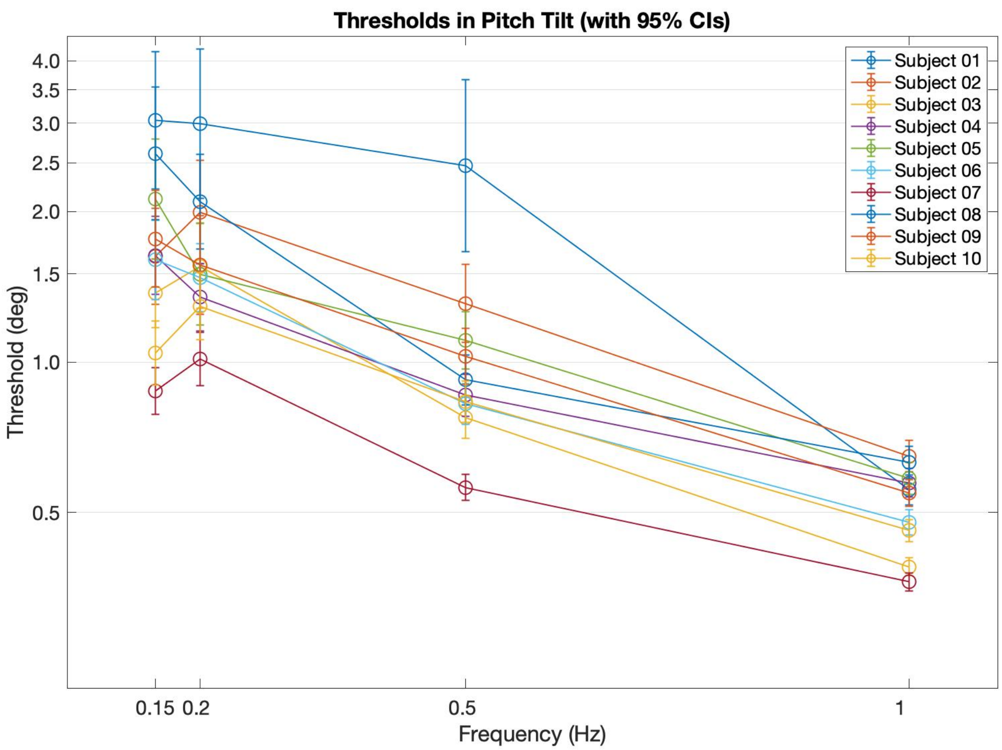


Figure 1 Individual pitch tilt thresholds for all ten subjects plotted as a function of frequency. The error bars characterize 95% confidence intervals.

This trend is more apparent in ***Figure 2*** where vestibular perceptual thresholds are presented as geometric means across subjects, over frequencies.

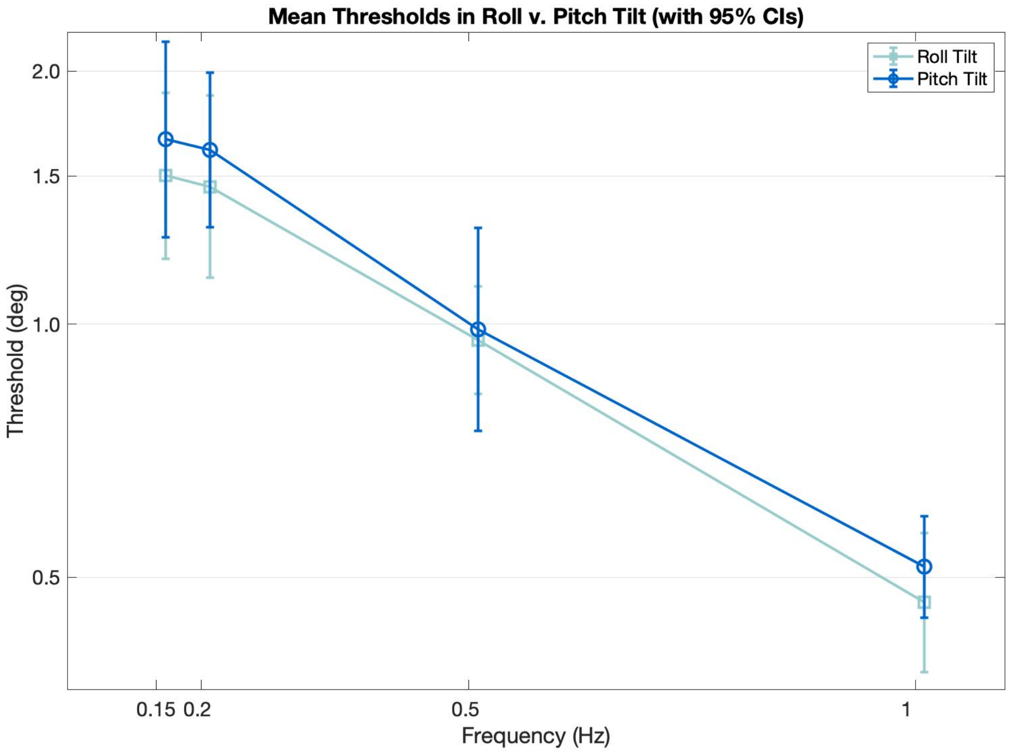


Figure 2 Average (arithmetic mean) thresholds of all ten subjects as a function of the frequency of motion. The light blue line represents thresholds in roll tilt, and the dark blue line represents thresholds in pitch tilt. The error bars characterize 95% confidence intervals.

Comparing mean pitch tilt thresholds to mean roll tilt thresholds in ***Table 1***, we see a general trend where pitch tilt thresholds are higher than roll tilt thresholds.

Table 1 Average (geometric mean) thresholds in roll tilt and pitch tilt over all frequencies with the differences in thresholds and percent differences in thresholds shown in the last two rows. In this particular scenario, for differences in thresholds, a positive difference means that roll tilt thresholds were higher than pitch tilt thresholds at that frequency and a negative difference means that roll tilt thresholds were lower than pitch tilt thresholds at that frequency. Furthermore, for percent differences in thresholds, roll tilt thresholds were evaluated by maintaining pitch tilt thresholds as the "actual" threshold.

	0.15 Hz	0.2 Hz	0.5 Hz	1.0 Hz
ROLL TILT THRESHOLDS	1.5017°	1.4562°	0.9567°	0.4666°
PITCH TILT THRESHOLDS	1.6583°	1.6119°	0.9855°	0.5145°

DIFFERENCE IN THRESHOLDS (Roll Tilt Thresholds – Pitch Tilt Thresholds)	-0.1565°	-0.1557°	-0.0288°	-0.0480°
PERCENT DIFFRENCE IN THRESHOLDS (Roll Tilt Thresholds in Comparison to Pitch Tilt Thresholds)	-9.4434%	-9.6594%	-2.9224%	-9.3294%

With the general linear model fit previously detailed and the results of which are displayed in ***Table 2***, we found the roll tilt thresholds were significantly lower than pitch tilt, across the frequencies tested (p = 0.045).

Table 2 Outputs of the general linear model with inputs of individual vestibular perceptual thresholds in roll and pitch tilt at various frequencies. The p-value for the statistical significance of the axis effect (particularly, pitch tilt thresholds < roll tilt thresholds) is highlighted in blue. *The output of the model is a two-tailed t-test; however due to the a priori hypothesis, this was modified to a one-tailed t-test.

	ρ_i (std)	β_j				β_k	ε_{ijk}
		0.15 Hz	0.2 Hz	0.5 Hz	1.0 Hz		
ESTIMATE	0.2038	0	-0.0296	-0.4856	-1.1696	0.0821	0.2134
STANDARD ERROR	-	0	0.0676	0.0676	0.0676	0.0478	-
TSTAT	-	0	-0.4376	-7.1816	-17.2972	1.7164	-
P-VALUE	-	0	0.66	< 0.005	< 0.005	0.045*	-

The axes difference is consistent at each frequency (i.e., roll tilt thresholds are lower than pitch tilt thresholds) as shown in ***Figure 3***. Statistical tests, previously detailed, confirm the normal distribution of log-transformed roll tilt (p = 0.6219) and pitch tilt (p = 0.4098); analysis without post-hoc corrections demonstrate that roll tilt thresholds are not significantly lower than pitch tilt thresholds at any particular frequency ($p = 0.2072$ at 0.15 Hz, $p = 0.0824$ at 0.2 Hz, $p = 0.0992$ at 0.5 Hz, $p = 0.0573$ at 1.0 Hz).

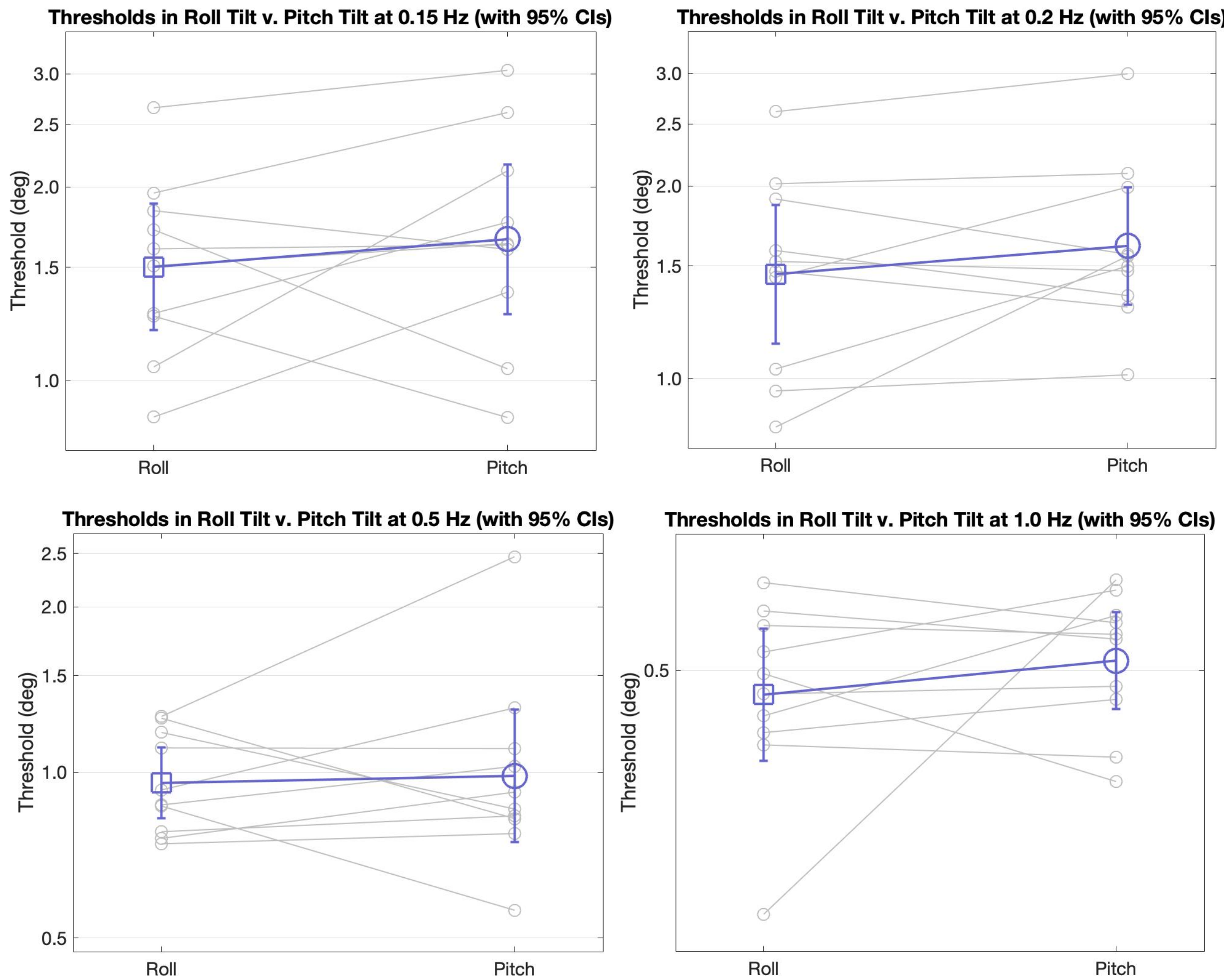
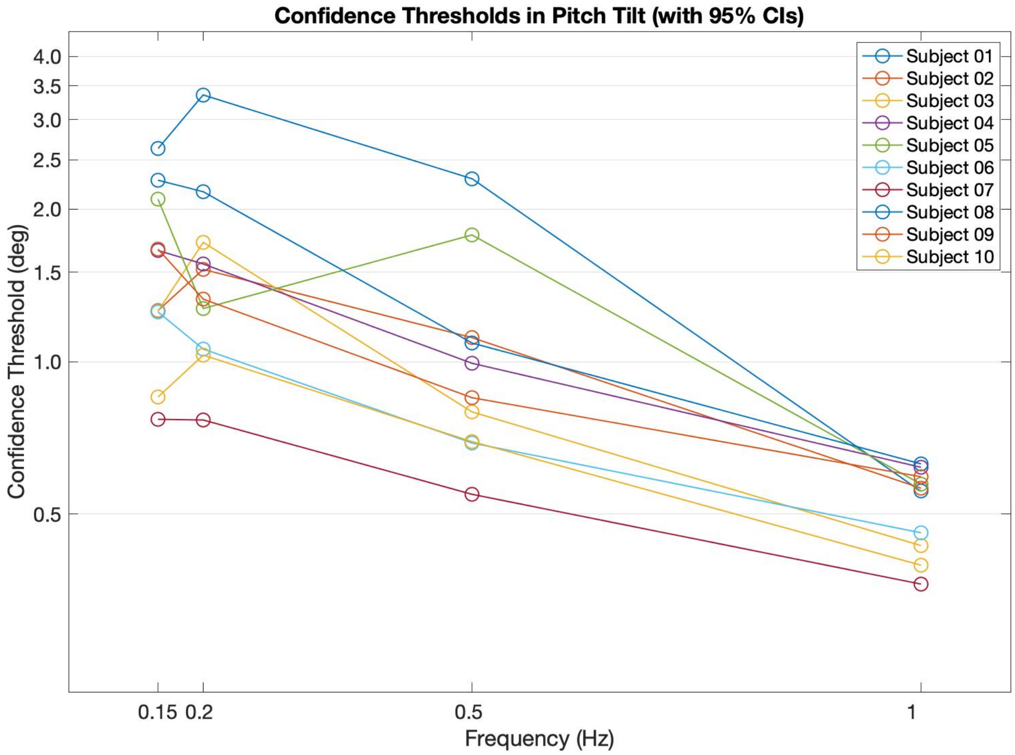


Figure 3 Average (geometric mean) thresholds in the purple of all ten subjects overlaid on individual vestibular perceptual thresholds for all ten subjects in grey, as a function of axes, for each frequency. The error bars show 95% confidence intervals.

Subjects were able to effectively perform the confidence task, yielding similar thresholds via the confidence-signal detection as that obtained via the bias-reduced generalized linear model, with higher thresholds for pitch vs. roll at all frequencies as seen in ***Figure 4***. It should be noted, however, that substantial differences do exist and would require further investigation into the precision of the confidence-signal detection model and the accuracy of the bias-reduced generalized linear model.



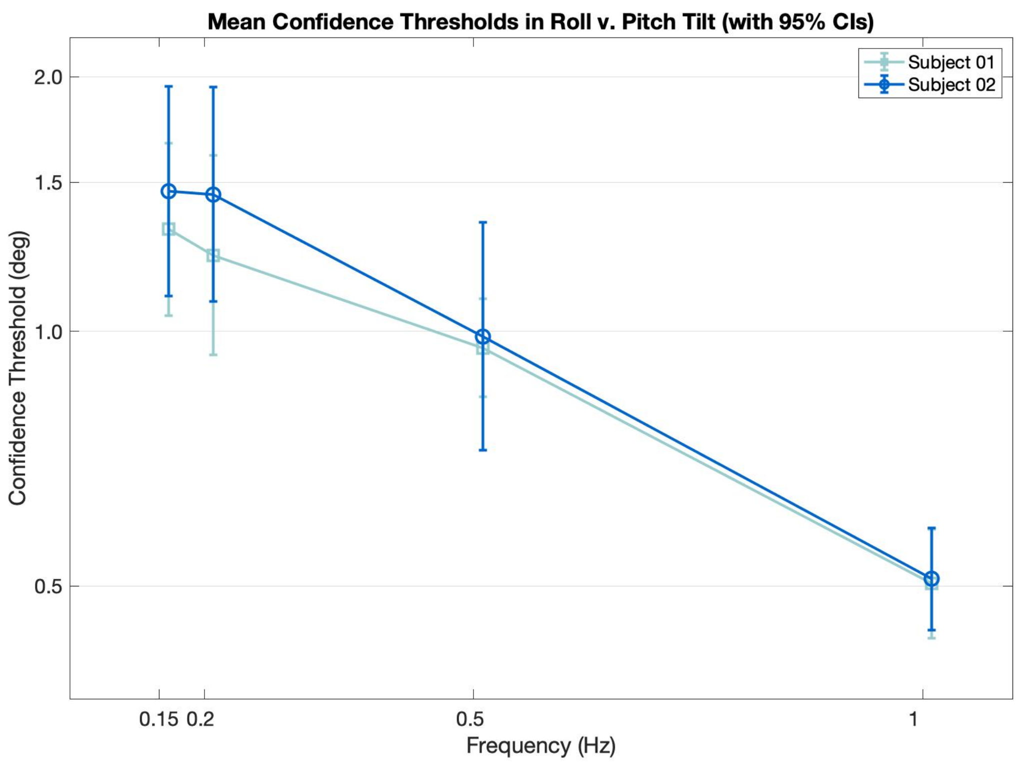
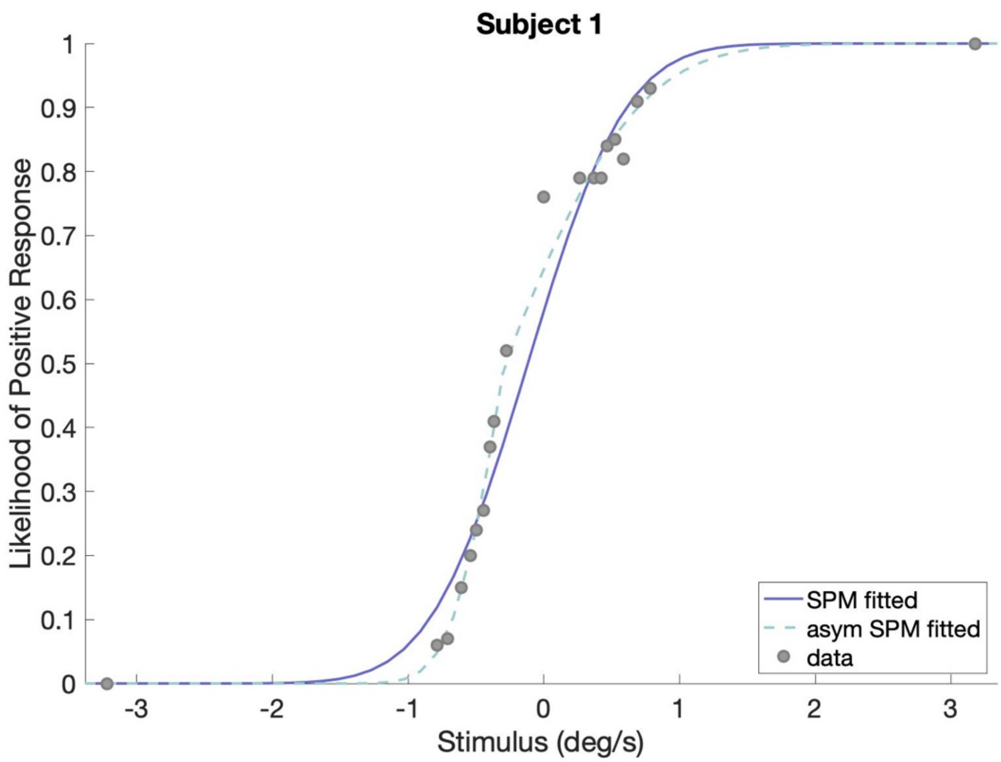
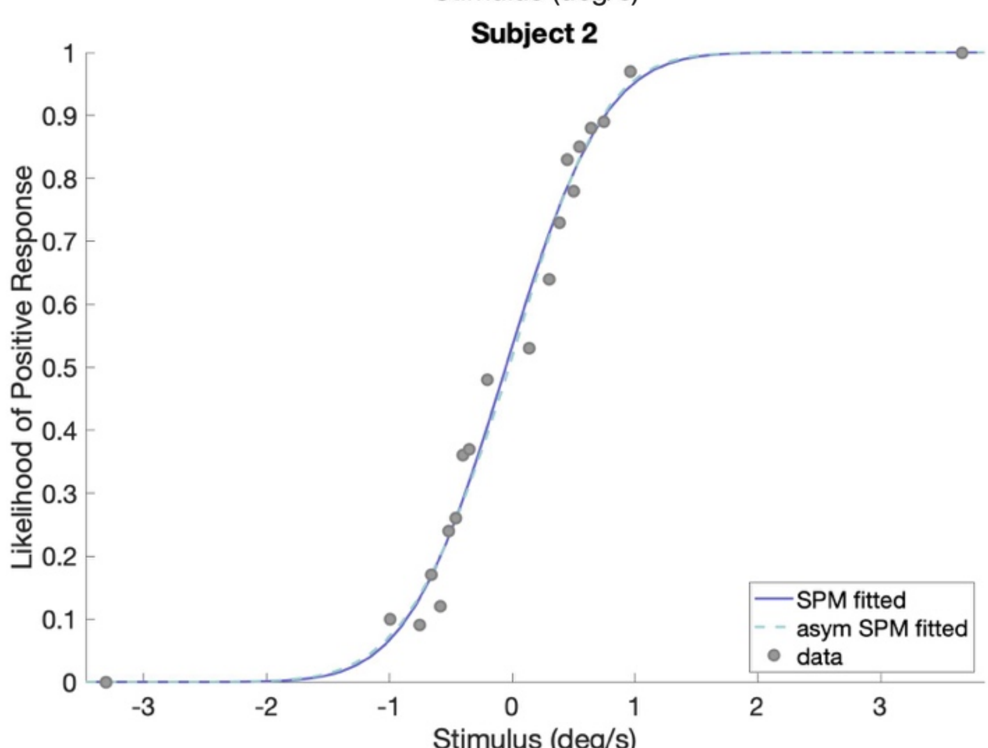


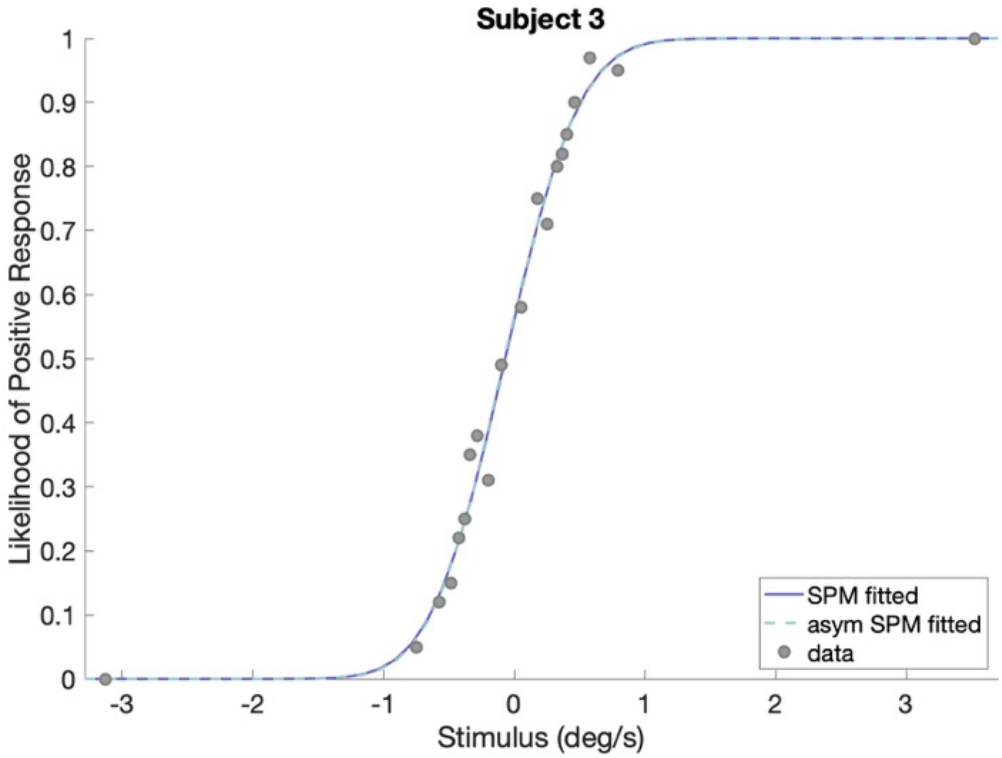
Figure 4 *(Top)* Individual pitch tilt confidence thresholds for all ten subjects plotted as a function of the frequency. *(Bottom)* Average (arithmetic mean) confidence thresholds of all ten subjects as a function of frequency of motion. The light blue line represents confidence thresholds in roll tilt, and the dark blue line confidence represents thresholds in pitch tilt. The error bars characterize 95% confidence intervals.

Phase II of the Study

Fitting the single sigma model and the hybrid dual sigma model to the data, psychometric curves for each subject were created as shown in ***Figure 5***.







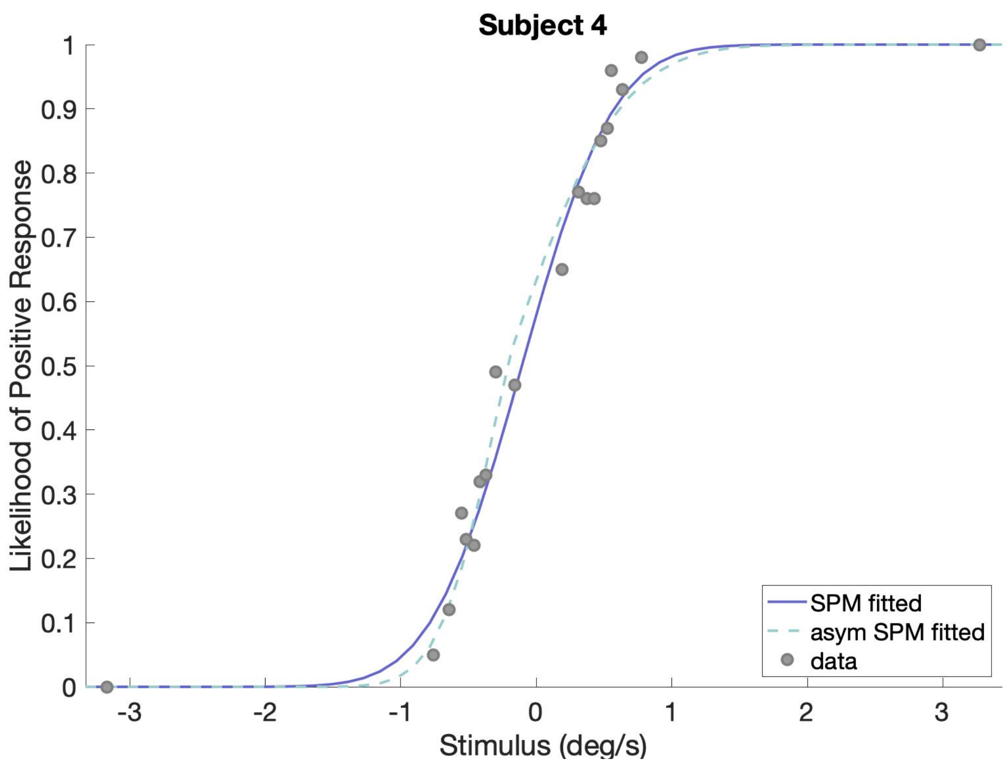


Figure 5 Psychometric curves of each subject fit using the single sigma model (shown in light purple) and the dual sigma model (shown in light blue) laid over with the concentration of stimuli (shown as grey circles).

Visually, the symmetric and asymmetric model seem to be indistinguishable for subjects 2 and 3; while the symmetric and asymmetric model seem to be slightly different for subject 2 and distinctly different for subject 1. Applying the model selection criterion, previously detailed and the results of which are displayed in ***Table 3***, demonstrate that subjects 2, 3, and 4 show the single sigma model to be a better fit of the data while subject 1 shows the hybrid dual sigma model to be a better fit of the data.

Table 3: Summary of subjects' thresholds using the single sigma and hybrid dual sigma and their respective BICs. The last column corresponds to the difference in BICs such that differences resulting in a positive value (highlighted with dark blue) suggest that the hybrid dual sigma is a better fit of the data, differences resulting in a negative value (highlighted with light blue) suggest that the single sigma is a better fit of the data, and differences of +/- 2 suggest that both are equally as good of a fit.

SUBJECT	SINGLE SIGMA MODEL		HYBRID DUAL SIGMA MODEL			SS BIC – DS BIC
	σ	BIC	σ_1	σ_2	BIC	
1	0.5667	1772.1	0.2980	0.7675	1744.7	27.4
2	0.6288	1788	0.6679	0.5941	1795.4	-7.4
3	0.4475	1753.5	0.4369	0.4562	1761.1	-7.6
4	0.52947	1739.5	0.36661	0.65094	1741.9	-2.4

For subjects 2 and 3, the symmetric model is considerably better than the asymmetric model, and for subject 1, the asymmetric model is considerably better than the symmetric model. Furthermore, in subject 1, the σ_1 is lower than σ_2 which corresponds to being better able to identify backward pitch tilts (i.e., subject ending with nose up) and less precise and perceiving forward tilt. However, the difference for subject 4 is only slightly in favor of the single sigma model.

CHAPTER IV| DISCUSSION

Phase I of the Study

As mentioned in the introduction, to our knowledge, two studies have investigated pitch tilt thresholds. The study by Teasdale involved the comparison of thresholds in roll and pitch tilt with tilt angular velocities of 0.01, 0.03, and 0.05 °/ sec with combined motion detection and direction recognition task (Teasdale et al. 1999). They conclude that roll tilt had lower thresholds than pitch; however, they had a small number of subjects and implemented a unique subject configuration. Subjects either stood on a platform, kneeled on a platform, sat on a platform, or were seated on the platform with their torso fixed but head free; this creates a confounding factor as controlled motion is not consistently administered to the vestibular system. The study by Hartmann et al. involved comparison of thresholds between a cohort of healthy, baseline subjects and a cohort of artistic gymnasts in roll tilt and pitch tilt at 0.5 and 3 Hz (Hartmann et al. 2014). While it provided insight into differences that exist between the two groups, this study did not perform statistical tests or draw any conclusions on the difference between the two axes in the cohort of healthy baseline subjects.

Findings from our phase I were (1) pitch tilt thresholds vary with frequency as had been previously established in roll tilt; and (2) pitch tilt thresholds are statistically significantly higher than (i.e., less sensitive than) roll tilt thresholds. While the effect size for the latter is small, the difference between axes is consistent at all four frequencies we tested. Furthermore, this difference was statistically significant at higher frequencies (0.5 and 1 Hz). While speculative, there are a few reasons that may explain the difference between pitch and roll tilt thresholds. As mentioned in the introduction, human movement is principally in the forward-backward direction with likely active minimization of movement in the left-right direction and therefore lower thresholds in roll tilt. Furthermore, the utricle (a component of the otolith organs of the vestibular system that sense gravity and linear acceleration) is pitched up at 30° relative to head level (Curthoys et al. 1999). Thus, the change in stimulation to the utricle is smaller for pitch tilt ($G * (sin(\theta + 30°) - sin(30°))$) starting from head level, than for roll tilt ($G * sin\theta$). For a 1° tilt, this is approximately a 16.7% difference, which is similar to the differences observed between pitch and roll thresholds. It should be noted, though, that these are all theoretical; there may not be any causation, and this difference between thresholds in pitch and roll tilt axis may merely be. Furthermore, as the size effect is small, testing with more subjects may provide a more thorough conclusion.

In everyday tasks, slightly lower sensitivity in pitch tilt may be compensated for with the aid of visual cues. For our forward-facing eyes, head pitch tilt almost always yields a change in the visual scene (stationary scene moves up and down), while roll head tilt may yield fewer substantive changes in the visual scene unless vertical cues are present (e.g., trees, ceilings, floors, doorways).

Phase II of the Study

As mentioned in the introduction, to our knowledge, one study has investigated directional asymmetries. The authors conclude that directional asymmetries occurred consistently only in "heave at 0.5 Hz"; additionally, they noted a "significant directional asymmetry…in 27% of conditions tested within subjects [and]… in at least one type of motion in 92% of subjects." However, there are limitations in the statistical analysis used by the authors. Firstly, the primary metric used was the "asymmetry index" (AI), defined as: $AI = log_2(\frac{\sigma_P}{\sigma_N})$, where the two threshold estimates are found by separately fitting data collected in each direction (i.e., for data collected in X-axis translation, σ_P characterizes subject responses for positive X translation motions and σ_N characterizes subject responses for negative X translation) using the log of velocity. Briefly, this metric can lead to false positives, in which there may appear to be a directional asymmetry when there is not one present. Secondly, one-tailed tests for the presence of an asymmetry in either direction were applied with $\alpha = 0.05$, which would result in an expected false positive rate of 10% (potentially accounting for some of the 27% of significant asymmetries identified). Thirdly, no correction for multiple statistical tests was applied. It can, therefore, be inferred that given the eight conditions per subject, at an $\alpha = 0.05$, one would expect 57% of subjects to have at least one false positive. Thus, it remained unclear whether asymmetries were common in vestibular perceptual thresholds.

Findings from our phase II found that some subjects (one of four) have large directional asymmetries in pitch, while other subjects were symmetric (two of three were highly symmetric, and one of three was slightly symmetric). In the subject who did have a directional asymmetry, the threshold representing backward motion was lower than or more sensitive than the threshold representing forwards motion. While speculative, this asymmetry may arise from movements in the forward direction being more commonplace than backward motion. Further, such unwanted forward motions could be detected and well-guarded against with the help of visual cues and an individual's ability to steady themselves/ recover. At this point, it is unclear why some individuals might have a large forward vs. backward asymmetry in pitch tilt, while others do not.

CHAPTER V | CONCLUSION

As per the objectives initially set in the introduction, the following conclusions can be made:

Objective 1 | This is the first study to quantify pitch tilt thresholds across a range of frequencies, providing a comparative baseline of healthy subjects. Pitch tilt thresholds increased at lower frequencies and stabilized around 0.15-0.2 Hz.

Objective 2 | Pitch tilt thresholds, across each frequency tested, were observed to be similar to, but slightly higher than, roll tilt thresholds.

Objective 3 | This is the first study to report directional asymmetries in pitch tilt at 1 Hz in some subjects. While two subjects were highly symmetric and one less so, one subject showed a considerable asymmetry with lower thresholds for backward motions.

These findings on pitch tilt thresholds and directional asymmetries may be particularly relevant for postural balance and locomotion. In clinical medicine, this healthy baseline may be useful for comparative studies in clinical populations for "mechanism" impact; how do pitch tilt thresholds differ in populations that tend to fall forwards/ backward as a result of conditions with direct vestibular effect of direct motion/ balance effect? Moreover, directional asymmetries may be useful for comparative studies in clinical populations for "pathological" impact; could specific populations need lower thresholds to better prevent falling backward where it is harder to recover?

In aerospace, these can be useful tools in investigating spatial disorientation and space motion sickness in current astronauts as well as in older, returning astronauts suffering from post-flight sensorimotor impairment. Spatial disorientation (SD) and space motion sickness (SMS) are believed to be the result of a few things - the lack of gravity which results in the removal of static utricular stimulation with head upright, may cause a feeling of tumbling backward after main engine cut-off; visual reorientation illusion or reorientation of sense of up/ down based on visual cues; etc. Given the physiological response in pitch, pitch tilt thresholds may be a useful tool for characterization of both conditions. While speculative, could asymmetries be used as a predictive measure for these conditions? Furthermore, this could be particularly pertinent for older, returning astronauts suffering from post-flight sensorimotor impairments. As detailed in the introduction, thresholds increase dramatically after the age of 40-years old —and astronaut candidates range typically fly during their late 30s to 40s. With this increase in thresholds, they have an increased risk of failing the modified Romberg balance test (even after accounting for age effects), and therefore, an increased risk of falling as well as sub-optimally performing manual control nulling tasks (Rosenberg et al. 2018). This increased risk coupled with other physiological impairments resulting from long-duration exposure to micro-gravity can prove to be hazardous for astronauts upon return to Earth or surface explorations of other planets. These impairments can be further heightened with the anti-motion sickness drug that astronauts take (promethazine) as it has been found to increase thresholds (Diaz-Artiles et al. 2017).

BIBLIOGRAPHY

Benson, A. J., E. C. Hutt, and S. F. Brown. 1989. "Thresholds for the Perception of Whole Body Angular Movement about a Vertical Axis." Aviation, Space, and Environmental Medicine.

Benson, A. J, M. B. Spencer, and J. R. R. Stott. 1986. "Thresholds for the Detection of the Direction of Whole-Body Linear Movement." Aviation, Space, and Environmental Medicine 57 (11): 1088–96.

Bermúdez Rey, María Carolina, Torin K. Clark, Wei Wang, Tania Leeder, Yong Bian, and Daniel M. Merfeld. 2016. "Vestibular Perceptual Thresholds Increase above the Age of 40." Frontiers in Neurology 7 (October). https://doi.org/10.3389/fneur.2016.00162.

Bisdorff, A R, C J Wolsley, D Anastasopoulos, A M Bronstein, and M A Gresty. 2018. "The Perception of Body Vertically (Subjective Postural Vertical) in Peripheral and Central Vestibular Disorders," 12.

Bringoux, L. 2002. "Perception of Slow Pitch and Roll Body Tilts in Bilateral Labyrinthine-Defective Subjects." Neuropsychologia 40 (4): 367–72. https://doi.org/10.1016/S0028-3932(01)00103-8.

Bronstein, Adolfo M. 1999. "The Interaction of Otolith and Proprioceptive Information in the Perception of Verticality: The Effects of Labyrinthine and CNS Disease." Annals of the New York Academy of Sciences 871 (1): 324–333.

Chaudhuri, Shomesh E., and Daniel M. Merfeld. 2013. "Signal Detection Theory and Vestibular Perception: III. Estimating Unbiased Fit Parameters for Psychometric Functions." Experimental Brain Research 225 (1): 133–46. https://doi.org/10.1007/s00221-012-3354-7.

Curthoys, I. S., G. A. Betts, A. M. Burgess, H. G. MacDOUGALL, A. D. Cartwright, and G. M. Halmagyi. 1999. "The Planes of the Utricular and Saccular Maculae of the Guinea Pig." Annals of the New York Academy of Sciences 871 (1 OTOLITH FUNCT): 27–34. https://doi.org/10.1111/j.1749-6632.1999.tb09173.x.

Diaz-Artiles, Ana, Adrian J. Priesol, Torin K. Clark, David P. Sherwood, Charles M. Oman, Laurence R. Young, and Faisal Karmali. 2017. "The Impact of Oral Promethazine on Human Whole-Body Motion Perceptual Thresholds." Journal of the Association for Research in Otolaryngology 18 (4): 581–90. https://doi.org/10.1007/s10162-017-0622-z.

Grabherr, Luzia, Keyvan Nicoucar, Fred W. Mast, and Daniel M. Merfeld. 2008. "Vestibular Thresholds for Yaw Rotation about an Earth-Vertical Axis as a Function of Frequency." Experimental Brain Research 186 (4): 677–81. https://doi.org/10.1007/s00221-008-1350-8.

Hartmann, Matthias, Sarah Furrer, Michael H. Herzog, Daniel M. Merfeld, and Fred W. Mast. 2013. "Self-Motion Perception Training: Thresholds Improve in the Light but

Not in the Dark." Experimental Brain Research 226 (2): 231–40. https://doi.org/10.1007/s00221-013-3428-1.

Hartmann, Matthias, Katia Haller, Ivan Moser, Ernst-Joachim Hossner, and Fred W. Mast. 2014. "Direction Detection Thresholds of Passive Self-Motion in Artistic Gymnasts." Experimental Brain Research 232 (4): 1249–58. https://doi.org/10.1007/s00221-014-3841-0.

Jeffreys, Harold. 1998. Theory of Probability. 3. ed., reprinted. Oxford Classic Texts in the Physical Sciences. Oxford: Clarendon Press.

Karmali, Faisal, María Carolina Bermúdez Rey, Torin K. Clark, Wei Wang, and Daniel M. Merfeld. 2017. "Multivariate Analyses of Balance Test Performance, Vestibular Thresholds, and Age." Frontiers in Neurology 8 (November). https://doi.org/10.3389/fneur.2017.00578.

Karmali, Faisal, Shomesh E. Chaudhuri, Yongwoo Yi, and Daniel M. Merfeld. 2016. "Determining Thresholds Using Adaptive Procedures and Psychometric Fits: Evaluating Efficiency Using Theory, Simulations, and Human Experiments." Experimental Brain Research 234 (3): 773–89. https://doi.org/10.1007/s00221-015-4501-8.

Leek, Marjorie R. 2001. "Adaptive Procedures in Psychophysical Research." Perception & Psychophysics 63 (8): 1279–92. https://doi.org/10.3758/BF03194543.

Lewis, R. F., A. J. Priesol, K. Nicoucar, K. Lim, and D. M. Merfeld. 2011a. "Dynamic Tilt Thresholds Are Reduced in Vestibular Migraine." Journal of Vestibular Research-Equilibrium & Orientation 21 (6): 323–30. https://doi.org/10.3233/Ves-2011-0422.

———. 2011b. "Abnormal Motion Perception in Vestibular Migraine." Laryngoscope 121 (5): 1124–25. https://doi.org/10.1002/Lary.21723.

Lim, Koeun, Faisal Karmali, Keyvan Nicoucar, and Daniel M. Merfeld. 2017. "Perceptual Precision of Passive Body Tilt Is Consistent with Statistically Optimal Cue Integration." Journal of Neurophysiology 117 (5): 2037–52. https://doi.org/10.1152/jn.00073.2016.

Merfeld, D. M. 2011. "Signal Detection Theory and Vestibular Thresholds: I. Basic Theory and Practical Considerations." Experimental Brain Research 210 (3–4): 389–405. https://doi.org/10.1007/s00221-011-2557-7.

Merfeld, Daniel M. 2011. "Signal Detection Theory and Vestibular Thresholds: I. Basic Theory and Practical Considerations." Experimental Brain Research 210 (3–4): 389–405. https://doi.org/10.1007/s00221-011-2557-7.

Moser, Ivan, Luzia Grabherr, Matthias Hartmann, and Fred W. Mast. 2015. "Self-Motion Direction Discrimination in the Visually Impaired." Experimental Brain Research 233 (11): 3221–30. https://doi.org/10.1007/s00221-015-4389-3.

Nouri, Sirine, and Faisal Karmali. 2018. "Variability in the Vestibulo-Ocular Reflex and Vestibular Perception." Neuroscience, September. https://doi.org/10.1016/j.neuroscience.2018.08.025.

Roditi, Rachel E., and Benjamin T. Crane. 2012. "Directional Asymmetries and Age Effects in Human Self-Motion Perception." Journal of the Association for Research in Otolaryngology 13 (3): 381–401. https://doi.org/10.1007/s10162-012-0318-3.

Rosenberg, M, Raquel C. Galvan-Garza, Torin K. Clark, David P. Sherwood, Laurence R. Young, and Faisal Karmali. 2018. "Human Manual Control Precision Depends on Vestibular Sensory Precision."

Taylor, M. M., and C. Douglas Creelman. 1967. "PEST: Efficient Estimates on Probability Functions." The Journal of the Acoustical Society of America 41 (4A): 782–87. https://doi.org/10.1121/1.1910407.

Teasdale, Normand, Vincent Nougier, Pierre-Alain Barraud, Christophe Bourdin, Bettina Debû, Didier Poquin, and Christian Raphel. 1999. "Contribution of Ankle, Knee, and Hip Joints to the Perception Threshold for Support Surface Rotation." Perception & Psychophysics 61 (4): 615–24. https://doi.org/10.3758/BF03205534.

Valko, Y., R. F. Lewis, A. J. Priesol, and D. M. Merfeld. 2012. "Vestibular Labyrinth Contributions to Human Whole-Body Motion Discrimination." Journal of Neuroscience 32 (39): 13537–42. https://doi.org/10.1523/JNEUROSCI.2157-12.2012.

Yi, Yongwoo, and Daniel M. Merfeld. 2016. "A Quantitative Confidence Signal Detection Model: 1. Fitting Psychometric Functions." Journal of Neurophysiology 115 (4): 1932–45. https://doi.org/10.1152/jn.00318.2015.

APPENDIX

QUESTIONNAIRES AND COVER LETTERS TO SUBJECTS IN THE RESEARCH STUDY

IRB Consent Form

University of Colorado
Boulder

Permission to Take Part in a Human Research Study

Title of research study: Human Perception of Small Motions in Pitch and Roll Tilt

IRB Protocol Number: 18-0361

Investigator: Torin Clark

Purpose of the Study

The purpose of this study is to measure people's ability to perceive small tilts. We are interested in how people perform in two directions: roll, and pitch tilting. The inner ear detects when the body is tilting in 3-dimensional space but measures each direction differently.

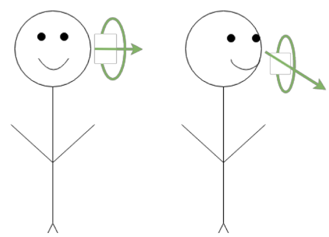
We invite you to take part in a research study because we are investigating how people perceive small motions in two directions of tilting. We have chosen you because we believe that you have a normally functioning vestibular system (helps perceive motion in the dark) and will be able to complete the study.

We expect that you will be in this research study for up to 20.5 hours total. The study consists of up to forty sessions lasting typically thirty minutes each that will be completed depending upon your availability and scheduling.

We expect up to 35 people will be in this research study.

Explanation of Procedures

These experiments will be performed in the Bioastronautics Laboratory in the Engineering Center at the University of Colorado based on your schedule. It will be important that you, the subject, can participate in the experiment for up to forty separate sessions (average 30 minutes each). Each session will test a different type of tilting: pitch or roll tilts, shown below.



Pitch Tilt Roll Tilt

On your first day participating in the experiment, you will be asked about any history of vestibular issues, then given brief questionnaires related to your vestibular system (history of motion sickness, etc.) and then will be introduced to the experiment. A researcher will explain to you how each axis of tilting will be achieved on the Tilt Translation Sled device. You will then be helped onto the Tilt Translation Sled device, buckled in using a seatbelt and the researchers will show you how to use the audio system to communicate back and forth with the operator. Next, the researchers will exit the Tilt Translation Sled and turn off the lights as it is important for the experiment that you, the subject, do not have any visual cues that will signal to you which direction you are tilting.

The first trial will begin with the Tilt Translation Sled chair briefly tilting in either the left/ right or forward/ backward direction, depending on whether it is a roll tilt or pitch tilt session. The researchers will then ask you which direction you felt you tilted and how confident you are in that response. The next trial will begin shortly after you have answered. Additionally, the researchers will occasionally ask you to report if you are experiencing motion sickness. If you feel more than minor motion sickness, you will be able to stop it at any time.

After the first session concludes, you will be unbuckled from the chair and will be welcome to leave. You will return for a total of up to 40 sessions depending upon your availability. The other sessions will be conducted the same as the first with the only change being your tilt axes (roll or pitch) on the Tilt Translation Sled device. Your total time commitment over the entire study will not exceed 20.5 hours.

Voluntary Participation and Withdrawal

Whether or not you take part in this research is your choice. You can leave the research at any time and it will not be held against you.

Efforts will be made to limit the use and disclosure of your personal information, including research study data, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization.

The person in charge of the research study can remove you from the research study without your approval. Possible reasons for removal include not following the instructions or completing the necessary tasks. A subject will be withdrawn without his/her consent if it is deemed that the experimental procedure is not being followed or the subject's actions cause a risk to themselves or others in the lab.

If you are a CU Boulder student or employee, taking part in this research is not part of your class work or duties. You can refuse to enroll, or withdraw after enrolling at any time, with no effect on your class standing, grades, or job at CU Boulder. You will not be offered or receive any special consideration if you take part in this research.

Risks and Discomforts

It is possible that this experiment may cause you to experience some motion sickness. The effects of motion sickness are dizziness and nausea, but the effects tend to subside shortly after the motion stopping. As mentioned before, you may stop the experiment at any time if you feel you are becoming too sick to continue. Furthermore, in the case of loss or theft of data, your data will be coded and the file linking the subject's name to his or her respective code will only be available on a password-protected computer within a locked laboratory.

There are no anticipated long-term consequences to participating in this experiment.

It is important that you tell the Principal Investigator, Torin Clark, if you think you have been injured as a result of taking part in this study. You can call him at (303)492-4015.

Confidentiality

Information obtained about you for this study will be kept confidential to the extent allowed by law. Research information that identifies you may be shared with the University of Colorado Boulder Institutional Review Board (IRB) and others who are responsible for ensuring compliance with laws and regulations related to research, including people on behalf of the Office for Human Research Protections. The information from this research may be published for scientific purposes; however, your identity will not be given out.

Cost of Participation

The only potential costs to the subjects will be for transportation. We will not provide compensation for this transportation.

Payment for Participation

If you agree to take part in this research study, we will pay you $10 per hour in cash for your time and effort. Payments will be made either after each session, at the conclusion of the study, or at any point that you wish to leave the study, as you desire.

It is important to know that payment for participation is taxable income.

Contact for Future Studies

We would like to keep your contact information on file so we can notify you if we have future research studies we think you may be interested in. This information will be used by only the principal investigator of this study and only for this purpose.
Please initial your choice below:

___ Yes, you may contact me for future research studies. The best way to contact me is: (enter preferred telephone number and/or email address)

____

___ No, you may not contact me for future research studies.

Questions

If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at (303)492-4015.
This research has been reviewed and approved by an Institutional Review Board (IRB). You may talk to them at (303) 735-3702 or irbadmin@colorado.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research subject.
- You want to get information or provide input about this research.

Signatures

Your signature documents your permission to take part in this research.

____

Signature of subject Date

____

Printed name of subject

____

Signature of person obtaining consent Date

____

Printed name of person obtaining consent

02.11.2019
IRB Approval Date
IRB Document Revision Date: March 13, 2018

Demographics and Vestibular History Questionnaire

<u>Demographics Information</u>

Subject ID: _______________

How would you describe yourself?

- ☐ White
- ☐ Asian
- ☐ Black or African American
- ☐ American Indian/Alaska Native
- ☐ Native Hawaiian or other Pacific Islander
- ☐ More than one race

Are you of Hispanic or Latino origin?

- ☐ Yes
- ☐ No

<u>Vestibular History Information</u>

Flight Experience

What is the extent of your previous flight experience?

- ☐ Little to no previous flight experience
- ☐ Passenger on commercial flights
- ☐ Passenger on small aircraft
- ☐ Private pilot

If you answered "Private pilot", please answer the following questions:

Years flying: ________________

Years flying acrobatics: __________________

Total approximate flight time (hrs): ___________________

Total flight time (hrs) in the last 12 months: __________________

Total flight time (hrs) in the last 30 days: ____________________

Centrifuge Experience

Have you ever been on a centrifuge?

- ☐ Yes
- ☐ No
- ☐ I'm not sure

If you answered "yes", please explain when, for how long, and if you experienced any motion sickness while spinning on the centrifuge:

____

____

Activities History

In this section, we will ask about two different types of activities, proprioceptive activities and bioenergetic activities. You will be asked how often you participate in these two categories of activities, so please reference the list below, which provides examples of activities in each category.

Proprioceptive Activities:

- Trampoline
- Gymnastics
- Climbing
- Judo
- Karate
- Other martial arts
- Downhill skiing
- Waterskiing
- Sailing
- Fencing
- Archery

Bioenergetic Activities:

- Running
- Basketball
- Cycling
- Football
- Handball
- Swimming
- Volleyball
- Rugby
- Cross-country skiing
- Canoe/Kayaking

These first two questions ask about your frequency of activity in the last ***12 months****.*

How regularly have you participated in any of the ***proprioceptive*** activities over the last ***12 months***?

○	○	○	○	○	○	○
Never	1 time	2-5 times	6-12 times	Monthly	Weekly	Daily

How regularly have you participated in any of the ***bioenergetic*** activities over the last ***12 months***?

○	○	○	○	○	○	○
Never	1 time	2-5 times	6-12 times	Monthly	Weekly	Daily

These next questions ask about your frequency of activity over your ***lifetime****. Specifically, we are asking the following: at the peak of your activity for the category in question, how frequently did you perform the activity?*

How regularly did you participate in any of the ***proprioceptive*** activities at the peak of your activity over your entire **lifetime**?

○	○	○	○	○	○	○
Never	1 time	2-5 times	6-12 times	Monthly	Weekly	Daily

Approximately how old were you when this peak of activity occurred? ____________

How regularly did you participate in any of the ***bioenergetic*** activities at the peak of your activity over your entire **lifetime**?

○	○	○	○	○	○	○
Never	1 time	2-5 times	6-12 times	Monthly	Weekly	Daily

Approximately how old were you when this peak of activity occurred? ____________

Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short)

1. Please State Your **Age** .... Years. *2.* Please State Your Sex (tick box) **Male** [ ] 1 **Female** [ ] 2

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

Your CHILDHOOD Experience Only (before 12 years of age), for each of the following types of transport or entertainment please indicate:

3. **As a CHILD (before age 12),** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

Your Experience over the LAST 10 YEARS (approximately), for each of the following types of transport or entertainment please indicate:

4. **Over the LAST 10 YEARS,** how often you **Felt Sick or Nauseated** (tick boxes):

	Not Applicable - Never Travelled	**Never Felt Sick**	**Rarely Felt Sick**	**Sometimes Felt Sick**	**Frequently Felt Sick**
Cars					
Buses or Coaches					
Trains					
Aircraft					
Small Boats					
Ships, e.g. Channel Ferries					
Swings in playgrounds					
Roundabouts in playgrounds					
Big Dippers, Funfair Rides					
	t	0	1	2	3

TTS OPERATOR CHECKLIST
Study: Thresholds

PREPARE TTS

1. Power "ON" TTS with lever on gray power box.
2. Turn on small display monitor on desk.
3. Plug in white VGA cord, if not already plugged in, to the small display monitor.
4. Follow directions on small display monitor (Click F1 on small keyboard mounted above the Computer.)
5. Verify that the the small display motor reads "Welcome to LabVIEW Real-Time 8.0" and the TTS on-board computer is ready to use. If not, then reboot the TTS and make sure all wires are completely plugged in.
6. Replace white VGA cord with the blue VGA cord on the small display monitor.
7. Plug in power cord to the video recording box.
8. Verify that both camera views come on the small display monitor.
9. Open TTS pressure valve ("TTS") while ensuring that the relief valve ("TTS Relief Valve") is closed and main pressure valve ("V101") is open.
10. Power on Computer.
11. Turn on Computer monitor.
12. Log into Computer (pw: [redacted]
13. Open LabVIEW (Start → Programs → National Instruments → LabVIEW 8.0 → LabVIEW)
14. Open LabVIEW Program "NASA Linear Track… March 2008 20 m sec… Control Jan 10.lvproj")
15. Open LabVIEW VI "Thresholding_S2018" (RT PXI Target → Vis on PXI)
16. Open Block Diagram (Window → Show Block Diagram) and verify that:
    - number of trials is set to 100
    - frequency is set to either 0.2, 0.5, or 1 Hz
    - initial angle is set to 6 degrees
    - and maximum angle is set to the specified angle for the frequency

Frequency (Hz)	0.15; 0.2	0.5	1
Maximum Angle	12	10	6

17. Click white "run"
18. Click "save all" in the "Save changes?" command window that pops up.
19. Verify that the white "run" button is now black.
20. Verify that the blue bar in the middle of the software is loading nominally. If not, then click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 14/15. You may get a window that states "Waiting to Disconnect from Engine" in which you should click "stop waiting and disconnect from the engine."
21. Enter subject number in the command windows that pops up. If the program stops responding, then click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 14/15. You may get a window that states "Waiting to Disconnect from Engine" in which you should click "stop waiting and disconnect from the engine."
22. Turn on the TTS light in LabVIEW, if not already on.

PREPARE AUDIO EQUIPMENT

1. Verify that the "Tilt Emergency Stop" button is engaged.
2. Turn on grey speakers on the TTS operator desk.
3. Turn on microphone on the TTS operator desk.
4. Turn on white noise maker underneath the TTS operator desk.
5. Turn on subject's headphones in the TTS.
6. Verify that the subject's microphone, headphones, and operator microphone are on.

PRE-SESSION WARM UP TILTS

1. Secure seatbelt.
2. Secure seatbelt E-Stop.
3. Check for loose wires, bolts, tools, etc.
4. Tilt TTS side to side manually and make sure nothing is in the path of travel.
5. Exit TTS room and close door.
6. Secure door with handles.
7. Disengage operator "Tilt Emergency Stop."
8. Press "E-Stop" button (middle green button).
9. Press "Tilt S-Stop" button (left green button).
10. Perform the tilt-specific interlock steps.
11. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
12. Enter the maximum angle in the "angle" user-input box. If the user-input box is greyed out, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 14/15.
13. Click "clear buffer."
14. Verify that the angle profile is displayed on the Chair Angle plot. If not, then click the up arrow next to the "angle" user-input box. Once the profile appears, then click the down arrow followed by the "clear buffer." If it still doesn't show up, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 14/15.
15. Click "run profile" when you're ready to tilt.

16. Monitor the TTS in the video cameras it completes the profile.
17. Verify that the TTS reaches the maximum angle on the camera, the “Chair Angle” plot, and the “tilt” measurement in the tilt-specific interlock box.
18. Click soft-stop. Ensure that this is done before the blue bar at the middle of the screen loads till the end.
19. Verify that the TTS reaches 0 degrees on the camera, and the “tilt” measurement in the tilt-specific interlock box.
20. Repeat Steps 12-19 for the maximum angle to the other side to verify that the TTS is operating properly.
21. Engage the “E-stop” button once completed.

PREPARE HAPTIC FEEDBACK EQUIPMENT

1. Remove the wrist cuff and remote from the charging ports, under the TTS desk.
2. Press the orange button on the wrist cuff.
3. Verify that the wrist cuff and remote are connected by clicking “vibrate” on the remote and verifying that a vibration is felt in the wrist cuff. If not, then press the orange button again and re-start from Step 2.

TESTING DAY 1

Inform & Prepare Subject For Training/Testing

1. Greet subject and show them around the lab
2. Ask subject if they need to use the restroom
3. Verify cell phone, keys, etc. are out of pockets
4. Verify subject is wearing clothing that fully covers skins (pants, long sleeves, socks, shoes)
5. Start by talking about how they will be secured onto the TTS chair.
6. Tell the subject that they can get off at any time, they should just let the operators know
7. Explain to the subjects that their head will be fixed in place with the headrest.
8. Explain the communication system to the subject
9. Explain the *two* cameras that will be monitoring the experiment
10. Explain the emergency stops but that they should inform the operators if they would like to stop
11. Explain what will happen when we are ready to test → we leave, home tilt, testing will begin such that light turns off when angle administration begins, cue to tell them to report, brought back to home, lights turn on.
12. Explain the haptic feedback system.

MAKE FINAL ADJUSTMENTS AND PREPARE FOR TRAINING/TESTING

1. Have subject sit down on the TTS chair with their head on the black headrest.
2. Check that their eyes/ears are centered on the chair (left/right and up/down)
3. Adjust the chair height such that their ears are centered in the headpiece cut-outs.
4. Gently tighten the headrest earpieces (with crank) around the subject's head
5. Clasp seatbelt and seatbelt E-Stop. Show the subject the seatbelt E-Stop.
6. Ask the subject to done the headphones.
7. Explain to subject what left/right actually means (we want them to think about their head not their feet).
8. Turn on operator microphone.
9. "*We want to make sure you can hear us. Can you hear us okay?"*
10. Adjust microphone volume as necessary.
11. "*During the experiment, on each trial you will tilt either right ear down/left ear down (forward/backward). After each tilt, you will verbally state which direction you think you were tilted. You will also report how confident you were, which we will explain more about later. Try to keep all comments and questions for when you are upright and lights are on."*
12. "*We want to make sure you can feel the haptic feedback cue for when you should report your direction and confidence level."*
13. Click vibrate on the remote.
14. In the microphone: "Did you feel that okay?"
15. Adjust vibration time as necessary.
16. Check room for any hazards, tilt the TTS chair side to side manually to ensure that it is clear of everything in the room.
17. Exit room.
18. Secure door with handles.

TRAINING

1. Turn on operator microphone.
2. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
3. Turn off operator microphone.
4. Disengage operator "Tilt Emergency Stop."
5. Press "E-Stop" button (middle green button).
6. Press "Tilt S-Stop" button (left green button).
7. Perform the tilt-specific interlock steps.
8. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
9. "*First, we will start with some practice. The lights will turn off and there will be a tilt, either left/right (forward/backward). I will cue you to report with the haptic buzz. Give us the response that immediately comes to mind rather than waiting. You can report direction as "left" or "right" and confidence between 50% and 100% where 50% means you are just guessing and 100% means you are certain. Please report in 5% increments. For example, 65% instead of 67.1%." Once you report, you will be brought back upright and the lights will turn on. We want you to focus on the direction your head tilts, either right ear down or left ear down. Sometimes thinking about your feet can make it confusing. Does that make sense? And even if you are not sure of the direction, you must choose. Just make your best guess."*
10. *"The sequence will begin as soon as you the lights turn off. Are you ready to practice a few?"* If yes, then proceed.
11. Enter 6 degrees in the "angle" user-input box. If the user-input box is greyed out, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11.
12. Click "clear buffer."
13. Verify that the angle profile is displayed on the Chair Angle plot. If not, then click the up arrow next to the "angle" user-input box. Once the

profile appears, then click the down arrow followed by the "clear buffer." If it still doesn't show up, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11.

14. Click "run profile" when you're ready to tilt.
15. Monitor the TTS in the video cameras it completes the profile.
16. Press vibration on the haptic feedback remote.
17. Once the subject has reported, click soft-stop.
18. Enter the subject-reported direction to LabVIEW by clicking either "left" or "right" in the user-input box.
19. Repeat steps 5 to 10 for 10 trials.
20. Turn on operator microphone.
21. *"That was good. Before we continue let's talk a little more about confidence assessment and what you need to do to be "well calibrated." Probabilities are numbers that express uncertainty. If you say that you are 70% confident that you tilted in a direction, you are saying that there are about 7 chances out of 10 that you tilted in that direction. If you answer 100%, that means that you are absolutely certain. If you answer 50%, that means you are just guessing. You can never say less than 50% because you will always tilt in one direction or the other. A key thing that we want you to learn is how to translate your internal feelings of certainty and uncertainty into probability judgments. When you do this task well, we call this being "well-calibrated." We want your confidence to be well-calibrated for this experiment. We would consider you well-calibrated if you were correct 50% of the time that you reported 50% confidence. Again, you would be well-calibrated if you were correct 60% of the time that you reported 60% confidence. And correct 100% of the time that you reported 100% confidence. Critically, confidence reports should not just be you reporting how large you thought the tilt was. You may be very confident in the direction of a small tilt. Or you may be not sure about the direction, even when you know the tilt was large. Just report how confident you are in the direction. Does that make sense?"*
22. *"Let's practice a few."*
23. Turn off operator microphone.
24. Repeat steps 5 to 10 for 10 trials.
25. Check that subjects' confidence ratings seemed consistent throughout.
26. If not, turn on microphone and briefly re-explain the confidence ratings and rerun the training.
27. Turn on microphone.
28. *"That's the end of this sequence. "Do you have any questions before we start testing?"* If not, then proceed.
29. *"We will disengage the motors now. We will re-engage the motors and home-tilt when we are ready to begin testing."*
30. Turn off operator microphone.
31. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
32. Click the hexagon "stop" button and engage operator "Emergency Stop."
33. Close out of the LabVIEW software.

SUBJECT TESTING

1. Turn on operator microphone.
2. *"Before we start, I want to emphasize four things. First, on average half the tilts are to the left and half are right. The direction is selected randomly by a computer. This means that previous trials directions have no impact on the next tilt direction. While very unlikely, you could even experience 10 or more tilts in a row in the same direction."*
3. *"Second, I want to emphasize that there is no expectation of a certain distribution of confidence assessments between 50 and 100%. The important thing is that for each trial you report the confidence that you experience for that specific trial. This means if you are guessing much of the time, that is OK, and if you are certain most of the time, that is okay too."*
4. *"Third, if you miss a trial because you are sleepy, daydreaming, fatigued, distracted, or for any other reason, it is very important that you tell me, instead of reporting. Just say "lapse". But if you were paying attention, please report with just your best guess. We expect you to not have any lapses. But it is totally fine if you do lapse, just please tell us. Does that make sense?"*
5. *"Lastly, if you can start to see light in the room during or after a tilt, please let us know. Similarly, if you are uncomfortable or sleepy and want to pause, please let us know. Otherwise, we will do sets of 100 tilts with time between each for you to respond... Sound good?"*
6. Turn off operator microphone.
7. Turn on operator microphone when ready to administer the tilt.
8. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
9. Turn off operator microphone.
10. Disengage operator "Tilt Emergency Stop."
11. Press "E-Stop" button (middle green button).
12. Press "Tilt S-Stop" button (left green button).
13. Perform the tilt-specific interlock steps.

14. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
15. Turn on operator microphone when ready to administer the tilt.
16. *"We will begin testing now."*
17. Turn off operator microphone
18. Enter 6 degrees in the "angle" user-input box.
19. Click "clear buffer."
20. Click "run profile" when you're ready to tilt.
21. Monitor the TTS in the video cameras it completes the profile.
22. Press vibration on the haptic feedback remote once it completes the profile.
23. Once the subject has reported, click soft-stop.
24. Enter the subject-reported direction to LabVIEW by clicking either "left" or "right" ("forward" or "backward") along with the confidence input in the user-input box.
25. Repeat steps 19 to 24 for the number of trials.
26. If the subject appears sleepy, pause when upright, turn on the microphone, and ask them how they are doing.
27. At the halfway point, turn on microphone and let the subject know that they are half-way through.
28. Turn on microphone.
29. *"That's the end of this session. Don't try to get out of the chair yourself, we will come and get you."*
30. Turn off operator microphone.
31. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
32. Click the hexagon "stop" button and engage operator "Tilt Emergency Stop."
33. Close out of the LabVIEW software.

ASSIST SUBJECT

1. Enter the TTS and help the subject get out of the seat (start with feet on ground)
2. Take haptic feedback device.

ACCESSING DATA

Accessing Data from Computer

1. Open Measurement and Automation Explorer **(MAX)** (Start → Programs → National Instruments → Measurement and Automation Explorer)
2. Open File Transfer Window (Remote Systems → Right Click on NASA Track → File Transfer)
3. Check "Anonymous Login" box on popup window and login.
4. Single click on desired file in the external directory (in 2019TEST folder)
5. Single click on desired file (E:\TTSData) in the local directory.
6. Single click "To Local."
7. Close out of all windows.
8. Transfer all spreadsheets to flash drive.

SHUT-DOWN PROCEDURES

1. Shut down computer (Start → Shut Down).
2. Turn off computer monitor.
3. Turn off operator microphone and speakers.
4. Replace blue VGA cord with the white VGA cord on the small display monitor.
5. Power off small display monitor.
6. Remove power plug from the recording box.
7. Close TTS pressure valve, open relief valve, and close main pressure valve if not being used by anyone else.
8. Power "OFF" TTS.
9. Plug in haptic feedback device to chargers.

TESTING DAY 2+

Make Final Adjustments and Prepare for Training/Testing

1. Have subject sit down on the TTS chair with their head on the black headrest.
2. Check that their eyes/ears are centered on the chair (left/right and up/down)
3. Adjust the chair height such that their ears are centered in the headpiece cut-outs.
4. Gently tighten the headrest earpieces (with crank) around the subject's head
5. Clasp seatbelt and seatbelt E-Stop. Show the subject the seatbelt E-Stop.
6. Explain to subject what left/right actually means (we want them to think about their head not their feet).
7. Turn on the microphone.
8. "*We want to make sure you can hear us. Can you hear us okay?"*
9. Adjust microphone volume as necessary.
10. "*During the experiment, on each trial you will tilt either right ear down/left ear down (forward/backward). After each tilt, you will verbally state which direction you think you were tilted. You will also report how confident you were, which we will explain more about later."*
11. In the microphone: "*We want to make sure you can feel the haptic feedback cue for when you should report your direction and confidence level."*
12. Click vibrate on the remote.
13. In the microphone: "Did you feel that okay?"
14. Adjust vibration time as necessary.
15. Check room for any hazards, tilt the TTS chair side to side manually to ensure that it is clear of everything in the room
16. Exit room
17. Secure door with handles.

SUBJECT TESTING

1. Turn on the microphone.
2. *"Just a few reminders: the direction of tilt is selected randomly by a computer; you must report confidence between 50 and 100%, by increments of 5%; there is no expectation of a certain distribution of confidence assessments; if you miss a trial because you are sleepy, daydreaming, fatigued, distracted, or for any other reason report the trial as "lapse;" and, if you can start to see light in the room during or after a tilt, please let us know. Similarly, if you are uncomfortable or sleepy and want to pause, please let us know. Otherwise, we will do sets of 100 tilts with time between each for you to respond. Sound good?"* If yes, then proceed.
3. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
4. Turn off operator microphone.
5. Disengage operator "Tilt Emergency Stop."
6. Press "E-Stop" button (middle green button).
7. Press "Tilt S-Stop" button (left green button).
8. Perform the tilt-specific interlock steps.
9. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
10. Monitor the TTS in the video cameras it completes the profile.
11. Turn on operator microphone.
12. *"Before we start testing, we will practice for a few trials."*
13. Turn off operator microphone.
14. Enter 4 degrees in the "angle" user-input box.
15. Click "clear buffer."
16. Click "run profile" when you're ready to tilt.
17. Monitor the TTS in the video cameras it completes the profile.
18. Press vibration on the haptic feedback remote.
19. Once the subject has reported, click soft-stop.
20. Repeat steps 5 to 10 with -4, 1, -1, 0.3, and -0.3 degrees.
21. Check that subjects' confidence ratings seemed consistent throughout.
22. If not, turn on microphone and briefly re-explain the confidence ratings and rerun the training.
23. Turn on microphone.
24. *"That's the end of this sequence. "Do you have any questions before we start testing?"* If not, then proceed. If subject answers yes, then perform steps from the "Training sub-section" of the "TESTING DAY1" section.
25. *"We will tell you when we are about to begin and the lights will turn off when the tilt is about to be administered."*
26. Turn off operator microphone
27. Turn on operator microphone when ready to administer the tilt.
28. *"We will begin testing now."*
29. Turn off operator microphone
30. Enter 6 degrees in the "angle" user-input box.
31. Click "clear buffer."
32. Click "run profile" when you're ready to tilt.
33. Monitor the TTS in the video cameras it completes the profile.
34. Press vibration on the haptic feedback remote once it completes the profile.
35. Once the subject has reported, click soft-stop.
36. Enter the subject-reported direction to LabVIEW by clicking either "left" or "right" ("forward" or "backward") along with the confidence input in the user-input box.
37. Repeat steps 31 to 36 for the number of trials.

38. If the subject appears sleepy, pause when upright, turn on the microphone, and ask them how they are doing.
39. At the halfway point, turn on microphone and let them know that they are half-way through.
40. Turn on microphone at the end of testing.
41. *"That's the end of this session. Don't try to get out of the chair yourself, we will come and get you."*
42. Turn off operator microphone.
43. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
44. Click the hexagon "stop" button and engage operator "Emergency Stop."
45. Close out of the LabVIEW software.

ASSIST SUBJECT

3. Enter the TTS and help the subject get out of the seat (start with feet on ground)
4. Take haptic feedback device.

ACCESSING DATA

Accessing Data from Computer

9. Open Measurement and Automation Explorer **(MAX)** (Start → Programs → National Instruments → Measurement and Automation Explorer)
10. Open File Transfer Window (Remote Systems → Right Click on NASA Track → File Transfer)
11. Check "Anonymous Login" box on popup window and login.
12. Single click on desired file in the external directory (in 2019TEST folder)
13. Single click on desired file (E:\TTSData) in the local directory.
14. Single click "To Local."
15. Close out of all windows.
16. Transfer all spreadsheets to flash drive.

SHUT-DOWN PROCEDURES

10. Shut down computer (Start → Shut Down).
11. Turn off computer monitor.
12. Turn off operator microphone and speakers.
13. Replace blue VGA cord with the white VGA cord on the small display monitor.
14. Power off small display monitor.
15. Remove power plug from the recording box.
16. Close TTS pressure valve, open relief valve, and close main pressure valve if not being used by anyone else.
17. Power "OFF" TTS.
18. Plug in haptic feedback device to chargers.

TTS Operator Checklist
Study: Thresholds

Operator 1
Operator 2
Both Operators

Prepare TTS

1. Power "ON" TTS with lever on gray power box.
2. Turn on small display monitor on desk.
3. Plug in white VGA cord, if not already plugged in, to the small display monitor.
4. Follow directions on small display monitor (Click F1 on small keyboard mounted above the Computer.)
5. Verify that the the small display motor reads "Welcome to LabVIEW Real-Time 8.0" and the TTS on-board computer is ready to use. If not, then reboot the TTS and make sure all wires are completely plugged in.
6. Replace white VGA cord with the blue VGA cord on the small display monitor.
7. Plug in power cord to the video recording box.
8. Verify that both camera views come on the small display monitor.
9. Open TTS pressure valve ("TTS") while ensuring that the relief valve ("TTS Relief Valve") is closed and main pressure valve ("V101") is open.
10. Power on Computer.
11. Turn on Computer monitor.
12. Log into Computer (pw: [redacted]
13. Open LabVIEW (Start → Programs → National Instruments → LabVIEW 8.0 → LabVIEW)
14. Open LabVIEW Program "NASA Linear Track… March 2008 20 m sec… Control Jan 10.lvproj")
15. Open LabVIEW VI "Thresholding_S2018" (RT PXI Target → Vis on PXI)
16. Open Block Diagram (Window → Show Block Diagram) and verify that:
    - number of trials is set to 100
    - frequency is set to either 0.2, 0.5, or 1 Hz
    - initial angle is set to 6 degrees
    - and maximum angle is set to the specified angle for the frequency

Frequency (Hz)	0.2	0.5	1
Maximum Angle	12	10	6

17. Click white "run" 
18. Click "save all" in the "Save changes?" command window that pops up.
19. Verify that the white "run" button is now black.
20. Verify that the blue bar in the middle of the software is loading nominally. If not, then click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11. You may get a window that states "Waiting to Disconnect from Engine" in which you should click "stop waiting and disconnect from the engine."
21. Enter subject number in the command windows that pops up. If the program stops responding, then click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11. . You may get a window that states "Waiting to Disconnect from Engine" in which you should click "stop waiting and disconnect from the engine."
22. Turn on the TTS light in LabVIEW, if not already on.

Prepare Audio Equipment

1. Verify that the "Tilt Emergency Stop" button is engaged.
2. Turn on grey speakers on the TTS operator desk.
3. Turn on microphone on the TTS operator desk.
4. Turn on white noise maker underneath the TTS operator desk.
5. Turn on subject's headphones in the TTS.
6. Verify that the subject's microphone, headphones, and operator microphone are on.

Pre-Session Warm Up Tilts

1. Secure seatbelt.
2. Secure seatbelt E-Stop.
3. Check for loose wires, bolts, tools, etc.
4. Tilt TTS side to side manually and make sure nothing is in the path of travel.
5. Exit TTS room and close door.
6. Secure door with handles.
7. Disengage operator "Tilt Emergency Stop."
8. Press "E-Stop" button (middle green button).
9. Press "Tilt S-Stop" button (left green button).
10. Perform the tilt-specific interlock steps.
11. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
12. Enter the maximum angle in the "angle" user-input box. If the user-input box is greyed out, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11.
13. Click "clear buffer."
14. Verify that the angle profile is displayed on the Chair Angle plot. If not, then click the up arrow next to the "angle" user-input box. Once the profile appears, then click the down arrow followed by the "clear buffer." If it still doesn't show up, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the

run button) exit out of the program, and re-start from Step 11.

15. Click "run profile" when you're ready to tilt.
16. Monitor the TTS in the video cameras it completes the profile.
17. Verify that the TTS reaches the maximum angle on the camera, the "Chair Angle" plot, and the "tilt" measurement in the tilt-specific interlock box.
18. Click soft-stop. Ensure that this is done before the blue bar at the middle of the screen loads till the end.
19. Verify that the TTS reaches 0 degrees on the camera, and the "tilt" measurement in the tilt-specific interlock box.
20. Repeat Steps 12-19 for the maximum angle to the other side to verify that the TTS is operating properly.
21. Engage the "E-stop" button once completed.

Prepare Haptic Feedback Equipment

1. Remove the wrist cuff and remote from the charging ports, under the TTS desk.
2. Press the orange button on the wrist cuff.
3. Verify that the wrist cuff and remote are connected by clicking "vibrate" on the remote and verifying that a vibration is felt in the wrist cuff. If not, then press the orange button again and re-start from Step 2.

TESTING DAY 1

Inform & Prepare Subject For Training/Testing

1. Greet subject and show them around the lab
2. Ask subject if they need to use the restroom
3. Verify cell phone, keys, etc. are out of pockets
4. Verify subject is wearing clothing that fully covers skins (pants, long sleeves, socks, shoes)
5. Start by talking about how they will be secured onto the TTS chair.
6. Tell the subject that they can get off at any time, they should just let the operators know
7. Explain to the subjects that their head will be fixed in place with the headrest.
8. Explain the communication system to the subject
9. Explain the *two* cameras that will be monitoring the experiment
10. Explain the emergency stops but that they should inform the operators if they would like to stop
11. Explain what will happen when we are ready to test → we leave, home tilt, testing will begin such that light turns off when angle administration begins, cue to tell them to report, brought back to home, lights turn on.
12. Explain the haptic feedback system.

Make Final Adjustments and Prepare for Training/Testing

1. Have subject sit down on the TTS chair with their head on the black headrest.
2. Check that their eyes/ears are centered on the chair (left/right and up/down)
3. Adjust the chair height such that their ears are centered in the headpiece cut-outs.
4. Gently tighten the headrest earpieces (with crank) around the subject's head
5. Clasp seatbelt and seatbelt E-Stop. Show the subject the seatbelt E-Stop.
6. Ask the subject to done the headphones.
7. Explain to subject what left/right actually means (we want them to think about their head not their feet).
8. Turn on operator microphone.
9. "*We want to make sure you can hear us. Can you hear us okay?"*
10. Adjust microphone volume as necessary.
11. "*During the experiment, on each trial you will tilt either right ear down/left ear down (forward/backward). After each tilt, you will verbally state which direction you think you were tilted. You will also report how confident you were, which we will explain more about later. Try to keep all comments and questions for when you are upright and lights are on."*
12. "*We want to make sure you can feel the haptic feedback cue for when you should report your direction and confidence level."*
13. Click vibrate on the remote.
14. In the microphone: "Did you feel that okay?"
15. Adjust vibration time as necessary.
16. Check room for any hazards, tilt the TTS chair side to side manually to ensure that it is clear of everything in the room.
17. Exit room.
18. Secure door with handles.
19. Open and run Matlab script "TTSMatlabScript.m."
20. Fill out the "Set-Up" dialog box in the Matlab script using the Subject's Identity Code as the File Name.

Training

1. Turn on operator microphone.
2. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
3. Turn off operator microphone.
4. Disengage operator "Tilt Emergency Stop."
5. Press "E-Stop" button (middle green button).
6. Press "Tilt S-Stop" button (left green button).
7. Perform the tilt-specific interlock steps.
8. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
9. "*First, we will start with some practice. The lights will turn off and there will be a tilt, either left/right (forward/backward). I will cue you to report with the haptic buzz. Give us the response that immediately comes to mind rather than waiting. You can report direction as "left" or "right" and confidence between 50% and 100% where 50% means you are just guessing and 100% means you are certain. Please report in 5% increments. For example, 65% instead of 67.1%." Once you report, you will be brought back upright and the lights will turn on. We want you to focus on the direction your head tilts, either right ear down or left ear down. Sometimes thinking about your feet can make it confusing. Does that make sense? And even if you are not sure of the direction, you must choose. Just make your best guess."*
10. *"The sequence will begin as soon as you the lights turn off. Are you ready to practice a few?"* If yes, then proceed.
11. Enter 6 degrees in the "angle" user-input box. If the user-input box is greyed out, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11.
12. Click "clear buffer."

13. Verify that the angle profile is displayed on the Chair Angle plot. If not, then click the up arrow next to the "angle" user-input box. Once the profile appears, then click the down arrow followed by the "clear buffer." If it still doesn't show up, then perform the tilt-specific interlock steps in reverse order, click the hexagon "stop" button (next to the run button) exit out of the program, and re-start from Step 11.
14. Click "run profile" when you're ready to tilt.
15. Monitor the TTS in the video cameras it completes the profile.
16. Press vibration on the haptic feedback remote.
17. Once the subject has reported, click soft-stop.
18. Enter the subject-reported direction to LabVIEW by clicking either "left" or "right" in the user-input box.
19. Repeat steps 5 to 10 for 10 trials.
20. Turn on operator microphone.
21. *"That was good. Before we continue let's talk a little more about confidence assessment and what you need to do to be "well calibrated." Probabilities are numbers that express uncertainty. If you say that you are 70% confident that you tilted in a direction, you are saying that there are about 7 chances out of 10 that you tilted in that direction. If you answer 100%, that means that you are absolutely certain. If you answer 50%, that means you are just guessing. You can never say less than 50% because you will always tilt in one direction or the other. A key thing that we want you to learn is how to translate your internal feelings of certainty and uncertainty into probability judgments. When you do this task well, we call this being "well-calibrated." We want your confidence to be well-calibrated for this experiment. We would consider you well-calibrated if you were correct 50% of the time that you reported 50% confidence. Again, you would be well-calibrated if you were correct 60% of the time that you reported 60% confidence. And correct 100% of the time that you reported 100% confidence. Critically, confidence reports should not just be you reporting how large you thought the tilt was. You may be very confident in the direction of a small tilt. Or you may be not sure about the direction, even when you know the tilt was large. Just report how confident you are in the direction. Does that make sense?"*
22. *"Let's practice a few."*
23. Turn off operator microphone.
24. Repeat steps 5 to 10 for 10 trials.
25. Check that subjects' confidence ratings seemed consistent throughout.
26. If not, turn on microphone and briefly re-explain the confidence ratings and rerun the training.
27. Turn on microphone.
28. *"That's the end of this sequence. "Do you have any questions before we start testing?"* If not, then proceed.
29. *"We will disengage the motors now. We will re-engage the motors and home-tilt when we are ready to begin testing."*
30. Turn off operator microphone.
31. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
32. Click the hexagon "stop" button and engage operator "Emergency Stop."
33. Close out of the LabVIEW software.

Subject Testing

1. Turn on operator microphone.
2. *"Before we start, I want to emphasize four things. First, on average half the tilts are to the left and half are right. The direction is selected randomly by a computer. This means that previous trials directions have no impact on the next tilt direction. While very unlikely, you could even experience 10 or more tilts in a row in the same direction."*
3. *"Second, I want to emphasize that there is no expectation of a certain distribution of confidence assessments between 50 and 100%. The important thing is that for each trial you report the confidence that you experience for that specific trial. This means if you are guessing much of the time, that is OK, and if you are certain most of the time, that is okay too."*
4. *"Third, if you miss a trial because you are sleepy, daydreaming, fatigued, distracted, or for any other reason, it is very important that you tell me, instead of reporting. Just say "lapse". But if you were paying attention, please report with just your best guess. We expect you to not have any lapses. But it is totally fine if you do lapse, just please tell us. Does that make sense?"*
5. *"Lastly, if you can start to see light in the room during or after a tilt, please let us know. Similarly, if you are uncomfortable or sleepy and want to pause, please let us know. Otherwise, we will do sets of 100 tilts with time between each for you to respond... Sound good?"*
6. Turn off operator microphone.
7. Turn on operator microphone when ready to administer the tilt.
8. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
9. Turn off operator microphone.
10. Disengage operator "Tilt Emergency Stop."
11. Press "E-Stop" button (middle green button).
12. Press "Tilt S-Stop" button (left green button).

13. Perform the tilt-specific interlock steps.
14. Click “home-tilt” to allow TTS to calibrate and set home to “0.0 degrees”
15. Turn on operator microphone when ready to administer the tilt.
16. *“We will begin testing now.”*
17. Turn off operator microphone
18. Enter 6 degrees in the “angle” user-input box.
19. Click “clear buffer.”
20. Click “run profile” when you’re ready to tilt.
21. Monitor the TTS in the video cameras it completes the profile.
22. Press vibration on the haptic feedback remote once it completes the profile.
23. Once the subject has reported, click soft-stop.
24. Enter the subject-reported direction to LabVIEW by clicking either “left” or “right” in the user-input box.
25. Report the motion direction, subject-reported direction, and confidence level into the “TTSMatlabScript.m” Matlab script.
26. Repeat steps 10 to 16 for the number of trials.
27. If the subject appears sleepy, pause when upright, turn on the microphone, and ask them how they are doing.
28. At the halfway point, turn on microphone and let the subject know that they are half-way through.
29. Turn on microphone.
30. *“That’s the end of this session. Don’t try to get out of the chair yourself, we will come and get you.”*
31. Turn off operator microphone.
32. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
33. Click the hexagon “stop” button and engage operator “Tilt Emergency Stop.”
34. Close out of the LabVIEW software.

Assist Subject

1. Enter the TTS and help the subject get out of the seat (start with feet on ground).
2. Take haptic feedback device and headphones.

Shut-down Procedures

1. Verify that the Matlab data saved properly in the Microsoft Excel sheet labeled with the subjects’ identity code.
2. Analyze data for the specific identity code via DataAnalysis_wConf_wJK.m file and verify that the threshold estimate is reasonable.
3. Save all spreadsheets to flash drive.
4. Close out of “TTSMatlabScript.m” Matlab script.
5. Shut down computer (Start → Shut Down).
6. Turn off computer monitor.
7. Turn off operator microphone, if not already turned off, and speakers.
8. Replace blue VGA cord with the white VGA cord on the small display monitor.
9. Power off small display monitor.
10. Remove power plug from the recording box.
11. Close TTS pressure valve, open relief valve, and close main pressure valve if not being used by anyone else.
12. Power “OFF” TTS.
13. Plug in haptic feedback device to chargers.

TESTING DAY 2+

Make Final Adjustments and Prepare for Training/Testing

1. Have subject sit down on the TTS chair with their head on the black headrest.
2. Check that their eyes/ears are centered on the chair (left/right and up/down)
3. Adjust the chair height such that their ears are centered in the headpiece cut-outs.
4. Gently tighten the headrest earpieces (with crank) around the subject's head
5. Clasp seatbelt and seatbelt E-Stop. Show the subject the seatbelt E-Stop.
6. Explain to subject what left/right actually means (we want them to think about their head not their feet).
7. Turn on the microphone.
8. *"We want to make sure you can hear us. Can you hear us okay?"*
9. Adjust microphone volume as necessary.
10. "*During the experiment, on each trial you will tilt either right ear down/left ear down (forward/backward). After each tilt, you will verbally state which direction you think you were tilted. You will also report how confident you were, which we will explain more about later."*
11. In the microphone: "*We want to make sure you can feel the haptic feedback cue for when you should report your direction and confidence level."*
12. Click vibrate on the remote.
13. In the microphone: "Did you feel that okay?"
14. Adjust vibration time as necessary.
15. Check room for any hazards, tilt the TTS chair side to side manually to ensure that it is clear of everything in the room
16. Exit room
17. Secure door with handles.
18. Open and run Matlab script "TTSMatlabScript.m."
19. Fill out the "Set-Up" dialog box in the Matlab script.

Subject Testing

1. Turn on the microphone.
2. *"Just a few reminders: the direction of tilt is selected randomly by a computer; you must report confidence between 50 and 100%, by increments of 5%; there is no expectation of a certain distribution of confidence assessments; if you miss a trial because you are sleepy, daydreaming, fatigued, distracted, or for any other reason report the trial as "lapse;" and, if you can start to see light in the room during or after a tilt, please let us know. Similarly, if you are uncomfortable or sleepy and want to pause, please let us know. Otherwise, we will do sets of 100 tilts with time between each for you to respond. Sound good?"* If yes, then proceed.
3. *"We will begin by engaging the motors and performing a home tilt which zeros the chair. Sound good?"* If yes, then continue.
4. Turn off operator microphone.
5. Disengage operator "Tilt Emergency Stop."
6. Press "E-Stop" button (middle green button).
7. Press "Tilt S-Stop" button (left green button).
8. Perform the tilt-specific interlock steps.
9. Click "home-tilt" to allow TTS to calibrate and set home to "0.0 degrees"
10. Monitor the TTS in the video cameras it completes the profile.
11. Turn on operator microphone.
12. *"Before we start testing, we will practice for a few trials."*
13. Turn off operator microphone.
14. Enter 4 degrees in the "angle" user-input box.
15. Click "clear buffer."
16. Click "run profile" when you're ready to tilt.
17. Monitor the TTS in the video cameras it completes the profile.
18. Press vibration on the haptic feedback remote.
19. Once the subject has reported, click soft-stop.
20. Repeat steps 5 to 10 with -4, 1, -1, 0.3, and -0.3 degrees.
21. Check that subjects' confidence ratings seemed consistent throughout.
22. If not, turn on microphone and briefly re-explain the confidence ratings and rerun the training.
23. Turn on microphone.
24. *"That's the end of this sequence. "Do you have any questions before we start testing?"* If not, then proceed. If subject answers yes, then perform steps from the "Training sub-section" of the "TESTING DAY1" section.
25. *"We will tell you when we are about to begin and the lights will turn off when the tilt is about to be administered."*
26. Turn off operator microphone
27. Turn on operator microphone when ready to administer the tilt.
28. *"We will begin testing now."*
29. Turn off operator microphone
30. Enter 6 degrees in the "angle" user-input box.
31. Click "clear buffer."
32. Click "run profile" when you're ready to tilt.
33. Monitor the TTS in the video cameras it completes the profile.
34. Press vibration on the haptic feedback remote once it completes the profile.
35. Once the subject has reported, click soft-stop.
36. Enter the subject-reported direction to LabVIEW by clicking either "left" or "right" in the user-input box.

37. Report the motion direction, subject-reported direction, and confidence level into the "TTSMatlabScript.m" Matlab script under the subject's specific identity code.
38. Repeat steps 22 to 28 for the number of trials.
39. If the subject appears sleepy, pause when upright, turn on the microphone, and ask them how they are doing.
40. At the halfway point, turn on microphone and let them know that they are half-way through.
41. Turn on microphone at the end of testing.
42. *"That's the end of this session. Don't try to get out of the chair yourself, we will come and get you."*
43. Turn off operator microphone.
44. Perform the tilt-specific interlock steps in reverse order (enable → OK2en → engage).
45. Click the hexagon "stop" button and engage operator "Emergency Stop."
46. Close out of the LabVIEW software.

Assist Subject

1. Enter the TTS and help the subject get out of the seat (start with feet on ground)
2. Take haptic feedback device.

Shut-down Procedures

1. Verify that the Matlab data saved properly in the Microsoft Excel sheet labeled with the subjects' identity code.
2. Analyze data for the specific identity code via DataAnalysis_wConf_wJK.m file and verify that the threshold estimate is reasonable.
3. Save all spreadsheets to flash drive.
4. Close out of "TTSMatlabScript.m" Matlab script.
5. Shut down computer (Start → Shut Down).
6. Turn off computer monitor.
7. Turn off operator microphone and speakers.
8. Replace blue VGA cord with the white VGA cord on the small display monitor.
9. Power off small display monitor.
10. Remove power plug from the recording box.
11. Close TTS pressure valve, open relief valve, and close main pressure valve if not being used by anyone else.
12. Power "OFF" TTS.
13. Plug in haptic feedback device to chargers.

RAW DATA

Table 4 Post-analysis raw data for subjects 1 and 2.

RPTS01

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	201	200	201	200	200	200	200	200
Threshold Estimate (deg)	3.0378	2.9955	2.4657	0.55492	2.6564	2.6142	1.2638	0.56921
Confidence Threshold Estimate (deg)	2.6332	3.3567	2.2934	0.55492	2.1233	1.7826	0.99693	0.56921
K	2.6181	4.0971	3.5678	1	2.3165	2.9456	3.8792	1
SEM of Threshold Estimate (deg)	0.31607	0.34345	0.39554	0.068357	0.298	0.31855	0.15486	0.063839
SEM of Confidence Threshold Estimate (deg)	0.22426	0.3096	4.9242	0.15399	0.20627	0.16699	0.080332	0.11086
SEM of K	0.13734	0.27598	2.3717	4.9644	0.12854	0.1708	0.24496	4.6999
Binary Fit Mu	0.3273	0.1191	-0.1657	0.1565	-0.2443	-0.4024	-0.1606	0.0808
Binary Fit Sigma	3.0019	2.95661	2.421	0.5453	2.6228	2.5763	1.2429	0.5612
Binary Fit BIC	186.5077	198.7046	216.2273	186.3882	199.7117	204.8819	190.3623	183.7258
Standard Max Likelihood Mu	0.3273	0.1191	-0.1657	0.1565	-0.2443	-0.4024	-0.1606	0.0808
Standard Max Likelihood Sigma	3.0019	2.9561	2.421	0.5453	2.6228	2.5763	1.2429	0.5612
Standard Max Likelihood BIC	186.4977	198.6946	216.2173	186.3782	199.7017	204.8719	190.3522	183.7158
Asymmetric Max Likelihood Mu	1.6319	-0.5223	0.5207	0.1934	-1.6581	0.0234	0.1356	0.258
Asymmetric Max Likelihood Sigma 1	4.3093	2.1767	3.4537	0.586	0.8672	3.2296	1.6393	0.7468
Asymmetric Max Likelihood Sigma 2	1.4473	3.8112	1.2815	0.4799	4.2204	2.0951	0.9317	0.3449
Asymmetric Max Likelihood BIC	189.2234	202.9981	218.9036	191.5818	202.1558	209.8054	195.5728	188.5598

RPTS02

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	199	200	200	200	200	200
Threshold Estimate (deg)	1.6243	1.9921	1.3096	0.64876	1.6025	1.4406	0.92959	0.24814
Confidence Threshold Estimate (deg)	1.2617	1.5212	1.1157	0.56266	1.2824	1.2176	0.6697	0.56013
K	2.2624	1.3772	1.7148	2.2975	1.7544	2.75	3.0085	1.9497
SEM of Threshold Estimate (deg)	0.22125	0.23744	0.18055	0.072934	0.17094	0.17126	0.099779	0.070019
SEM of Confidence Threshold Estimate (deg)	0.086125	0.14036	0.079258	0.037315	0.080093	0.086744	0.049144	0.032657
SEM of K	0.1546	0.10453	0.13184	0.18681	0.11627	0.2083	0.17001	0.16585
Binary Fit Mu	-0.2675	-0.3796	-0.8031	-0.1645	-0.2522	-0.8447	-0.2884	0.0394
Binary Fit Sigma	1.5954	1.9551	1.283	0.6385	1.5788	1.4117	0.9137	0.6114
Binary Fit BIC	194.6926	178.6745	170.0774	182.1792	182.977	183.0383	181.3551	192.4972
Standard Max Likelihood Mu	-0.2675	-0.3796	-0.8031	-0.1645	-0.2522	-0.8447	-0.2884	0.0394
Standard Max Likelihood Sigma	1.5954	1.9551	1.283	0.6385	1.5788	1.4117	0.9137	0.6114
Standard Max Likelihood BIC	1.9468	178.6645	170.0673	182.1692	182.967	183.0282	181.3451	192.4872
Asymmetric Max Likelihood Mu	-0.2541	-0.2652	-1.0064	-0.4134	0.5636	-0.9026	0.4598	-0.2652
Asymmetric Max Likelihood Sigma 1	1.6190	2.1245	0.6687	0.2933	2.64	1.2994	2.2063	0.2743
Asymmetric Max Likelihood Sigma 2	1.5782	1.8159	1.4609	0.8875	0.7937	1.4684	0.2221	1.0305
Asymmetric Max Likelihood BIC	199.9733	183.8217	174.5671	185.682	185.5728	188.2725	173.9654	195.3509

Table 5 Post-analysis raw data for subjects 3 and 4.

RPTS03

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	202	200	200	200	200	200	200	200
Threshold Estimate (deg)	1.372	1.5546	0.77417	0.3898	0.87721	0.83983	0.74171	0.40386
Confidence Threshold Estimate (deg)	1.2562	1.7186	0.79469	0.43385	0.67063	0.63186	1.0707	0.381
K	2.2417	1.4615	2.2978	2.6304	2.9025	3.0251	0.92651	2.6913
SEM of Threshold Estimate (deg)	0.15842	0.19469	0.095642	0.04146	0.098611	0.097153	0.088939	0.042388
SEM of Confidence Threshold Estimate (deg)	0.1198	0.21081	0.080961	0.028258	0.049452	0.05707	0.12026	0.030663
SEM of K	0.15512	0.15103	0.18226	0.2666	0.15173	0.15833	0.085252	0.13629
Binary Fit Mu	0.1398	-0.0595	0.0235	0.1086	-0.2201	-0.1055	-0.1324	0.0581
Binary Fit Sigma	1.3477	1.531	0.7641	0.3835	0.8625	0.8280	0.7297	0.3972
Binary Fit BIC	184.5693	187.4623	199.2668	173.9993	184.3279	188.9814	191.0018	168.3557
Standard Max Likelihood Mu	0.1398	-0.0595	0.0235	0.1086	-0.2201	-0.1055	-0.1324	0.0581
Standard Max Likelihood Sigma	1.3477	1.531	0.7641	0.3835	0.8625	0.8280	0.7297	0.3972
Standard Max Likelihood BIC	184.5593	187.4523	199.2568	173.9892	184.3179	188.9714	190.9918	168.3457
Asymmetric Max Likelihood Mu	0.7009	-0.6992	-0.1631	0.2564	0.3491	-0.4789	0.2260	0.1921
Asymmetric Max Likelihood Sigma 1	2.0113	0.6893	0.545	0.5248	1.7676	0.3401	1.3105	0.5296
Asymmetric Max Likelihood Sigma 2	0.5014	2.259	1.0104	0.177	0.3447	1.2378	0.3500	0.2344
Asymmetric Max Likelihood BIC	183.5098	189.664	204.2443	176.842	186.2455	192.5022	192.2932	172.3322

RPTS04

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	200	200	200	200	200
Threshold Estimate (deg)	1.6325	1.3475	0.85799	0.5737	1.5082	1.5855	1.182	0.6438
Confidence Threshold Estimate (deg)	1.6576	1.5569	0.99235	0.6187	1.4397	1.5178	1.1924	0.76047
K	1.5581	1.5852	2.804	2.4013	1.8499	1.6099	1.4922	1.8612
SEM of Threshold Estimate (deg)	0.17927	0.15439	0.096731	0.066795	0.17471	0.16805	0.14655	0.075151
SEM of Confidence Threshold Estimate (deg)	0.16468	0.17251	0.080174	0.052553	0.11464	0.11373	0.10437	0.074297
SEM of K	0.090457	0.1141	0.15023	0.13798	0.11393	0.089393	0.08743	0.12269
Binary Fit Mu	0.0778	0.1135	-0.1945	-0.0909	-0.3127	0.5191	0.0595	0.1293
Binary Fit Sigma	1.6066	1.3247	0.8433	0.5654	1.4846	1.5576	1.1609	0.6321
Binary Fit BIC	180.2498	190.0089	178.5269	186.2467	193.91	173.4942	195.7270	169.982
Standard Max Likelihood Mu	0.0778	0.1135	-0.1945	-0.0909	-0.3127	0.5191	0.0595	0.1293
Standard Max Likelihood Sigma	1.6066	1.3247	0.8433	0.5654	1.4846	1.5576	1.1609	0.6321
Standard Max Likelihood BIC	180.2398	189.9989	178.5168	186.2367	193.9	173.4842	195.7170	169.972
Asymmetric Max Likelihood Mu	0.6257	0.416	-0.5303	-0.1011	0.0736	1.4025	0.3880	0.3659
Asymmetric Max Likelihood Sigma 1	2.2288	1.6657	0.4128	0.5506	2.0545	2.3989	1.5717	0.9021
Asymmetric Max Likelihood Sigma 2	0.9224	0.9376	1.1804	0.5763	1.1014	0.3983	0.7030	0.3334
Asymmetric Max Likelihood BIC	183.1704	195.0579	182.3123	191.5354	198.6826	174.6986	200.4495	173.1926

Table 6 Post-analysis raw data for subjects 5 and 6.

RPTS05

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	199	200	200	200	200
Threshold Estimate (deg)	2.1187	1.4989	1.1052	0.58589	1.0496	1.0351	1.108	0.43902
Confidence Threshold Estimate (deg)	2.0925	1.2704	1.7775	0.57228	0.95593	0.91695	1.0781	0.45039
K	0.45671	0.28784	0.9246	0.98508	0.69409	0.72878	0.53914	0.52905
SEM of Threshold Estimate (deg)	0.27607	0.23584	0.1311	0.073563	0.12864	0.13083	0.27154	0.055914
SEM of Confidence Threshold Estimate (deg)	0.19786	0.15884	0.20704	0.088902	0.098439	0.087469	0.24082	0.045835
SEM of K	0.041699	0.034327	0.034657	0.057753	0.058127	0.05967	0.063036	0.045238
Binary Fit Mu	-0.7136	-0.3455	0.2323	-0.1334	-0.0612	-0.2835	0.1421	0.0735
Binary Fit Sigma	2.0752	1.4697	1.0875	0.5769	1.0324	1.0105	1.0900	0.4319
Binary Fit BIC	194.9228	194.0445	178.885	188.8124	191.0129	190.9909	215.9433	180.7669
Standard Max Likelihood Mu	-0.7136	-0.3455	0.2323	-0.1334	-0.0612	-0.2835	0.1421	0.0735
Standard Max Likelihood Sigma	2.0752	1.4697	1.0875	0.5769	1.0324	1.0105	1.0900	0.4319
Standard Max Likelihood BIC	194.9128	194.0344	178.875	188.8024	191.0029	190.9809	215.9333	180.7569
Asymmetric Max Likelihood Mu	0.0559	-0.322	0.6415	-0.2254	-0.0825	0.1621	-0.0216	0.3226
Asymmetric Max Likelihood Sigma 1	3.6945	1.5113	1.4939	0.4239	1.0017	1.8053	0.7783	0.7005
Asymmetric Max Likelihood Sigma 2	1.0654	1.4406	0.4939	0.6735	1.0603	0.5053	1.4426	0.0822
Asymmetric Max Likelihood BIC	193.4721	199.3183	181.5165	193.6968	196.2844	193.9227	219.5122	183.5388

RPTS06

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	200	200	200	201	200
Threshold Estimate (deg)	1.599	1.4732	0.82439	0.47793	1.8368	1.5245	1.2543	0.46737
Confidence Threshold Estimate (deg)	1.254	1.0586	0.69204	0.45939	1.6758	1.178	1.0941	0.42808
K	0.84286	0.5907	0.57748	0.48427	0.76414	0.77602	0.82982	0.66982
SEM of Threshold Estimate (deg)	0.18235	0.15693	0.094516	0.057634	0.20528	0.18729	0.13929	0.056238
SEM of Confidence Threshold Estimate (deg)	0.092771	0.071979	0.049094	0.042303	0.15531	0.11094	0.071041	0.039723
SEM of K	0.060259	0.0412	0.040374	0.044746	0.060476	0.066126	0.054194	0.062628
Binary Fit Mu	-0.6553	-0.2005	-0.1402	-0.071	-0.0073	0.1647	-0.0483	-0.0172
Binary Fit Sigma	1.564	1.4489	0.8121	0.47	1.81	1.5009	1.2316	0.459
Binary Fit BIC	161.1069	178.9066	177.0337	186.7772	194.9441	202.2703	178.3551	174.072
Standard Max Likelihood Mu	-0.6553	-0.2005	-0.1402	-0.071	-0.0073	0.1647	-0.0483	-0.0172
Standard Max Likelihood Sigma	1.564	1.4489	0.8121	0.47	1.81	1.5009	1.2316	0.459
Standard Max Likelihood BIC	161.0969	178.8966	177.0236	186.7672	194.9341	202.2602	178.3451	174.062
Asymmetric Max Likelihood Mu	-0.1385	0.9084	-0.4548	-0.1428	-1.385	0.6604	0.246	0.0475
Asymmetric Max Likelihood Sigma 1	2.3233	2.8915	0.366	0.3674	0.1902	2.1194	1.5993	0.5383
Asymmetric Max Likelihood Sigma 2	1.0571	0.3526	1.1345	0.5521	3.5286	0.8162	0.8949	0.3882
Asymmetric Max Likelihood BIC	164.1666	179.7683	178.9461	191.6979	189.5055	206.218	182.7254	179.2249

Table 7 Post-analysis raw data for subjects 7 and 8.

RPTS07

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	200	200	200	203	199
Threshold Estimate (deg)	0.8755	1.0135	0.56167	0.36347	1.2586	0.95627	0.86854	0.49551
Confidence Threshold Estimate (deg)	0.7682	0.76649	0.54789	0.36363	1.0562	0.72851	0.94803	0.41457
K	2.39E+00	2.2767	1.7301	1.9258	2.244	2.4421	2.7945	2.2506
SEM of Threshold Estimate (deg)	0.10658	0.12215	0.061083	0.040625	0.15041	0.13503	0.099336	0.062356
SEM of Confidence Threshold Estimate (deg)	0.060064	0.051938	0.032398	0.026147	0.054753	0.053833	0.065816	0.032955
SEM of K	0.15156	0.13812	0.10148	0.13563	0.13774	0.14634	0.161	0.18903
Binary Fit Mu	-0.1998	-0.1489	-0.0434	0.0475	0.0847	-0.1279	0.0392	-0.0471
Binary Fit Sigma	0.8590	0.9958	0.5532	0.3558	1.24	0.9425	0.8565	0.4866
Binary Fit BIC	198.4112	192.8892	173.8322	176.5007	198.0892	203.9229	192.4336	195.2975
Standard Max Likelihood Mu	-0.1998	-0.1489	-0.0434	0.0475	0.0847	-0.1279	0.0392	-0.0471
Standard Max Likelihood Sigma	0.8590	0.9958	0.5532	0.3558	1.24	0.9425	0.8565	0.4866
Standard Max Likelihood BIC	198.4012	192.8791	173.8222	176.4907	198.0791	203.9129	192.4237	195.2875
Asymmetric Max Likelihood Mu	0.5691	0.2312	0.2044	-0.0743	-0.4718	-0.1384	-0.2652	-0.2651
Asymmetric Max Likelihood Sigma 1	2.2184	1.5685	0.8563	0.2304	0.6016	0.9241	0.5119	0.1958
Asymmetric Max Likelihood Sigma 2	0.0200	0.5576	0.3015	0.5267	1.9801	0.955	1.2432	0.7946
Asymmetric Max Likelihood BIC	196.3357	195.8206	176.4936	181.1888	202.6378	209.204	196.4509	196.7392

RPTS08

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	200	200	200	200	200
Threshold Estimate (deg)	2.6113	2.0925	0.92073	0.63018	1.9572	2.0164	0.75883	0.52741
Confidence Threshold Estimate (deg)	2.2775	2.1598	1.087	0.62752	1.669	1.7369	1.0899	0.60184
K	1.159	1.2535	1.0579	1.7178	1.5204	1.7127	0.64633	1.8539
SEM of Threshold Estimate (deg)	0.30556	0.21857	0.11456	0.072262	0.25395	0.23602	0.082574	0.057745
SEM of Confidence Threshold Estimate (deg)	0.20563	0.19263	0.1032	0.061377	0.14197	0.14604	0.12459	0.053922
SEM of K	0.078659	0.072003	0.0747	0.1017	0.089838	0.10465	0.054276	0.12785
Binary Fit Mu	-0.5331	-0.5373	-0.5923	-0.156	0.134787064	-0.3635	0.0102	0.0196
Binary Fit Sigma	2.5659	2.0582	0.9008	0.6201	1.925479142	1.9832	0.7459	0.5197
Binary Fit BIC	174.7439	178.2116	158.8425	180.6556	2.14E+02	197.1678	177.6830	182.5815
Standard Max Likelihood Mu	-0.5331	-0.5373	-0.5923	-0.156	0.134787002	-0.3635	0.0102	0.0196
Standard Max Likelihood Sigma	2.5659	2.0582	0.9008	0.6201	1.925479192	1.9832	0.7459	0.5197
Standard Max Likelihood BIC	174.7339	178.2016	158.8325	180.6455	2.14E+02	197.1578	177.6730	182.5715
Asymmetric Max Likelihood Mu	-0.9442	-1.1113	-0.7352	-0.441	-0.063883988	-1.0068	0.3153	0.2088
Asymmetric Max Likelihood Sigma 1	1.9974	1.2683	0.4963	0.2024	1.660652077	1.0138	1.1333	0.7496
Asymmetric Max Likelihood Sigma 2	3.0012	2.5899	1.0328	0.9098	2.262796816	2.7534	0.3960	0.2964
Asymmetric Max Likelihood BIC	179.5642	182.3213	161.7491	181.4244	2.19E+02	199.7561	179.7211	185.2819

Table 8 Post-analysis raw data for subjects 9 and 10.

RPTS09

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	201	200	200	200	200	199	200
Threshold Estimate (deg)	1.7622	1.564	1.0259	0.54736	1.2715	1.9085	0.87276	0.59345
Confidence Threshold Estimate (deg)	1.6675	1.3265	0.84822	0.59243	1.3584	1.9326	0.75744	0.52163
K	1.0913	1.7146	0.97431	2.2486	1.4136	2.114	4.0714	2.8961
SEM of Threshold Estimate (deg)	0.2226	0.22741	0.12914	0.06109	0.15307	0.21098	0.10427	0.074291
SEM of Confidence Threshold Estimate (deg)	0.11448	0.10749	0.059824	0.053338	0.084079	0.15773	0.047782	0.031444
SEM of K	0.080523	0.12743	0.059153	0.17739	0.10877	0.16135	0.39591	0.22107
Binary Fit Mu	-0.4135	-0.2044	0.1055	0.0203	-0.0204	-0.1644	0.1761	0.2707
Binary Fit Sigma	1.7279	1.5357	1.0105	0.5393	1.2516	1.8803	0.8585	0.5827
Binary Fit BIC	164.7945	194.8363	199.5256	181.4969	191.7821	189.8127	180.9623	179.1477
Standard Max Likelihood Mu	-0.4135	-0.2044	0.1055	0.0203	-0.0204	-0.1644	0.1761	0.2707
Standard Max Likelihood Sigma	1.7279	1.5357	1.0105	0.5393	1.2516	1.8803	0.8585	0.5827
Standard Max Likelihood BIC	164.7845	194.8263	199.5156	181.4869	191.7721	189.8027	180.9522	179.1376
Asymmetric Max Likelihood Mu	-0.7747	-0.1633	0.4051	-0.1875	0.1378	0.3859	0.4012	0.3578
Asymmetric Max Likelihood Sigma 1	1.1847	1.6071	1.3632	0.3236	1.4585	2.5737	1.1079	0.6624
Asymmetric Max Likelihood Sigma 2	2.1286	1.4826	0.5528	0.7786	1.0648	1.3212	0.5230	0.3899
Asymmetric Max Likelihood BIC	167.9688	200.0963	203.3281	186.3948	196.8393	194.6306	184.2116	183.9036

RPTS10

	PITCH				ROLL			
Direction	1	1	1	1	0	0	0	0
f (Hz)	0.15	0.2	0.5	1	0.15	0.2	0.5	1
N (trials)	200	200	200	200	202	200	200	200
Threshold Estimate (deg)	1.0424	1.2931	0.8337	0.46024	1.7153	1.4722	0.78026	0.41833
Confidence Threshold Estimate (deg)	0.85235	1.0311	0.69498	0.39677	1.5965	1.4458	0.80614	0.4502
K	1.1559	0.86345	0.41422	0.63952	0.93038	1.2671	1.3378	0.9492
SEM of Threshold Estimate (deg)	0.14729	0.15446	0.094258	0.051474	0.20515	0.16792	0.086445	0.048801
SEM of Confidence Threshold Estimate (deg)	0.073987	0.069234	0.05724	0.027175	0.1242	0.11506	0.059473	0.037986
SEM of K	0.094215	0.058296	0.03956	0.052894	0.071311	0.089202	0.095932	0.076547
Binary Fit Mu	-0.0123	-0.1407	0.1647	-0.0744	0.1066	-0.153369913	0.3781	0.1156
Binary Fit Sigma	1.0221	1.2673	0.8219	0.4519	1.6891	1.451605593	0.7632	0.4111
Binary Fit BIC	194.3459	166.2243	180.5864	158.1696	189.4792	1.97E+02	163.6538	173.3898
Standard Max Likelihood Mu	-0.0123	-0.1407	0.1647	-0.0744	0.1066	-0.153369919	163.6538	0.1156
Standard Max Likelihood Sigma	1.0221	1.2673	0.8219	0.4519	1.6891	1.451605489	0.7632	0.4111
Standard Max Likelihood BIC	194.3359	166.2143	180.5764	158.1596	189.4692	1.97E+02	163.6438	173.3798
Asymmetric Max Likelihood Mu	-0.2154	-0.1643	0.5783	-0.3081	-0.3952	-0.774583256	0.4863	-0.1617
Asymmetric Max Likelihood Sigma 1	0.6894	1.2355	1.2334	0.1522	1.1036	0.628360493	0.8530	0.1606
Asymmetric Max Likelihood Sigma 2	1.3497	1.2944	0.2644	0.684	2.3284	2.196300692	0.5725	0.7962
Asymmetric Max Likelihood BIC	197.6000	171.4964	183.3973	156.7618	193.0771	1.99E+02	168.4223	178.409

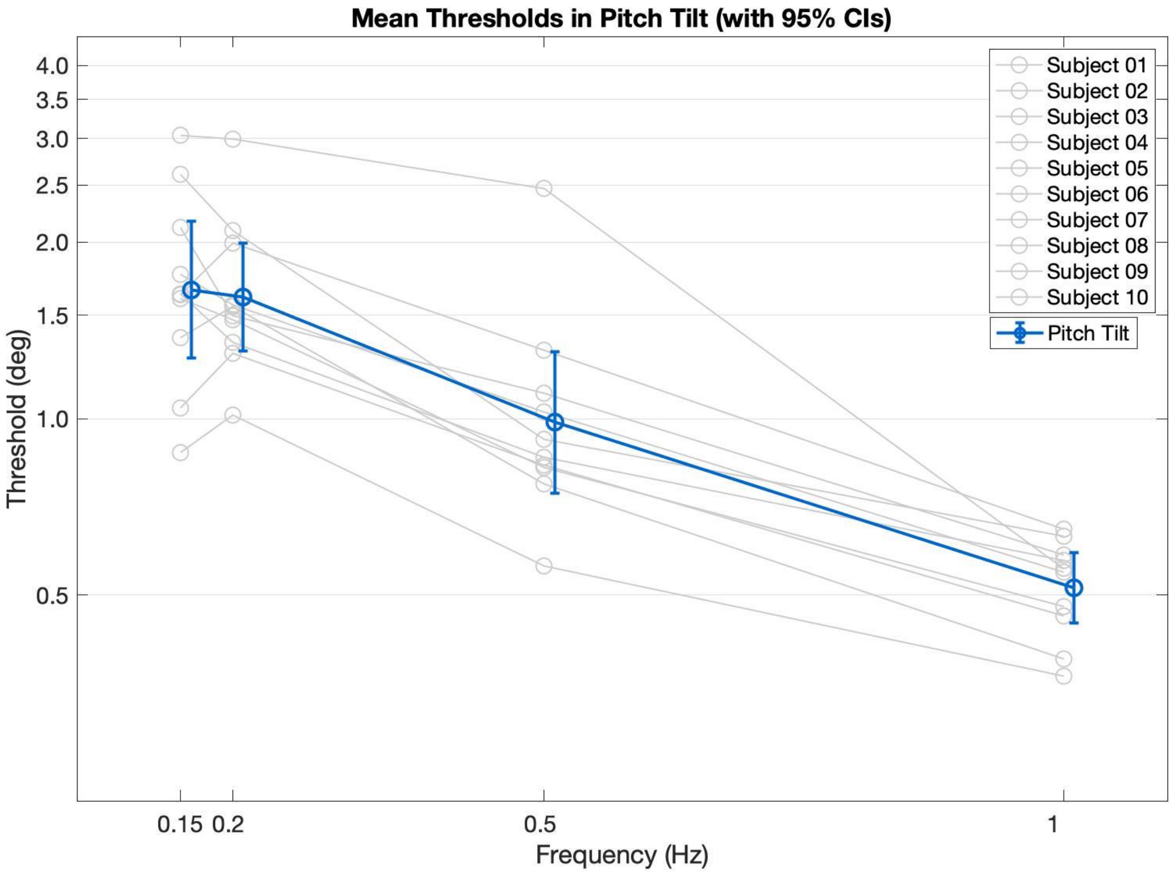


Figure 6 They grey lines depict individual pitch tilt thresholds for all ten subjects plotted as a function of frequency. The blue line depicts average (arithmetic mean) thresholds of all ten subjects as a function of frequency of motion. The error bars characterize 95% confidence intervals.

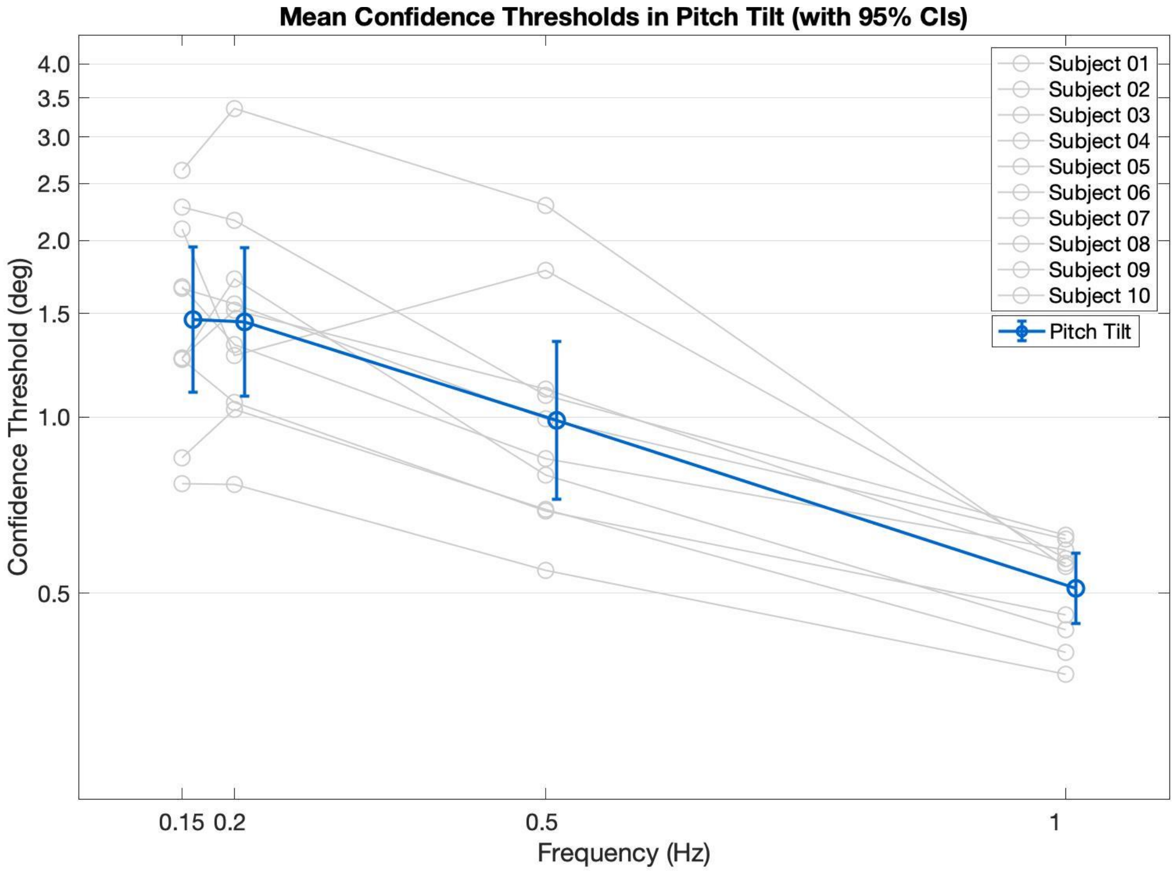


Figure 7 They grey lines depict individual pitch tilt confidence thresholds for all ten subjects plotted as a function of frequency. The blue line depicts average (arithmetic mean) confidence thresholds of all ten subjects as a function of frequency of motion. The error bars characterize 95% confidence intervals.

Table 9 Post-analysis raw data from 50 simulations for different combinations of underlying asymmetries and biases run for a varying number of trials. The last three columns detail the number of simulations for which the symmetric model is a better fit, both models are equally as good, and the asymmetric model is a better fit (in that order). These were determined based on differences in BIC where a positive value suggested that the hybrid dual sigma is a better fit of the data, differences of +/- 2 suggest that both are equally as good of a fit, and differences resulting in a negative value suggest that the single sigma is a better fit of the data.

UNDERLYING μ	UNDERLYING ASYMMETRY		NUMBER OF TRIALS	NUMBER OF SIMULATIONS		
	σ_P	σ_N		Symmetric Model Better Fit	Both Models Are Good Fits	Asymmetric Model Better Fit
0	1	1	100	31	14	5
			2000	49	1	0
0	0.3	0.8	2000	0	1	49
0	1	1.5	100	36	9	5
			500	42	5	3
			1000	36	9	5
			2000	27	15	8
			5000	27	15	8
0	1.5	1	100	32	14	4
			500	42	6	2
			1000	34	11	5
			2000	26	13	11
			5000	16	7	27
0	1	2	100	34	12	4
			500	24	17	9

			1000	17	18	15
			2000	6	7	37
0	2	1	100	33	13	4
			500	30	13	7
			1000	16	17	17
			2000	6	8	36
0.2	1	1	100	35	12	3
			2000	47	3	0
0.2	1	1.5	100	27	19	4
			500	41	3	6
			1000	33	13	4
			2000	25	10	15
			5000	9	8	33
0.2	1.5	1	100	29	19	2
			500	36	10	4
			1000	39	7	4
			2000	21	13	16
			5000	8	13	29
0.2	1	2	100	32	14	4
			500	24	16	10
			1000	15	15	20
			2000	2	6	42

0.2	2	1	100	28	18	4
			500	26	20	4
			1000	19	14	17
			2000	4	11	35
-0.2	1	1	100	36	11	3
			2000	49	1	0
-0.2	1	1.5	100	38	8	4
			500	41	8	1
			1000	34	10	6
			2000	36	9	5
			5000	11	10	29
-0.2	1.5	1	100	37	8	5
			500	37	11	2
			1000	34	12	4
			2000	27	14	9
			5000	3	10	37
-0.2	1	2	100	27	19	4
			500	31	10	9
			1000	18	15	17
			2000	8	10	32
			5000	0	1	49
-0.2	2	1	100	29	13	8

			500	21	17	12
			1000	19	12	19
			2000	4	3	43
0.5	1	1	2000	49	1	0
-0.3	0.3	0.8	2000	0	0	50