RESPIRATION-ENTRAINED ELECTROPHYSIOLOGICAL ACTIVITY IN THE ANTERIOR CINGULATE CORTEX DURING EFFORTFUL WALKING

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ABSTRACT

The anterior cingulate cortex (ACC) is a region of the brain known to contribute to emotional memory encoding, environmental information processing, error detection, and behavioral response modulation (Sachuriga et al., 2021). Although current scientific literature shows that various physiological patterns can influence activity within the ACC, the nature of the relationship between changes in respiration and activity within the ACC remains unclear. Clarifying how changes in respiratory patterns influence ACC activity can provide insight into how physical exertion and conscious modulation of breath impact activity within the ACC and potential behavioral outputs. To investigate this relationship, EEG activity localized to the ACC and respiratory activity were recorded for 15 human participants. Within each session, the participant performed six six-minute walking trials, with a four-minute rest period in between. The walking trials were conducted in the order of zero-degree, three-degree, and six-degree inclines (repeated once). Following data collection, analysis was performed to determine the degree of EEG activity modulation between inclines and within frequency bands of EEG activity. Statistical analysis revealed that inhalation significantly modulated the high beta frequency band of ACC activity, and exhalation significantly modulated the gamma frequency band of ACC activity across walking trials. While further research is needed to corroborate the results within this study, findings suggest that respiration patterns may modulate ACC activity to enhance information processing and environmental adaptation as physical exertion increases. This information not only clarifies the existing dynamic between the ACC and changes in respiratory patterns but also provides a foundation for understanding how phenomena such as executive dysfunction may arise in individuals diagnosed with mental illnesses such as major depressive disorder (MDD).

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CHAPTER I. INTRODUCTION

The brain is often thought of as the control center of the body. While this is true in some capacities, the delicate interplay it has with other bodily systems must be acknowledged. Uncovering the various dynamics that involve the brain contributes to a better understanding of how the brain is involved in bodily functions. One particularly insightful relationship is between respiration and electrophysiological activity in the brain– two seemingly automatic bodily functions. While such processes may be automatic, the reciprocal dynamics between the two is far from simple. Various respiration-related factors can influence electrophysiological activity in the brain, such as: sleep-wake states, mode of breathing, controlled respiration, and the level of physical activity. Presently, our current research goal is to understand how electrophysiological activity in the brain is modulated by respiration at different levels of physical activity. While current literature shows a clear connection between respiration and physical activity, as well as what occurs in the brain during effortful movements, a clear gap still exists in understanding how respiration modulates electrophysiological activity during these effortful movements.

In order to discover the dynamics of such a relationship, my research team uses electroencephalography (EEG) in combination with a respiration “sensor” that measures patterns of inhalation and exhalation in human participants. As our participants perform a physical task at different levels of effort by walking at inclines of 0%, 3%, and 6%, we are able to measure and record changes in the relevant physical metrics. By having the participants cycle through a set number of trials, both neural and respiratory data can be aligned to particular phases of physical intensity (as well as the rest period in between the walking trials). Following collection, we plan to perform signal processing on the collected data and create Hilbert transforms (a frequency-processing technique used to extract the phase of a signal and show amplitude changes over time). From this, we may gauge the significance of the relationship between neural activity trends and phases of respiration. More specifically, because we posit

that respiration modulates electrophysiological activity in the brain during effortful movement, we expect to observe a significant change in the Hilbert transforms over the course of the movement trials. Additionally, we can utilize phase-amplitude couplings (PACs) to assess the degree to which EEG activity changes in response to respiration. From here, visualizations such as comodulograms may be produced, which present PACs over time.

With that in mind, the current focus of our project is to look at the significance of the relationship between respiration and the anterior cingulate cortex (ACC). Part of the larger limbic system, the ACC contributes to emotional regulation and decision-making while integrating environmental cues (Sachuriga et al., 2021). More specifically, the ACC is involved in effort-based decision-making and reward pursuit, which is particularly relevant to our current study (Rolls, 2023). By aiming to specifically understand this region, a foundation may be laid for understanding how physical activity plays into effort-based decision-making (especially vigorous activity). Furthermore, this research can then be applied to understand how certain phenomena commonly involved with various mental illnesses, such as loss of interest, may work. This can be addressed in part by our current research, given that a requirement of our participants is that they are not diagnosed with any major mental illness including but not limited to anxiety, depression, bipolar disorder, and ADHD, which assists with establishing a basis for normal, or expected, activity.

CHAPTER II. LITERATURE REVIEW

Section 2.1: Understanding oscillations in the context of physiological patterns

First, one should understand the idea of oscillations and what they describe in terms of physiological patterns. The human body automatically performs several rhythmic functions – including respiration and electrophysiological activity within the brain. These rhythmic patterns imply a continual transition between the phases that construct the pattern. For example, respiration occurs in two phases: inhalation and exhalation (otherwise referred to as inspiration and expiration). The quasi-rhythmic nature of respiration allows one to approximate the pattern through a sine wave. The translation of respiration to a sine wave transcribes the phases of respiration to the boundaries of the wave. Conventionally, the peaks of the sine wave correspond to inhalation, while the troughs correspond to exhalation. Like the respiratory system, one can use the same mathematical approximations to understand the oscillatory patterns within the brain's electrophysiological output. The brain contains numerous regions that have evolved to perform specific functions. With this in mind, it is important to recognize that the brain does not output only one oscillatory pattern (such as when recording respiratory activity). While there may be a degree of global synchronization throughout the brain, distinct regions will have distinct patterns of electrophysiological activity. Generally, brain regions that perform related functions to one another will have a higher degree of synchronization than brain regions that are unrelated to one another.

Section 2.2: Phase-locking between respiratory and electrophysiological activity in the brain

Similar to how two regions of the brain can have synchronization of their electrophysiological activity (indicating related functions), synchronization can also occur between regions of the brain and related physiological outputs, such as respiration. Phase-locking describes the synchronization of the phases of two separate but related patterns (in this

context, between respiration phases and their neural correlates). The degree of synchronization between these two patterns implies the strength of their relationship. While most of the brain presents oscillatory patterns that occupy some frequency level (a spectral power band), certain regions will present heightened, synchronized activity in alignment with respiration phases. The brain regions of increased synchronization indicate a function related to respiratory activity. Thus, providing evidence for phase-locking between specific brain regions and respiratory activity gives insight into which neural functions are related to respiration. Studies conducted by Kluger et al. (2023) and Biskamp et al. (2017) illustrate the significant components of this dynamic by presenting how respiration phases are tightly phase-locked with pre-frontal cortical, hippocampal, and general cortical activity. The cortex, particularly the pre-frontal cortex (which contains the ACC), is an essential region for planning and pre-execution of motor activity; thus, learning that respiration has implications on motor planning and decision-making may help study the interaction between physical activity and reward perception, which will be discussed.

In addition to demonstrating phase-locking between respiration and cortical activity, research has also revealed that respiration modulates electrophysiological activity in the brain (referred to as respiration-modulated brain oscillations, or RMBOs) on both the cortical *and* subcortical levels (Kluger & Gross, 2021). By collecting respiratory and neural data across the brain, researchers demonstrated the presence of such RMBOs by tracking the correlations in the consistency of respiratory patterns with specific neural activity patterns. Although the data from the 2021 study was collected while participants were at rest, it nonetheless provides a foundation against which the results collected from our research may be compared. However, an understanding still needs to be formed about how the relationship on both the cortical and subcortical levels transforms through different rigors of physical activity and the behavioral implications that such changes may have.

Such entrainment patterns have entrainment have been demonstrated within rodent-based studies. One study, conducted by Lockmann et al. in 2016, provided insight into the

degree of electrophysiological activity entrainment during slow-wave sleep within the hippocampus of rodent models. Through the usage of local field potentials, Lockmann et al. determined that during induced slow-wave sleep states, the hippocampus produces both oscillatory and non-oscillatory patterns of activity, only the former of which are phase-locked to respiration. Local field potentials, or LFPs, demonstrate the cumulative electrical activity of a population of neurons, encompassing both spiking and changes in post-synaptic potentials. As a direct measurement of electrophysiological activity in regions of interest, LFPs can be used to visualize oscillatory neural activity across the power spectrum. Thus, researchers may use LFPs to discern when time-locking occurs by viewing the preferential activation of neurons in response to a specific stimulus. In context, researchers can use LFPs to determine if certain neural populations increase their firing rate during specific phases of respiration.

Ultimately, Lockmann et al. define three unique hippocampal oscillatory states during slow-wave sleep: a slow oscillation (SO) state with a frequency below 1.5 Hz, which presented coupling with neocortical transitions , a theta state with a frequency above 3 Hz, which varied across the hippocampal cellular layers, and a third rhythm with a frequency below 1.5 Hz, characterized by oscillatory coupling between the dentate gyrus and respiratory phases (Lockmann et al., 2016). Based on their findings, this third low frequency oscillatory state (referred to as a hippocampal respiration-induced rhythm, or HRR), is separate from the other two low-frequency oscillatory patterns observed and is the *only* pattern significantly entrained to respiration rhythm (Lockmann et al., 2016). Defining this unique state reconciles previous confusion due to conflicting results on hippocampal oscillatory entrainment in the slow oscillatory state and the theta state, which function independently of one another and signify separate hippocampal transitions (Lockmann et al., 2016). Furthermore, the specific involvement of the dentate gyrus within the HRR pattern potentially indicates a relationship between emotionally guided behavior and olfaction due to the region's oscillatory entrainment to olfactory bulb activity *and* respiratory patterns within the rodent model (Lockmann et al., 2016).

Overall, the Lockmann et al. study demonstrates that hippocampal low-frequency oscillations can exists within the same frequency range and simultaneously correspond to different phase-coupling rhythms independent of one another. This finding is particularly insightful, as it demonstrates how hippocampal low-frequency oscillations are modulated by *both* neocortical activity and respiratory activity, with each entrainment having a specific information-processing task.

Section 2.3: Respiration and physical activity

The current gap in knowledge that my proposed topic aims to clarify is the manner in which the interaction between respiration and neural activity changes as a result of physical exertion. While preliminary evidence collected from animal models exists, there is still a major lack of corroborating evidence in human models. Part of the goal of this study will be to determine if the results derived from similar animal-based studies conceptually translates to human models. Rodents are a commonly used experimental model and have been found to have states of neural activity similar to those of humans. This was clarified in a 2014 study conducted by J. Jacobs, wherein he analyzed the differences between the different states of neural activity in human and rodent models. Ultimately, Jacobs revealed that although spectral power band frequency ranges in rodent models do not directly align with those of humans (with observed frequencies being lower in humans than in rodents), the spectral states and their characteristics generally translate to one another, signifying that a pattern found in a rodent model may provide support for further investigation within human participants (Jacobs, 2014). Such clarification provides a foundation for investigating respiration-entrained electrophysiological activity through human studies based on the findings derived from related rodent-based publications.

Another insightful rodent-based study with relevance to my research topic was that of Nguyen Chi et al.'s 2016 publication, which investigated the alignment of respiratory activity and hippocampal theta oscillations during both an immobilized wake-state and a treadmill wake-

state. Similar to the study conducted by Lockmann et al., Nguyen Chi et al. chose to investigate the hippocampus within their study. Although not explicitly mentioned in either publication, the strength of the relationship found between respiratory entrainment and hippocampal modulation acts an additional motivator for investigating the respiration-entrained electrophysiological activity in the anterior cingulate cortex. While the hippocampus is a subcortical structure and the anterior cingulate cortex is within the frontal lobe, both structures are functionally linked and work together to construct several functions (including, but not limited to, goal-oriented behavior). For example, both the hippocampus and the ACC are part of the Papez circuit, a neurological pathway that is heavily implicated in emotional regulation and its influence on physical actions.

From their investigation, Nguyen Chi et al. made a number of observations in variations between hippocampal oscillatory entrainments to respiratory activity between an immobilized wake-state and a treadmill wake state. Of particular interest were slow oscillation hippocampal entrainments (i.e., frequencies less than 1.5 Hz) and theta band hippocampal entrainments (i.e., frequencies between 4-8 Hz). Similar to the results of Lockmann et al., Nguyen Chi et al. observed a high degree of entrainment between hippocampal slow oscillations and respiratory activity in their rodent models, particularly during the treadmill wake state. In comparison, theta band hippocampal oscillations did not show a consistent pattern of entrainment with respiratory activity during both wake state types. Despite this inconsistency, an intriguing insight was that hippocampal slow oscillation entrainment was at its highest when the respiration rate was below that of the hippocampal theta band oscillatory frequency. What this observation potentially indicates, as suggested by Nguyen Chi et al., is that the rate of hippocampal slow oscillation entrainment to respiration may depend on the rate of respiration rather than remain fixed (Nguyen Chi et al., 2016). This insight potentially supports investigation into the variation of oscillatory entrainment across different levels of physical exertion, which acts as another point of motivation behind my intended research topic, as we plan to observe respiratory activity and

electrophysiological activity in human participants while walking along several different inclines. Furthermore, the corroboration of significant hippocampal slow oscillation entrainment to respiratory activity in both the Lockmann et al. and Nguyen Chi et al. studies indicate the presence of a significant connection between these specific patterns of activity. As mentioned above, although the anterior cingulate cortex is not within the same region as the hippocampus, the strong functional link between both structures may indicate that ACC slow oscillations are also of significance when analyzing entrainment to respiratory patterns and should be focused on during eventual data analysis.

To further support the investigation of electrophysiological entrainment to respiratory activity in humans, one can look to the 2015 study conducted by Bradford et al., which investigated how cortical activity changed across different levels of physical exertion. Within their study, human participants completed 30-minute walks at both a 0% and 15% treadmill incline. Similar to my own research, Bradford et al. makes use of wet EEG technology to observe electrophysiological activity in the brain. From their collected data, they concluded that the greater the level of physical exertion, the greater the level of cortical oscillatory synchronization observed across the theta and gamma spectral power bands (Bradford et al., 2015). Of particular interest, the anterior cingulate, left sensorimotor, and pre-frontal cortical areas produced a significant increase in theta oscillatory coupling (Bradford et al., 2015). Furthermore, their team observed a heightened level of theta oscillation synchronization when performing effortful tasks requiring concentrated effort (which was related to a beam-walking task within this study) (Bradford et al., 2015). Knowing that the role of the ACC is significantly linked to goal-oriented and effortful behavior, this study both solidifies the ACC's function in deliberate physical activity and provides insight into another frequency range of interest when examining the data pertaining to my research.

Overall, the demonstrated increase in the oscillatory activity across the cortex proves to be particularly insightful given the specific functions of cortical areas in the planning and

execution of motor activity (especially within the ACC). Ultimately, Bradford et al.'s study suggests that the greater the degree of physical exertion (and thus, respiration), the greater the synchronization (i.e., modulation) of cortical activity between the respiratory and cortical networks so that factors such as changes in physical environment and sensory input can be integrated to change physical output as needed, or otherwise provide the brain with a gauge of the energy being expended so that it may conserve any remaining energy as needed. While this study provides supporting evidence to further validate my chosen research topic, it also demonstrates which questions have yet to be addressed. In particular, respiration-entrained modulation of ACC oscillatory activity across the power spectrum has yet to be specifically studied, which is what my research aims to focus on. Investigation of my research topic may also reveal information such as the magnitude of change in ACC oscillatory entrainment across physical trials and other potential patterns of entrainment between ACC activity and respiratory phases between different levels of exertion.

Section 2.4: Conclusion

Current literature makes clear that there is an observable relationship between respiration and neural activity across different regions in the brain. The patterns that make up this relationship have yet to be completely mapped, but significant progress has been made in the translation of dynamics between rodent models and human models, as well as to mapping the general areas in which the brain is phase-locked to respiratory patterns. However, there is much to be learned about the way that these two components of the body affect one another. In particular, the phase-locking of different types of activity to respiratory patterns (such as beta band oscillations) have yet to be revealed, which is the gap that future research must cross. The ultimate aim of current studies is to explain the specific two-way dynamics between respiration and neural activity of cortical areas while considering external factors (particularly intensity of physical activity). Such research can ultimately be translated into possible behavioral readouts and abnormalities, including phenomena such as executive dysfunction in individuals with major

depressive disorder and similar mental health diagnoses. Additional research would be needed to clarify if this data can be applied to such a topic, but there may be room for a connection between comparing the degree of cortical activity phase locked to respiratory activity while completing physical tasks of varying intensities in healthy adults versus adults with depression.

CHAPTER III. METHODS

The research behind this project utilized data collected from 15 human participants. The participants had to be between the ages of 18 and 89 and without any prior diagnoses of major depressive disorder (MDD), general anxiety disorder (ADD), and/or attention-deficit/hyperactivity disorder (ADHD). Other qualifiers, such as specific gender or fitness level, were not required for participation. Additionally, participants had to be able-bodied, able to express verbal and written informed consent, and able to understand the general process of data collection for this project. Prior to beginning data collection, the participants were fitted with the necessary equipment to measure and record the relevant biometrics, which can be categorized into three groups.

Section 3.1: Preparing EEG data collection

Figure 1. A trial participant being fitted with the appropriate EEG cap.

The first category of collected data was electrophysiological data. To collect this data, the participant was first fitted with an EEG cap containing electrodes that indirectly measured the electrical activity in different brain regions. Overall, there were 64 electrodes on the cap, which, when combined, construed an approximation of global brain activity. Other team members filtered the EEG activity to find it localized to the ACC.

Before collecting the participant's EEG data, the equipment was calibrated to account for the participant's head measurements. To do so, my team and I used the camera and Xensor program provided by the company Ant Neuro. After fitting the participants with the appropriate cap size, they were sat in front of the Xensor camera at eye level, and a head reference was attached to the cap. The provided pointer and clicker were then used to trace the participant's head, which amounted to about 220 reference points per participant. After reviewing the

provided model and ensuring that no erroneous points were traced, the model was saved and exported to our local drive. Following this calibration, the EEG cap was connected to the amplifier, which magnified the EEG signal for ease of visualization and analysis. The amplifier was then connected to a tablet, which visualized the live EEG signal.

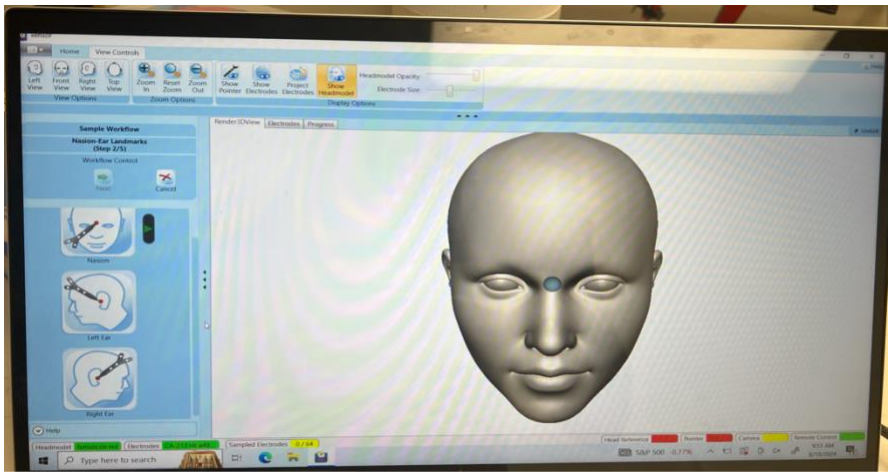


Figure 2. The Xensor calibration interface prior to initialization of participant fitting.

As mentioned, electroencephalograms (EEGs) indirectly measure electrical activity in the brain. Because the electrical signals of the brain are transduced through the skull, skin, and hair, simply using the cap on its own would have been insufficient to pick up substantial electrical signals. To improve conductivity, an electrode gel was injected into each of the 64 electrodes between the cap and the participant's scalp. Furthermore, the EEG cap contained two connected electrooculogram (EOG) electrodes. The ground electrodes were placed on the cheekbone and the bone behind the participant's left ear. Similar to the EEG cap electrodes, an electrode gel was placed between the EOG electrodes and the participant's skin to improve electrical conductivity. It was then secured with medical tape. Once this step was completed, the Xensor software was checked to ensure that each electrode impedance was at or below 20 kΩ.

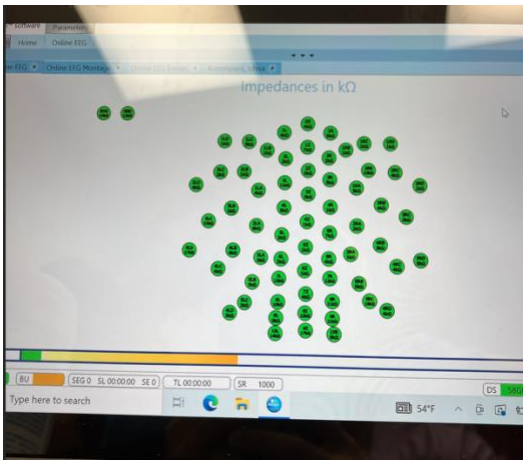


Figure 3. An example of all EEG cap electrodes being at or below the impedance threshold.

Section 3.2: Preparing respiration data collection

The second category of collected data was respiration data. Here, the participant's respiratory activity (i.e., their inhalation and exhalation patterns) were measured and recorded. To do so, the participant was fitted with a respiration band that sat above their diaphragm. After wrapping the respiration band around the participant, they were asked to inhale deeply and then exhale completely. Once they had expelled their breath, the band was tightened to sit as close as possible to their chest without causing discomfort. A monitor on the fitted band measured the relative expansion and shrinking of the band. The cable connected to this monitor was plugged into the Sensebox, which collected the respiration data throughout the trial.

Section 3.3: Initiating data collection

To mitigate the risk of injury from falling, the participants were fitted with a body harness prior to beginning the walking trials. This harness was connected to the frame surrounding the treadmill with rope, and then the participant's knees were checked to ensure their knees would not meet the ground in a sitting position. Following the harness fitting, a backpack containing the attached amplifier, tablet, and Sensebox was placed on the participant's back. After a final check that all equipment was secure, they were directed to the treadmill, and the walking trials were initiated.

Because this pilot study aimed to assess how changes in respiratory activity modulated electrophysiological activity in the brain, the participants performed several levels of physical exertion. Each participant was instructed to perform six walking trials of three intensities, with a four-minute break in between each six-minute walking trial. The walking trials increased from a zero-degree incline to a three-degree incline and then finally to a six-degree incline. This pattern reset at the fourth walking trial. The EEG and respiration data were continually measured and recorded throughout the trials.

Section 3.4: Data analysis

The majority of data preparation and analysis was performed within a Python program, which contains several functions. The first portion of the script aimed to process and visualize the EEG data. Based on pre-determined definitions for each of the frequency band boundaries (delta, theta, alpha, low beta, high beta, and gamma) and the raw EEG signal file that was passed through, a spectrogram and a raw EEG signal visualization was produced for each of the 15 participant files.

Following this, the following code block within the script aimed to process the respiratory data. A function was written to take in each of the MATLAB files containing the participant respiration data and find the instantaneous phase of respiration throughout the course of the walking trials. Both the respiration signal and the instantaneous phase of respiration are plotted. Based on where the peaks of the instantaneous phase of respiration occur, and the width of the respiration phase peaks, the script then computes the time windows of inhalation and exhalation throughout each walking trial and the window lengths. The script then uses the pre-computed band power spectra and mean of the window computations to produce the band power distribution for the ACC's EEG activity across each walking trial. After computing the mean band power across every trial for each frequency band, a repeated measures ANOVA test was then performed across incline levels for every frequency band to determine the level of statistical significance of the change in band power spectra between incline levels.

CHAPTER IV. RESULTS

Section 4.1: Inhalation high beta band power spectra varied significantly across incline trials

Of the six frequency bands included in this study (delta, theta, alpha, low beta, high beta, and gamma), only high beta band activity was concluded to be significant across incline trials ($\alpha = 0.05$, p = 0.0419, F = 3.39). All other frequency bands produced an F-value at or around a value of 1, and a p-value greater than 0.05, indicating a statistically insignificant variance of EEG activity localized to the ACC across incline trials within such frequency ranges. The statistical analysis results are summarized in the table below. Further detail on the power spectra distribution across trials per participant is provided in the appendix within section 6.5.

REPEATED MEASURES ANOVA TEST RESULTS - INHALATION						
	DELTA	*THETA*	*ALPHA*	*LOW BETA*	*HIGH BETA*	*GAMMA*
P-VALUE	0.334	0.279	0.392	0.0419	0.312	0.124
F-VALUE	1.123	1.31	0.955	3.39	1.19	2.18
EFFECT SIZE	0.000414	0.000221	0.000289	0.000366	0.000222	0.000305

Table 1: Statistical analysis results for inhalation windows across frequency bands

Section 4.2: Exhalation gamma band power spectra varied significantly across incline trials

Of the six frequency bands included in this study (delta, theta, alpha, low beta, high beta, and gamma), only gamma band activity was concluded to be significant across incline trials ($\alpha = 0.05$, p = 0.0340, F = 3.63). All other frequency bands produced an F-value at or around a value of 1, and a p-value greater than 0.05, indicating a statistically insignificant variance of EEG activity localized to the ACC across incline trials within such frequency ranges. Additionally, similar to the inhalation analysis, all frequency bands yielded a small effect size. The results of the statistical analysis for each frequency band are summarized in the table below. Further

detail on the power spectra distribution across trials per participant is provided in the appendix within section 6.5.

REPEATED MEASURES ANOVA TEST RESULTS - EXHALATION						
	DELTA	*THETA*	*ALPHA*	*LOW BETA*	*HIGH BETA*	*GAMMA*
P-VALUE	0.0850	0.393	0.789	0.276	0.886	0.0349
F-VALUE	2.60	0.951	0.238	1.32	0.122	3.63
EFFECT SIZE	0.000885	0.000123	0.00005	0.000127	0.000017	0.000611

Table 2: Statistical analysis results for exhalation windows across frequency bands

CHAPTER V. DISCUSSION

Section 5.1: ACC activity is significantly modulated by changes in respiratory patterns

This study aimed to examine the degree to which respiratory patterns modulate electrophysiological activity in the anterior cingulate cortex (ACC). EEG and respiratory data were collected from 15 human participants throughout several walking trials of increasing incline (which corresponded to increased physical exertion) to study this relationship. However, the data collected from participants six and eight were ultimately omitted from the analysis, as a malfunction of the EEG recording technology resulted in faulty data collection. The relevant physiological data for the remaining participants then underwent several levels of analysis to examine the degree of EEG activity modulation across incline trials. Spectrograms were produced for each participant across the entire data collection session to visualize changes in EEG activity per frequency band. Following this, spectral analysis was performed to assess which specific frequency bands of activity in the ACC were significantly modulated by respiration patterns. The specific band power averages across trials for inhalation and exhalation for every participant are included within 6.5 of the appendix. Additionally, sample figures from participants one (session one) and thirteen for EEG signal , participant spectrograms, respiration signal alongside instantaneous phase of respiration, and band power spectra visualizations are included in section 6.1-6.4, respectively.

The main conclusion derived from analysis of the power band frequency averages across incline trials and participants was that EEG activity localized to the ACC is indeed modulated by changes in respiration. While modulation was observed across inhalation *and* exhalation windows, the frequency bands that were significantly affected differed between inhalation and exhalation. While the low beta frequency band (12-20 Hz) was significantly modulated for inhalation windows, only the gamma frequency band (30-49 Hz) was significantly modulated for exhalation windows. The delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), and high

beta (20-30 Hz) frequency bands did not vary significantly across incline trials for both inhalation and exhalation windows.

The high beta frequency band of brain activity is associated with several functions, such as controlling attentional focus, planning and executing movement, and complex problem-solving (Errington et al., 2020). Furthermore, recent research has revealed that beta frequency activity within the frontal lobe may be an indicator of movement-related learning, as increased beta frequency modulation during repetitive physical activity appears to initiate long-term potentiation within the brain (Ricci et al., 2019). Combined with the knowledge that the primary functions of the ACC also concern the ongoing modulation of response during task completion and encoding event-related memories, the results from our study may indicate that physical exertion enhances functions such as error detection and memory encoding to aid movement-related learning, possibly as a way to adapt to a changing environment more efficiently. Similarly, the gamma frequency band of brain activity is strongly associated with efficiency of information processing, reasoning tasks, and the integrity of one's working memory (Singh et al., 2020). Aside from the individual associations of the high beta and gamma frequencies of activity, evidence suggests that the coupling of beta and gamma oscillations within the primary motor cortex is essential for maintenance of motor control (Spooner & Wilson, 2022). Although this coupling was observed within the motor cortex, a similar alignment of beta and gamma frequency activity within the ACC may contribute to adaptive or corrective motor control. Nonetheless, further research would be needed to clarify any concurrent activity between the ACC and the primary motor cortex and any synchronization of activity frequency.

Section 5.2: Inhalation and exhalation may exert separate influences on EEG activity within the ACC

As detailed in section 4.2, while inhalation significantly modulated high beta frequency activity, exhalation significantly modulated gamma frequency activity. This difference in effect warrants the consideration of inhalation and exhalation as separate sources of influence on

brain activity, rather than assuming the enacting unit to be an entire breath. Furthermore, although inhalation and exhalation both had a frequency band of significant influence, the p-value computed for high beta band modulation across inhalation windows was smaller than the p-value computed for gamma band modulation across exhalation windows ($p = 0.0419$ vs. $p = 0.0349$). Although this alone does not confirm a stronger relationship between exhalation and gamma frequency modulation compared to inhalation and high beta frequency modulation, accompanying statistics appear to support this conclusion. The computed F-values, which indicate the magnitude of variation between incline groups against variation within incline groups, was larger for the gamma-exhalation pair than the high beta-inhalation pair. it may be worth further investigating the relationship between exhalation and theta band frequency activity within the ACC to determine if this relationship is consistent. While further research is needed to corroborate these findings, current analysis provides an intriguing insight on the unique roles of inhalation and exhalation in modulating activity within the ACC.

Section 5.3: Observed ACC modulation may not be due to variation of incline trials

Although the repeated measures ANOVA statistical test confirmed significant modulation of EEG activity within the ACC for both inhalation and exhalation, the effect size statistic (η^2) that was computed for every frequency band was consistently small (refer to *Table 1* and *Table 2* within chapter four for specific values). In context, a small effect size would indicate that the observed variance in power (dB) likely is not due to the incline variation during walking trials. While a small effect size is typically regarded as $\eta^2 = 0.01$, all calculated effect sizes were below this benchmark (Lakens, 2013). This result appears to contradict the significance of the power band modulations. Performing a post-hoc statistical analysis on the collected data, such as the Tukey's Honestly Significant Difference (HSD) test or the Fisher's Least Significant Difference (LSD) test, may provide further context for the initial statistical results and whether the observed significant differences truly correspond to a small magnitude of difference.

Section 5.4: Potential applications

The results provided within this study may help to establish a foundation for future studies that aim to examine the phenomenon of executive dysfunction and how it manifests in individuals with diagnoses such as major depressive disorder (MDD). Executive dysfunction is characterized by a cognitive dissonance between internally wanting to complete a task and not being able to physically rouse oneself to initiate said task (Van Dam et al., 2022). While executive dysfunction is not yet well understood, individuals afflicted with executive dysfunction commonly report experiencing a loss of autonomy, which can result in a host of adverse physical and mental effects. Deepening the current understanding of executive dysfunction by examining the relevant brain regions (such as the ACC) and how regional patterns change during physical activity could provide a pathway to a targeted therapeutic treatment. Furthermore, the implication of beta- and gamma-specific frequency modulation, both of which were found to be significant within this study, in maintaining executive control further supports the future research on the ACC and the role it may play in executive dysfunction (Minzenberg et al., 2015; Errington et al., 2020).

Section 5.5: Limitations and future directions

Within a shorter scope, however, future directions of research are clear. As this was the pilot portion of this study, data collection should move to participants diagnosed with mental illnesses such as MDD, attention-deficit/hyperactivity disorder (ADHD), and generalized anxiety disorder (GAD). Comparing the physiological data from such participants to the data collected from the pilot participants may reveal significant differences within ACC activity across trials and the degree to which respiration patterns modulate this activity. As mentioned, doing so may reveal a proximal cause of executive dysfunction, a potential therapeutic pathway, and other potential therapeutic insights.

Although the results collected from this study proved significant, limitations must still be addressed. To begin, the sample size of this study was relatively small, with less than twenty

unique participants being utilized. This limitation is partly because the data collected and analyzed within this paper was for the pilot chapter of this study. Completing this portion of the study was necessary to establish a norm for EEG and respiration activity, against which future participant data can be compared. However, additional data collection among participants that fit the pilot requirements would strengthen the results found within this study. Furthermore, the protocol and experimental setup process were refined throughout the course of data collection. While there were moments of trial and error, such as with the EEG data collection for participants six and eight, this ultimately resulted in a more streamlined collection process for future iterations of data collection. Nonetheless, this may have resulted in inaccurate data collection for some participants. Once more, to mitigate this, future iterations of this study may choose to work with pilot participants to corroborate the findings and activity trends that have been observed.

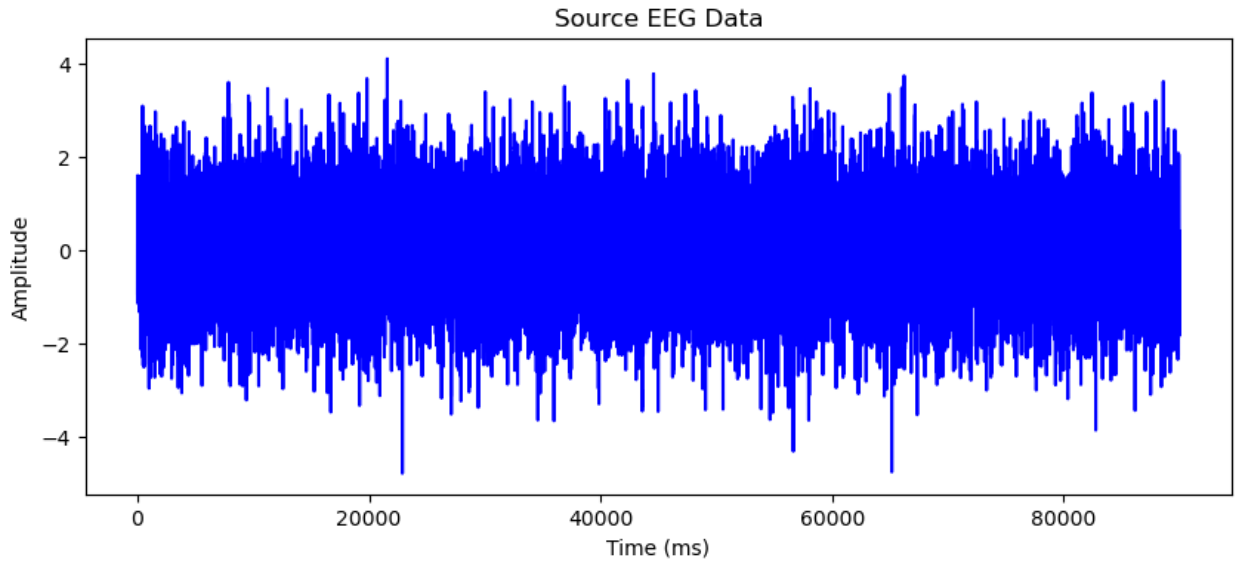
Section 5.6: Conclusions

While there is still much to be understood regarding the ACC's intricate relationship with physiological patterns, this study has provided valuable insights into both how this relationship works and its implications for behavioral outputs. Future studies should aim to address how this relationship may differ in individuals with different mental diagnoses or ratify the findings within this pilot study, especially if understanding executive dysfunction is an experimental aim. Although much work will be needed to translate such results into therapeutic impacts, this future is well within reach.

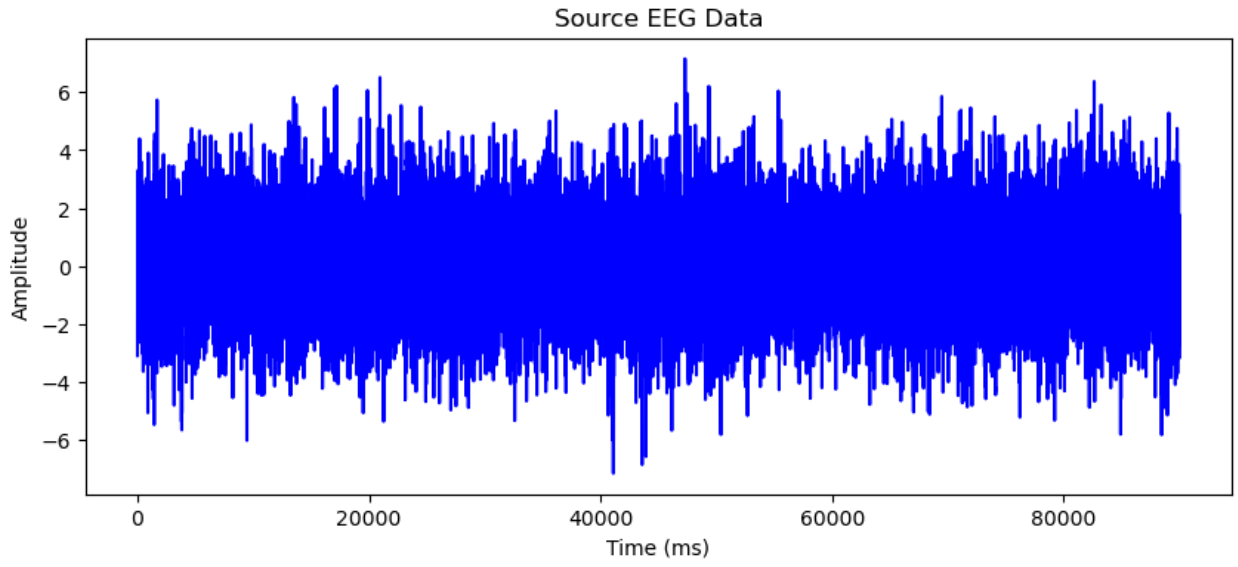
CHAPTER VI. APPENDIX

Section 6.1: Raw EEG data for participants one (session one) and thirteen

Participant one, session one:

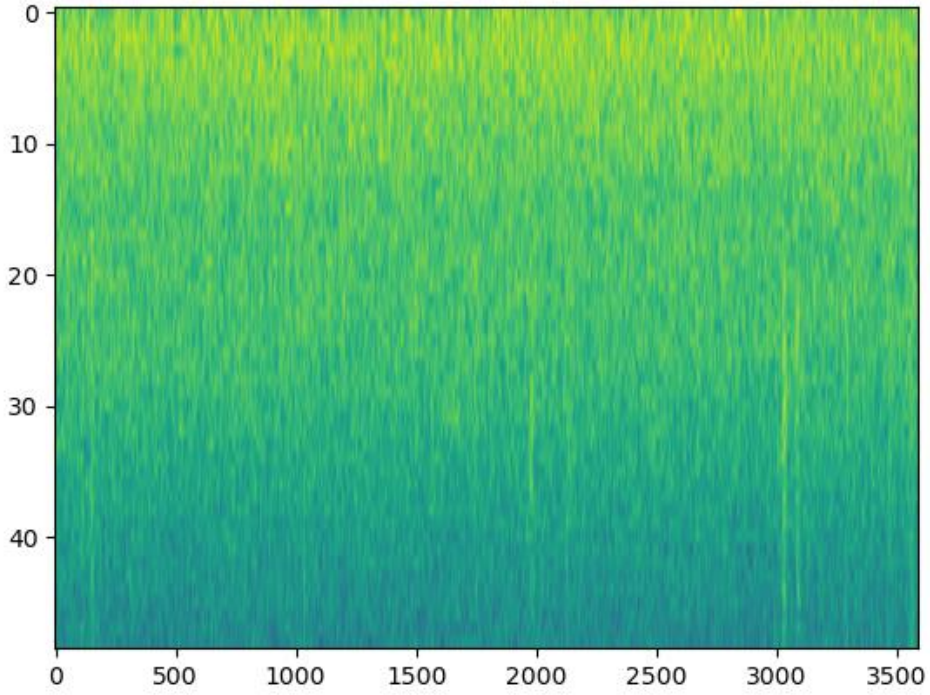


Participant thirteen:

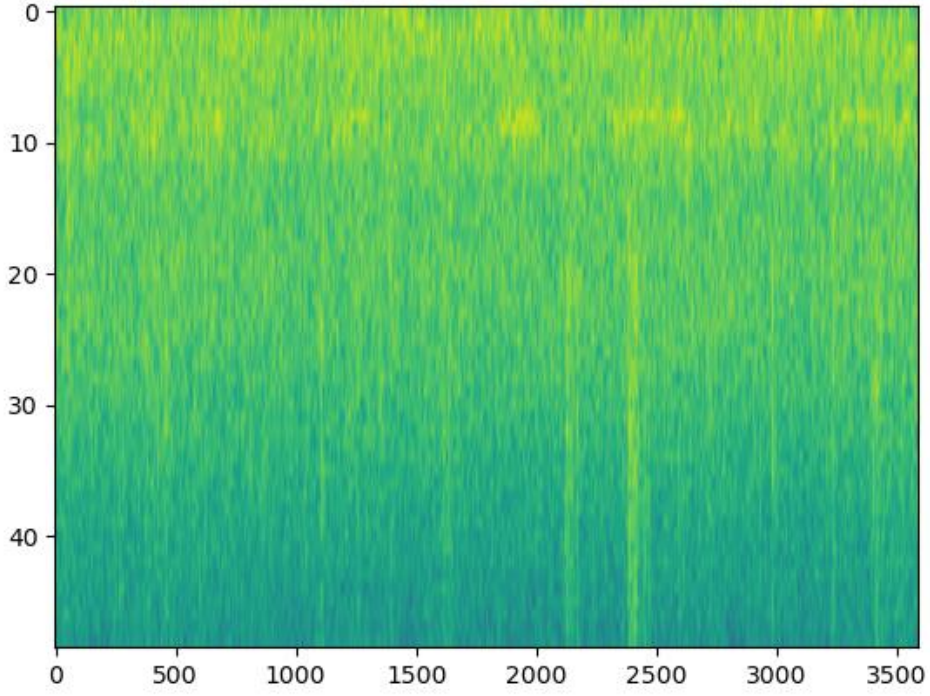


Section 6.2: Spectrograms for participants one (session one) and thirteen

Participant one, session one:

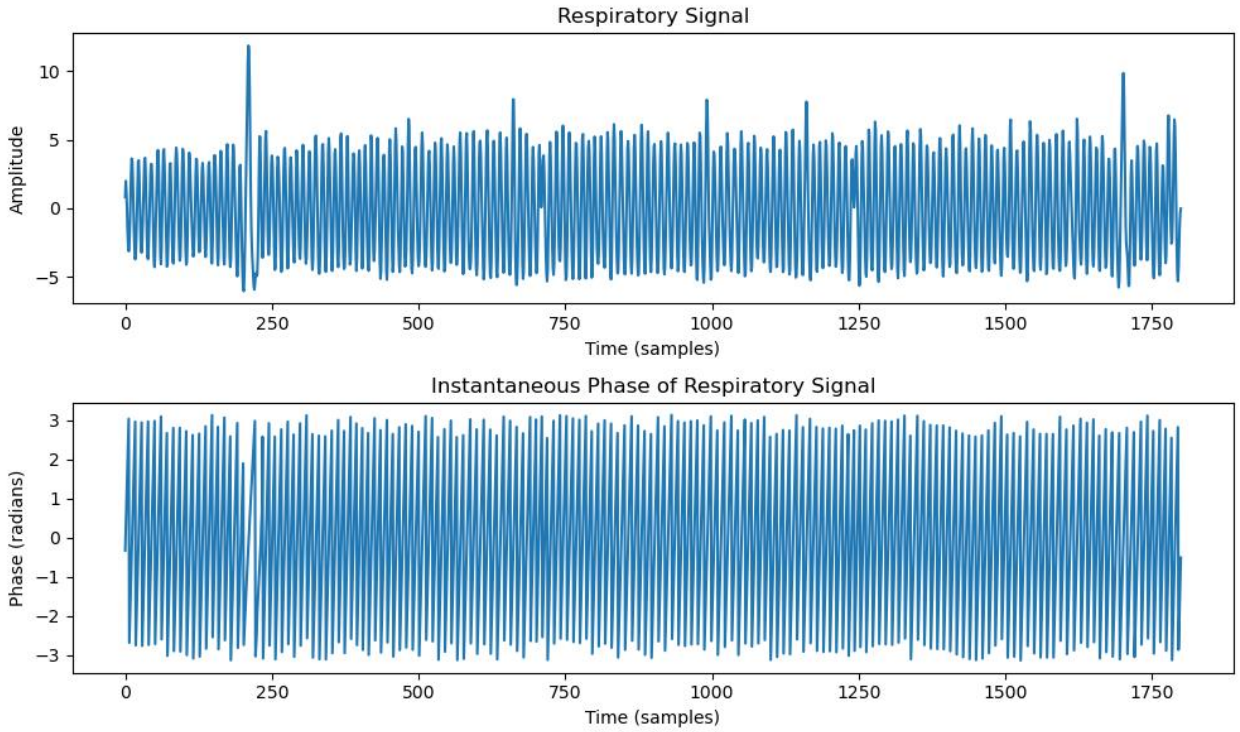


Participant thirteen:

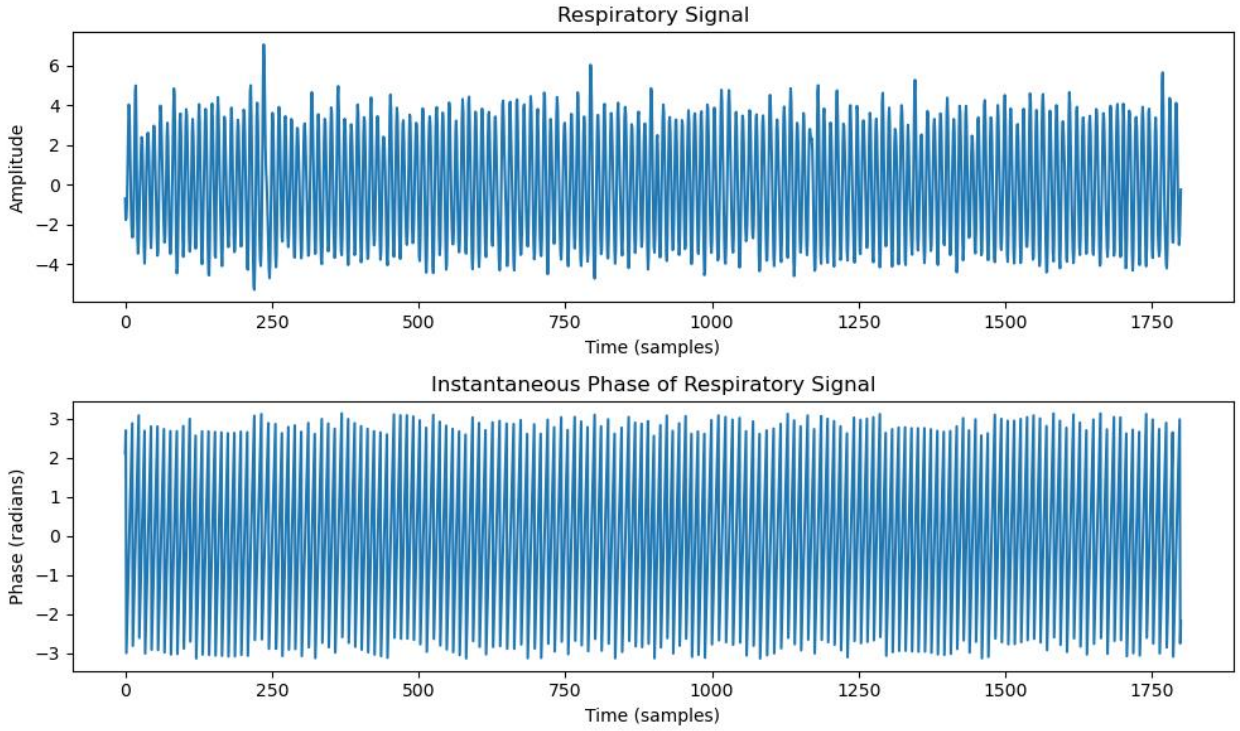


Section 6.3: Respiration data for participants one (session one) and thirteen, per trial

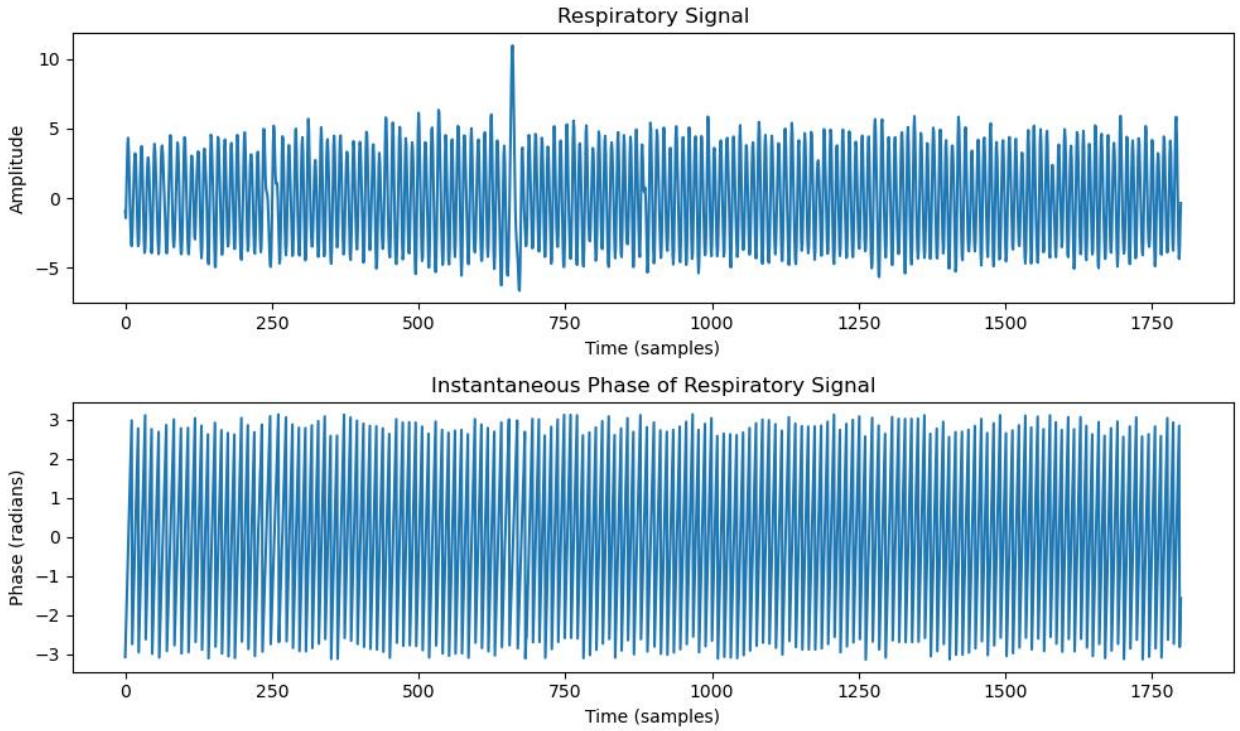
Participant one, session one, trial one:



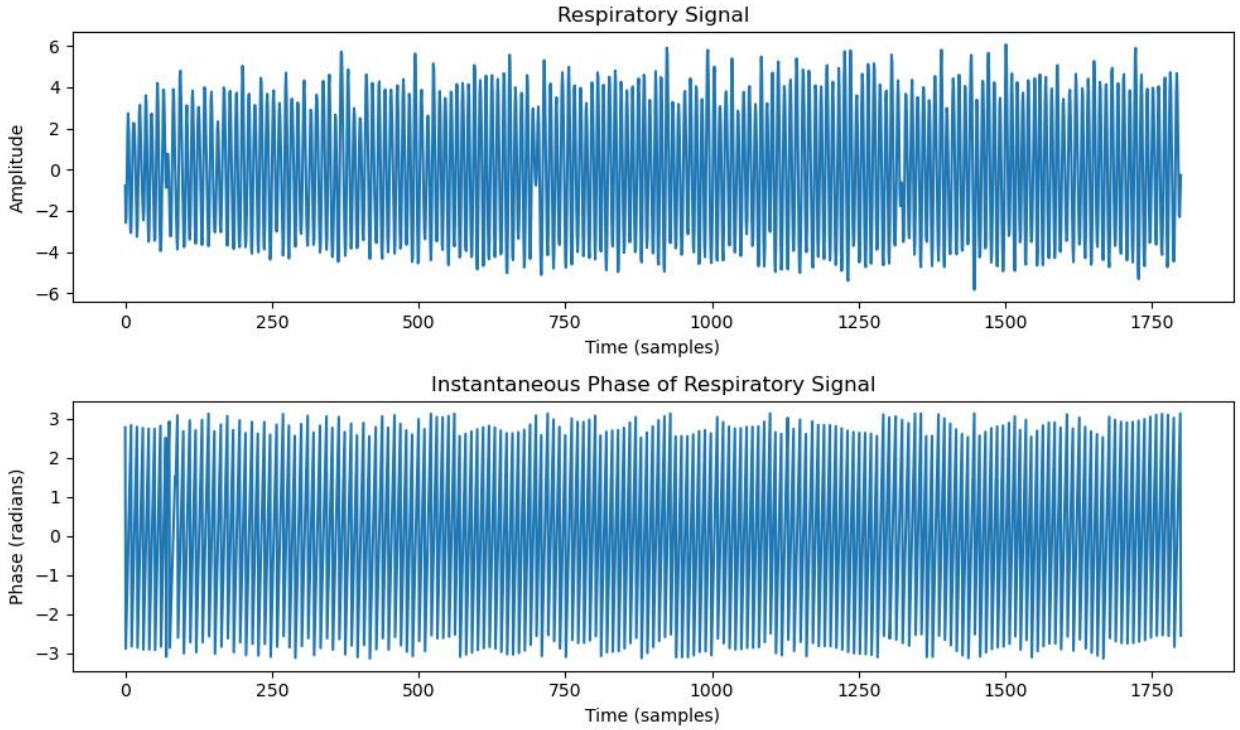
Participant one, session one, trial two:



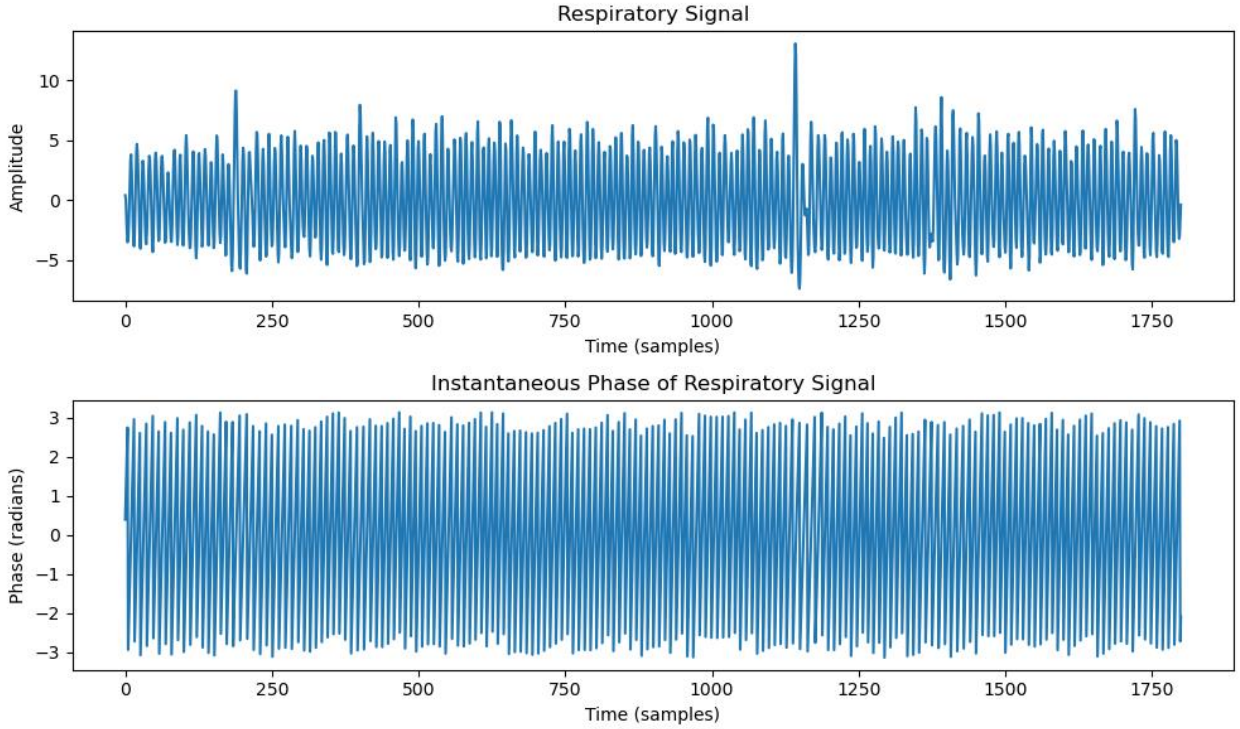
Participant one, session one, trial three:



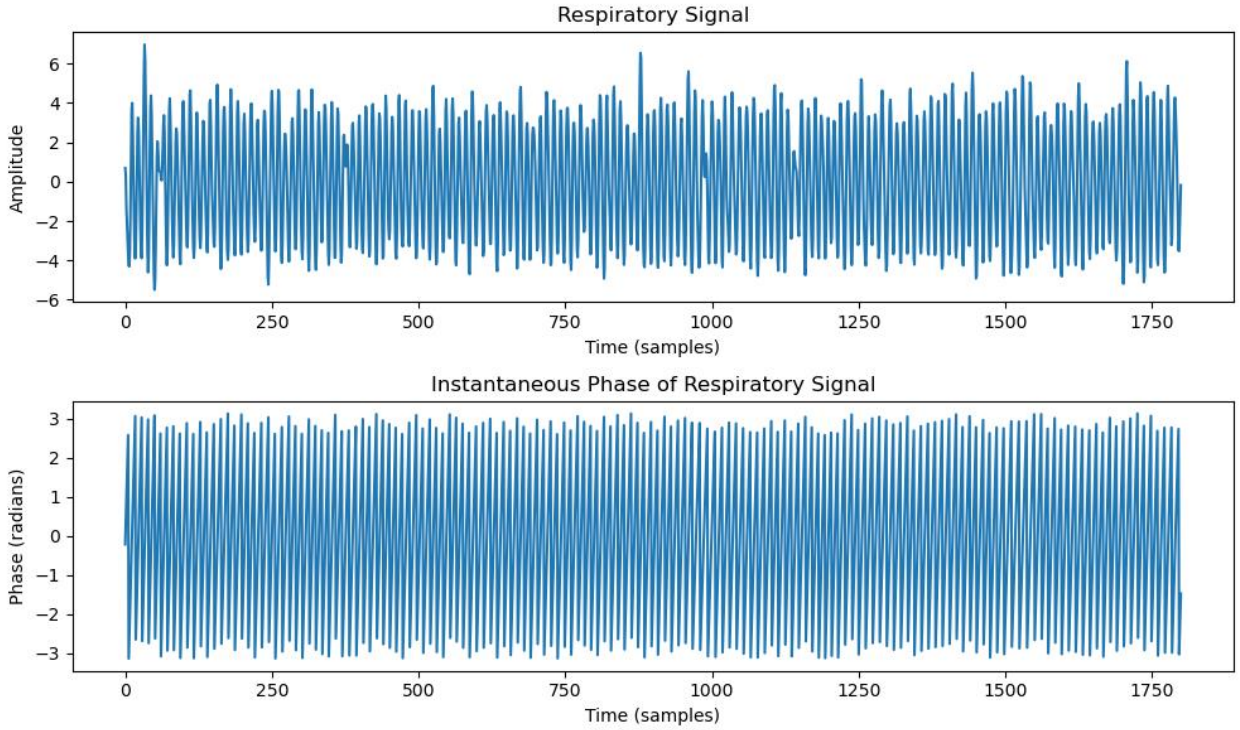
Participant one, session one, trial four:



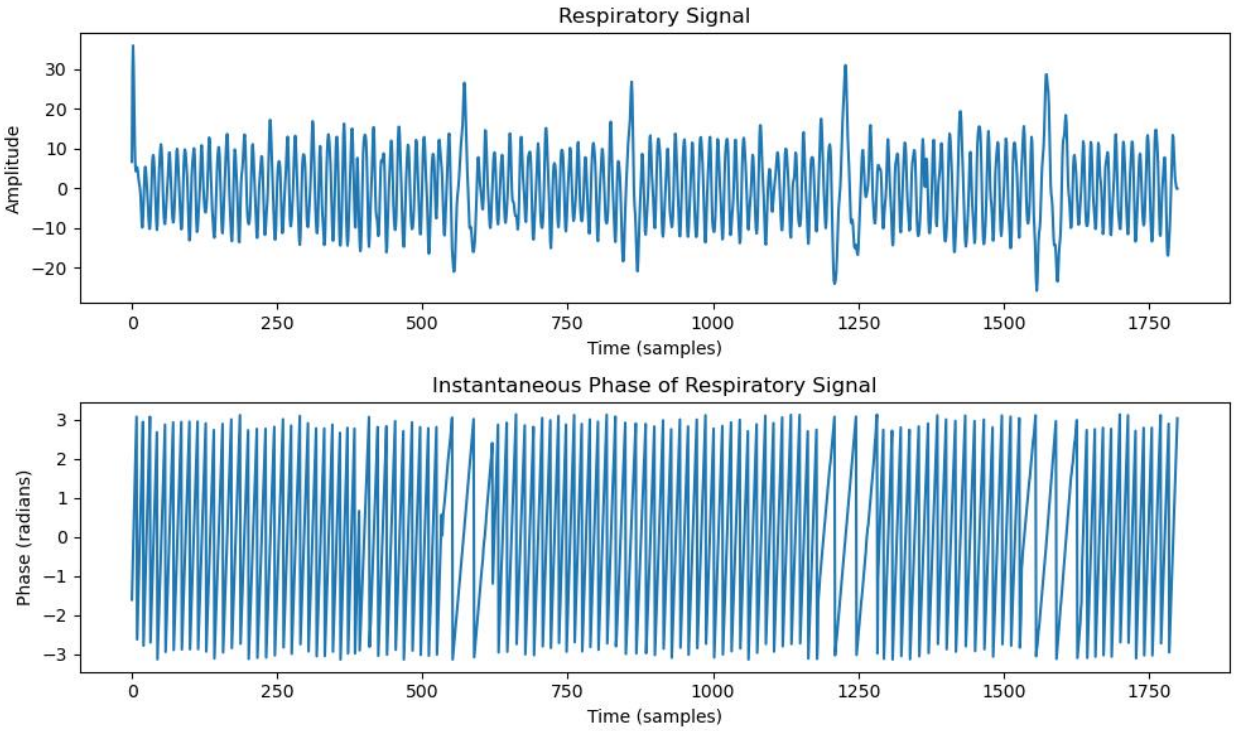
Participant one, session one, trial five:



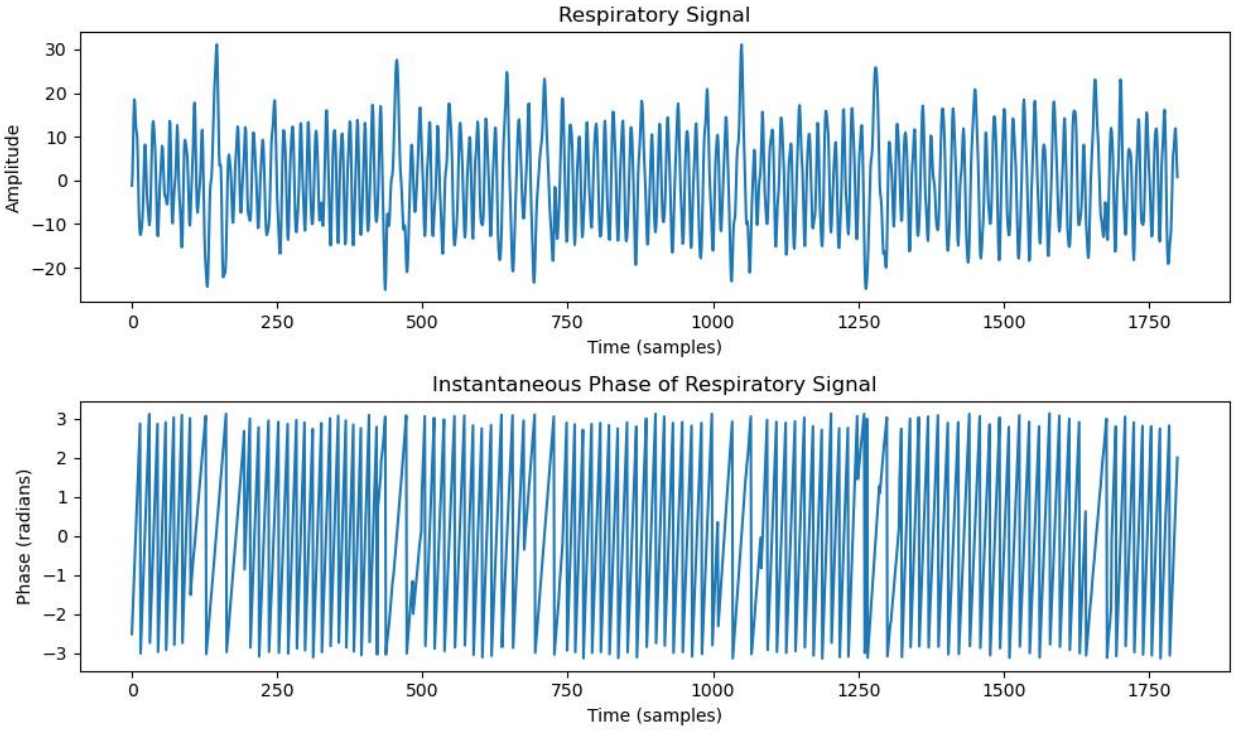
Participant one, session one, trial six:



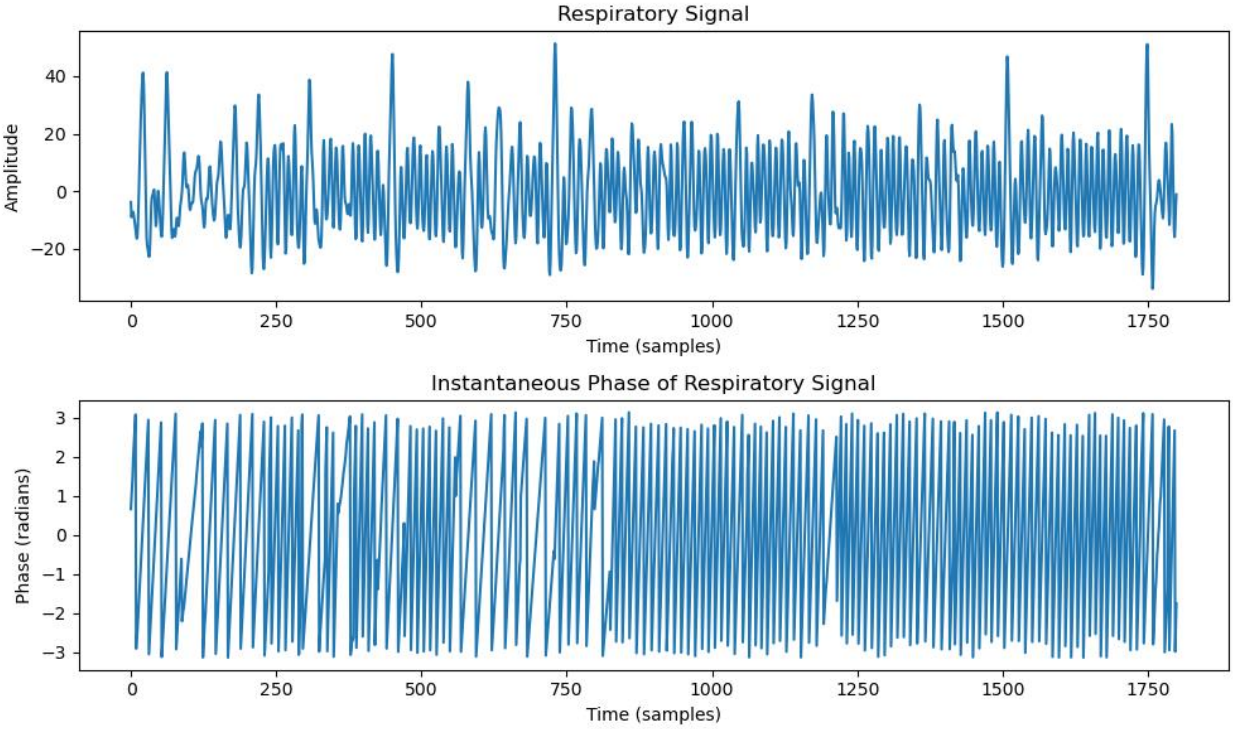
Participant thirteen, trial one:



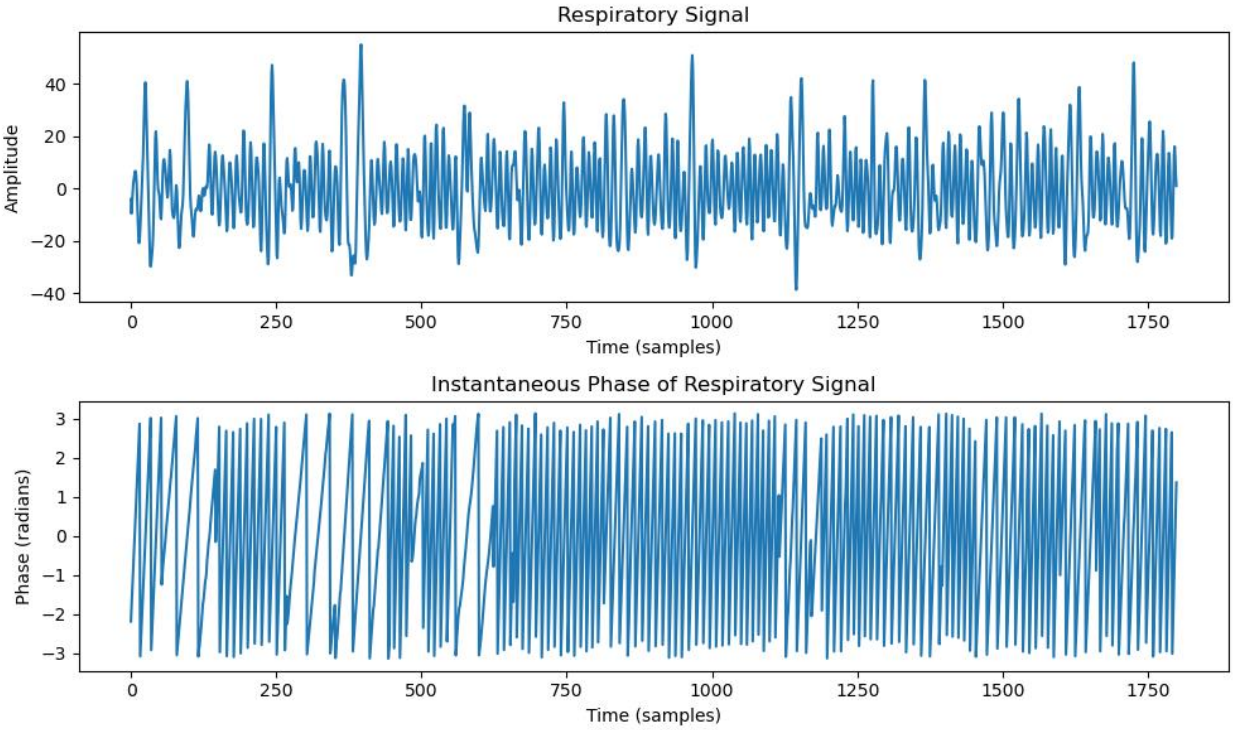
Participant thirteen, trial two:



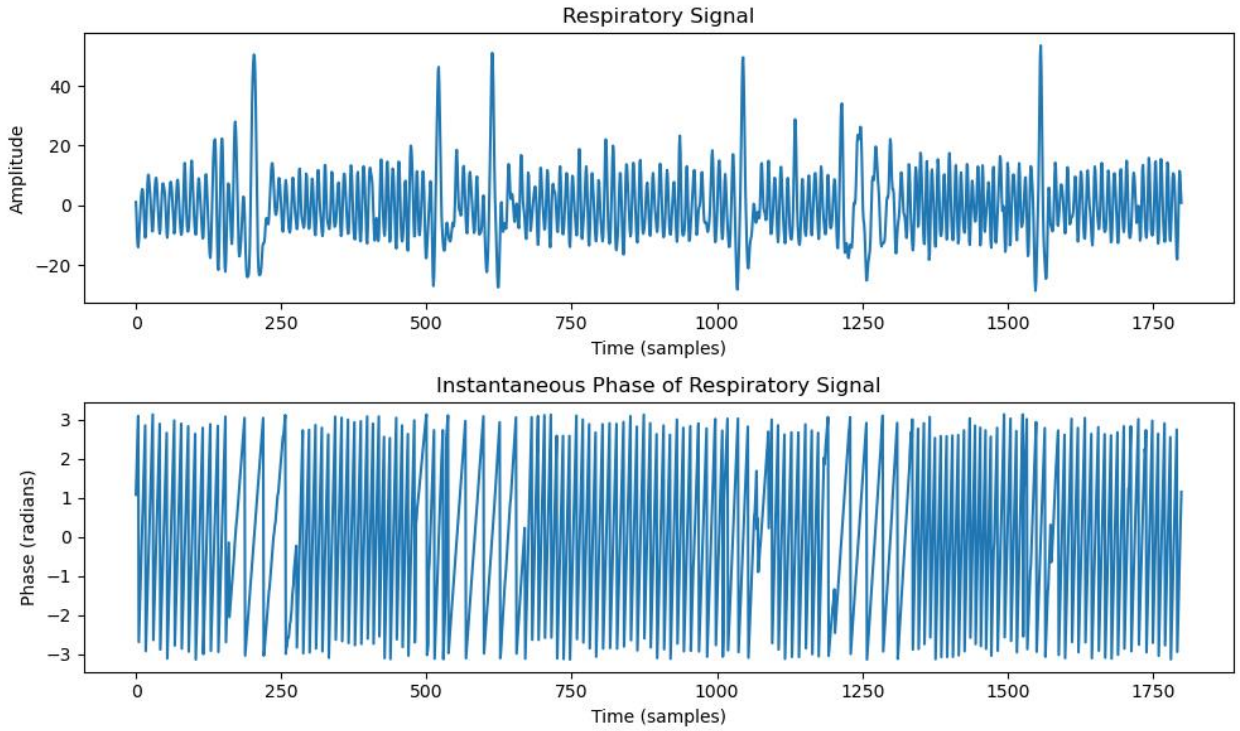
Participant thirteen, trial three:



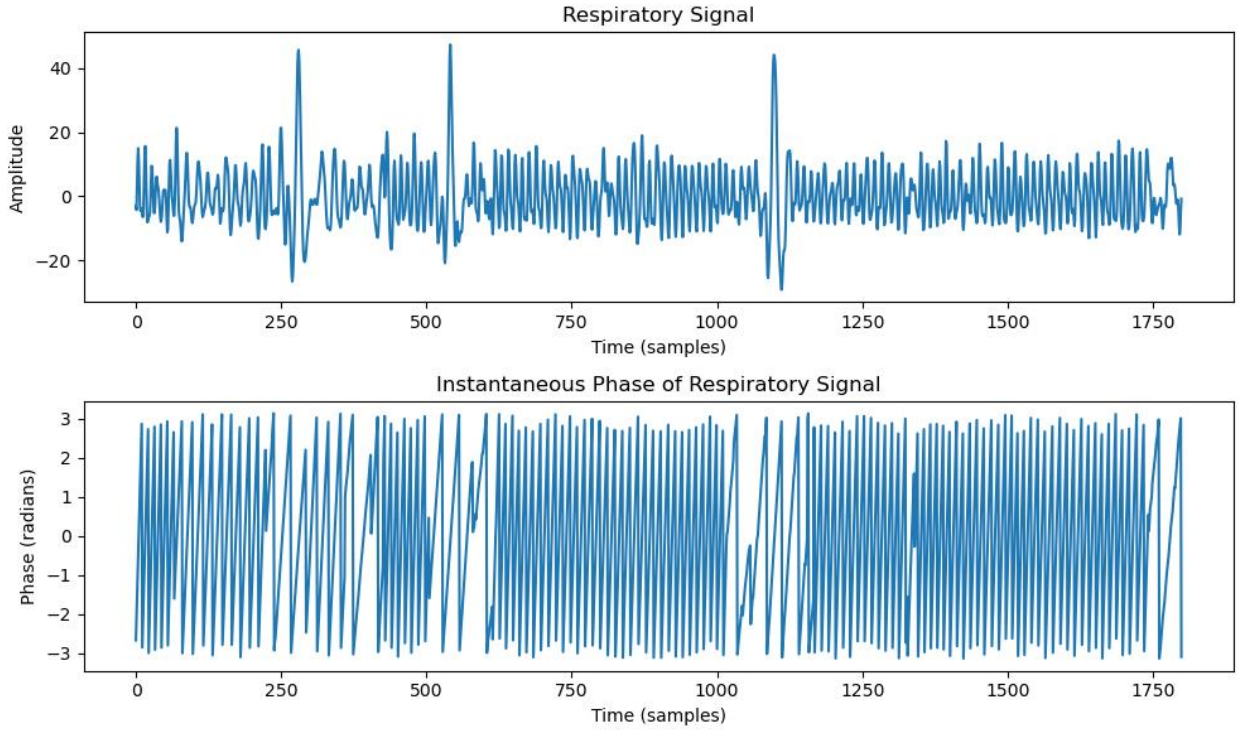
Participant thirteen, trial four:



Participant thirteen, trial five:

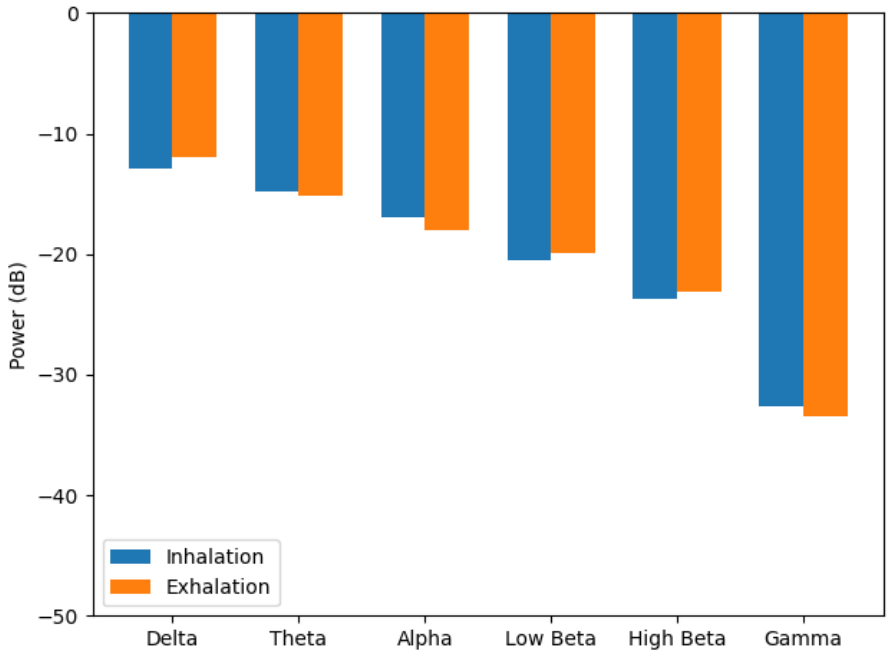


Participant thirteen, trial six:

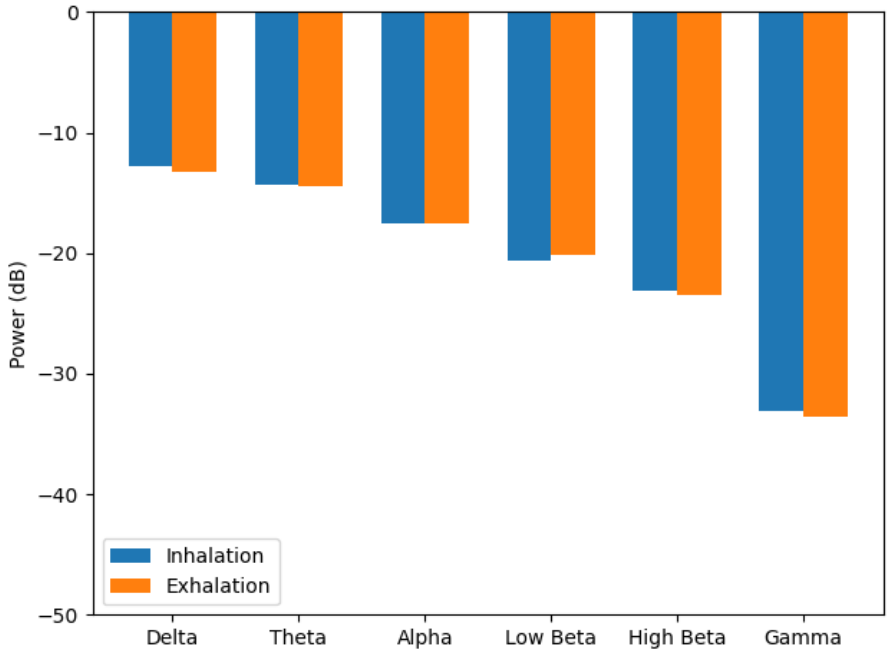


Section 6.4: Band power spectra for participants one (session one) and thirteen, per trial

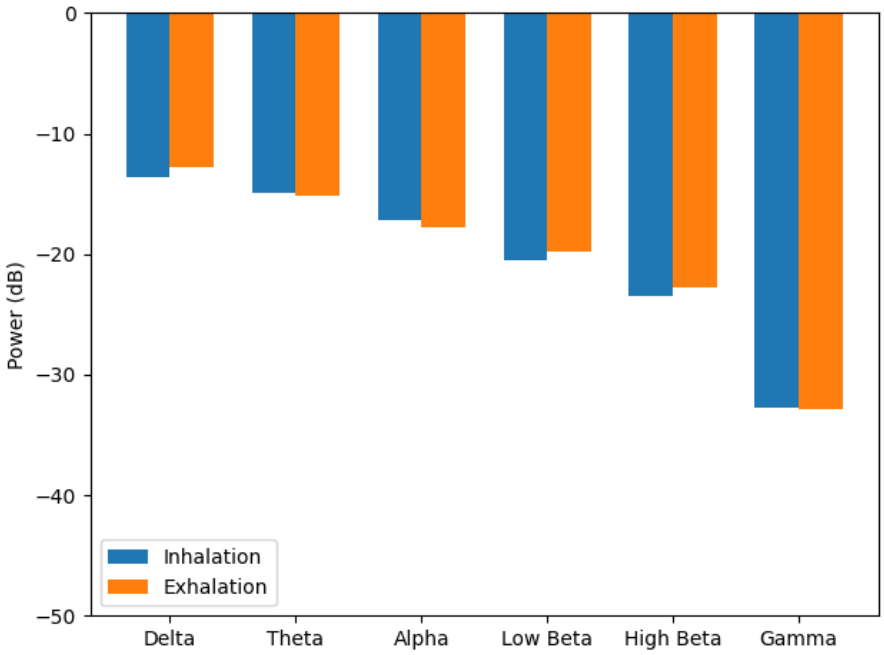
Participant one, session one, trial one:



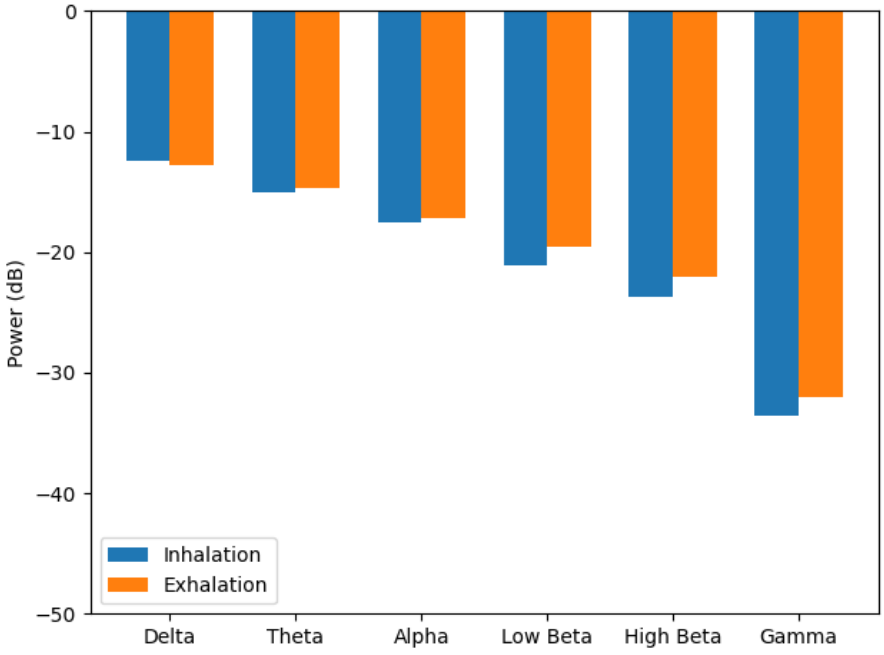
Participant one, session one, trial two:



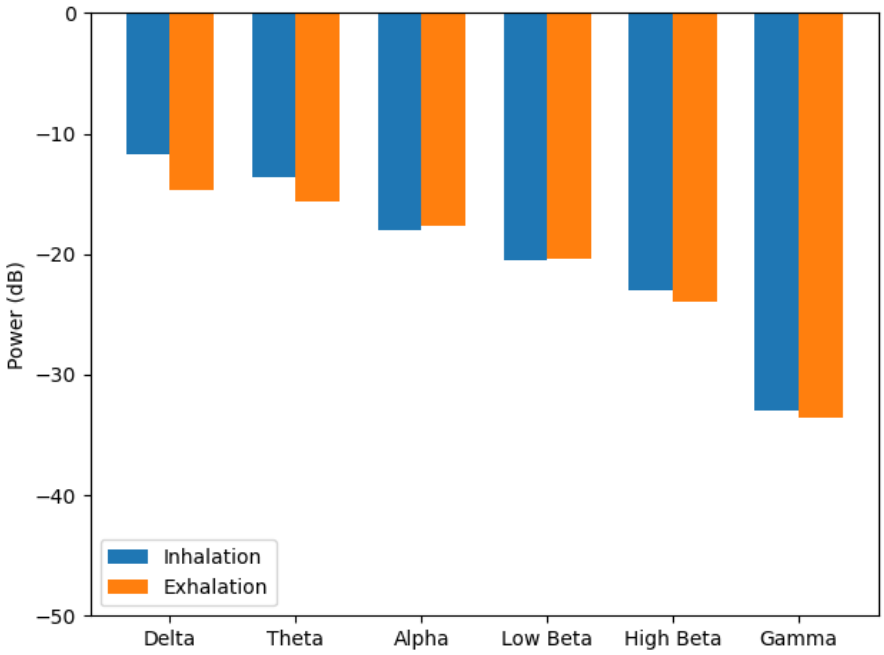
Participant one, session one, trial three:



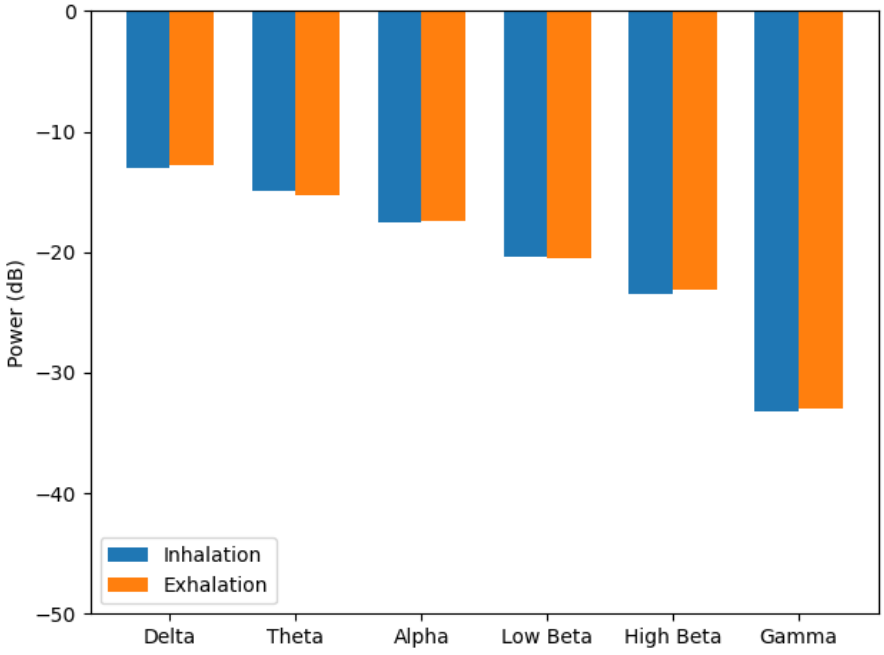
Participant one, session one, trial four:



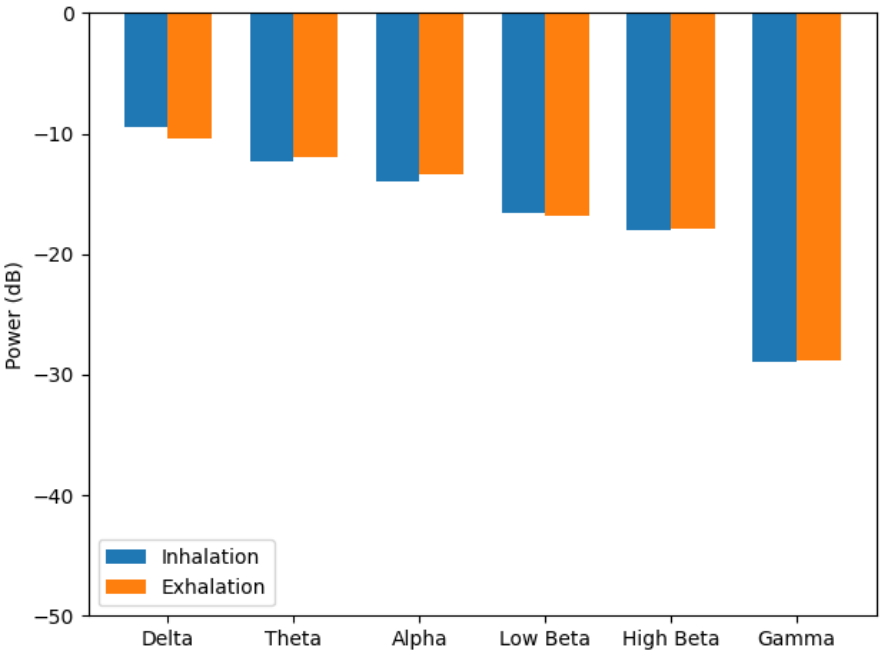
Participant one, session one, trial five:



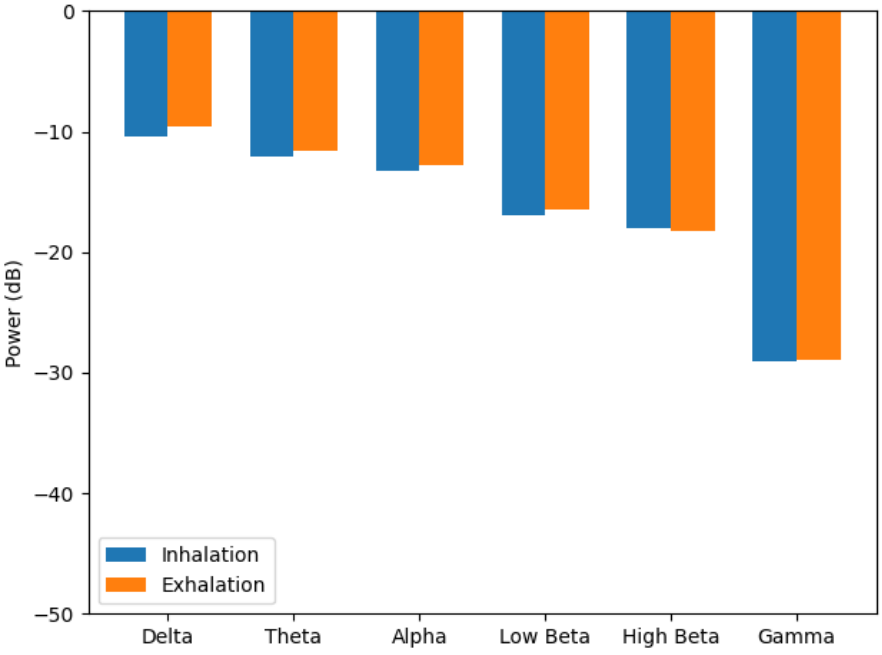
Participant one, session one, trial six:



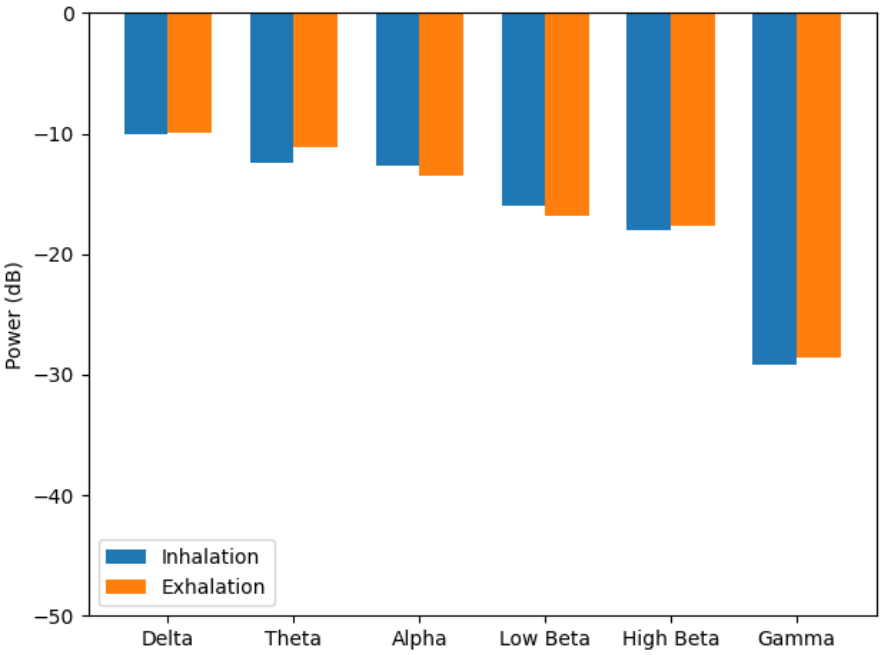
Participant thirteen, trial one:



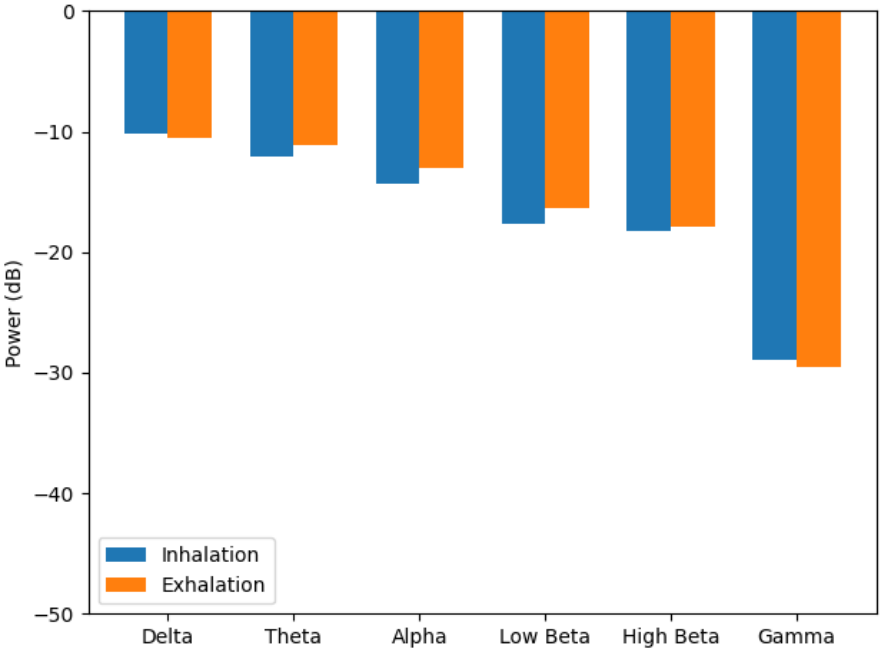
Participant thirteen, trial two:



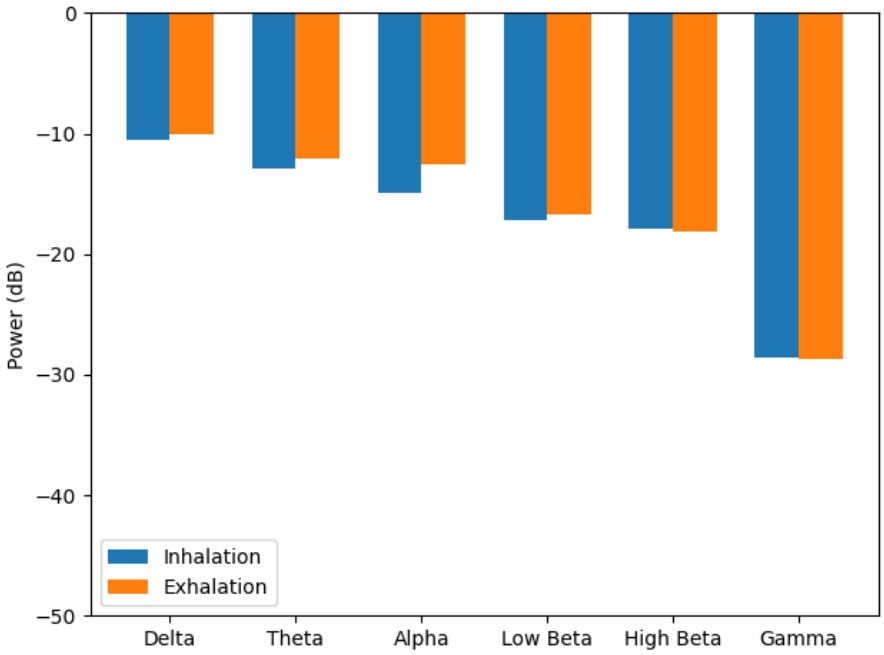
Participant thirteen, trial three:



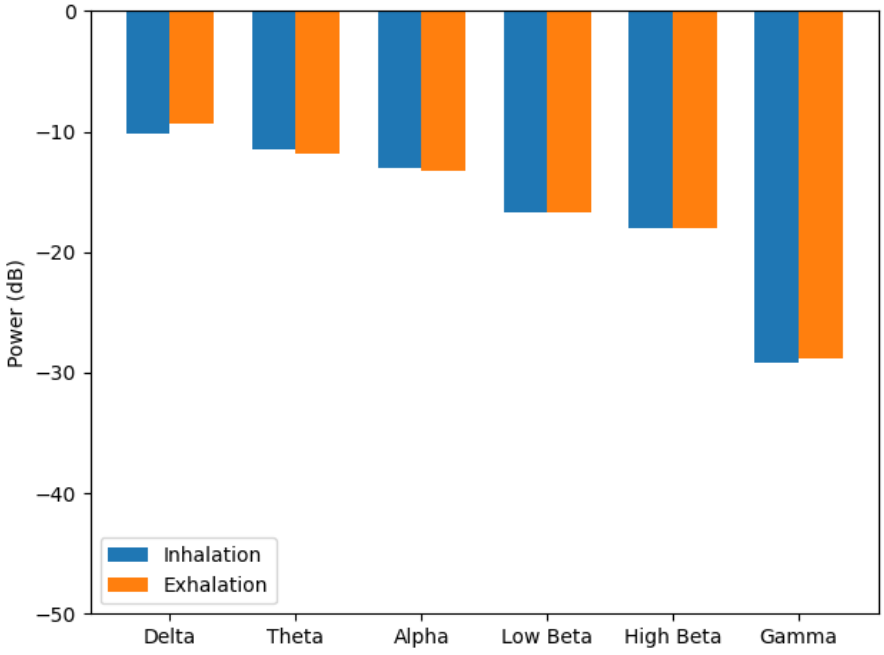
Participant thirteen, trial four:



Participant thirteen, trial five:



Participant thirteen, trial six:



Section 6.5: Band power means, per participant

Participant one, session one:

WS001 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.90562	-14.74591	-16.91098	-20.51633	-23.68722	-32.67243
3 degrees	-12.7461	-14.34318	-17.49971	-20.60013	-23.16466	-33.1401
6 degrees	-13.59673	-14.95663	-17.19466	-20.48178	-23.43761	-32.72891
0 degrees	-12.38969	-15.0516	-17.47215	-21.04133	-23.6994	-33.62112
3 degrees	-11.70436	-13.64939	-18.00884	-20.53359	-22.95403	-32.91935
6 degrees	-13.01598	-14.87874	-17.49852	-20.33276	-23.45371	-33.22057

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-11.89437	-15.10173	-17.95994	-19.9075	-23.12495	-33.45771
3 degrees	-13.27924	-14.49122	-17.52476	-20.17473	-23.51838	-33.59527
6 degrees	-12.77644	-15.14274	-17.78859	-19.77432	-22.7716	-32.85763
0 degrees	-12.78445	-14.68437	-17.2192	-19.52407	-22.04183	-31.98617
3 degrees	-14.65197	-15.60929	-17.62277	-20.39225	-23.97309	-33.52393
6 degrees	-12.75734	-15.22958	-17.42687	-20.47869	-23.11329	-33.01497

Participant one, session two:

WS001 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.81813	-16.28244	-19.13313	-20.49241	-22.17921	-32.4269
3 degrees	-16.26126	-16.4097	-19.22108	-20.63093	-22.7172	-32.18588
6 degrees	-15.54736	-15.66389	-19.17703	-20.79058	-23.10075	-32.36457
0 degrees	-16.00755	-16.51458	-18.6697	-20.40826	-23.09031	-32.68799
3 degrees	-15.5902	-15.92045	-17.6444	-19.95413	-23.14069	-32.03526
6 degrees	-14.39373	-16.05458	-19.00481	-20.20589	-22.69728	-32.62611

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.25803	-16.07672	-19.51284	-20.19405	-22.68136	-32.20987
3 degrees	-14.96494	-15.66929	-19.58916	-19.90713	-23.02512	-32.56039
6 degrees	-15.53365	-15.98498	-19.18309	-20.02404	-22.29027	-32.13631
0 degrees	-14.98566	-15.95683	-20.52674	-20.34555	-21.48405	-31.87755
3 degrees	-16.83862	-15.80643	-19.72249	-20.5654	-22.60067	-33.41748
6 degrees	-15.51844	-16.20255	-19.35532	-20.09292	-22.78009	-32.11924

Participant two:

WS002

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.32499	-16.24994	-20.02641	-20.18241	-22.37904	-35.64279
3 degrees	-13.19086	-16.68405	-19.91382	-19.77108	-22.50331	-35.55432
6 degrees	-13.83996	-16.52095	-20.49814	-19.89239	-22.1048	-35.80731
0 degrees	-12.45594	-16.60164	-20.49358	-19.50971	-23.24485	-35.34086
3 degrees	-12.68175	-17.04911	-19.46394	-19.43575	-22.29596	-35.52372
6 degrees	-13.28186	-15.94776	-19.83652	-19.9881	-22.83041	-35.73805

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.95437	-16.96993	-19.65784	-19.70918	-22.30959	-35.44033
3 degrees	-12.35837	-16.51639	-20.22068	-19.33254	-22.21481	-35.55907
6 degrees	-13.07076	-17.06124	-20.21478	-20.19461	-22.12894	-35.68288
0 degrees	-12.81456	-16.83712	-20.02099	-19.78018	-21.78298	-35.66945
3 degrees	-13.06368	-15.77682	-19.58645	-19.62057	-22.67993	-35.65986
6 degrees	-13.86005	-16.4954	-20.8285	-19.49313	-21.84687	-35.83181

Participant three, session one:

WS003 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.39702	-13.55783	-16.89906	-19.65974	-20.76439	-32.37936
3 degrees	-12.1713	-13.74211	-17.03436	-19.29234	-21.22887	-32.50841
6 degrees	-13.02541	-13.68663	-15.694	-19.25502	-21.45571	-32.2041
0 degrees	-11.52259	-13.1962	-17.50425	-18.8425	-21.45904	-32.24077
3 degrees	-11.26203	-14.13305	-16.77674	-19.45191	-21.46986	-32.4481
6 degrees	-13.46795	-13.7767	-15.92446	-18.97294	-20.32884	-32.4213

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.2987	-14.42005	-17.08623	-19.63808	-21.22882	-32.21891
3 degrees	-11.602	-13.75033	-16.81094	-19.44081	-21.21778	-32.4281
6 degrees	-11.66914	-13.77338	-17.53263	-19.63539	-20.69849	-32.19637
0 degrees	-11.68045	-14.35553	-16.56089	-19.25111	-21.18939	-32.12178
3 degrees	-11.42941	-14.61075	-16.82991	-19.99327	-20.8933	-32.14031
6 degrees	-12.29527	-14.34481	-16.78706	-19.53895	-20.73678	-32.0725

Participant three, session two:

WS003 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-14.92985	-18.20588	-22.70677	-24.07187	-26.22322	-37.37372
3 degrees	-15.55145	-18.07152	-21.97188	-23.64539	-25.8983	-37.26125
6 degrees	-14.66515	-18.70693	-21.62775	-24.06444	-26.21031	-37.04871
0 degrees	-15.20682	-18.8976	-21.95977	-23.3656	-25.93581	-37.45054
3 degrees	-15.21537	-17.92287	-22.02751	-23.72179	-26.00625	-37.55497
6 degrees	-15.102	-18.27878	-23.04957	-24.18437	-25.24846	-36.81089

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-14.7688	-18.39622	-22.1666	-23.8368	-25.7421	-37.50665
3 degrees	-14.37991	-18.97803	-21.89481	-23.92396	-26.13652	-37.65923
6 degrees	-15.58171	-18.52925	-22.7878	-23.66015	-25.48241	-37.53595
0 degrees	-14.19237	-17.87067	-22.02849	-23.85006	-25.64713	-37.31781
3 degrees	-14.66348	-17.86199	-21.41003	-23.82236	-25.73903	-37.32595
6 degrees	-15.40174	-17.79334	-22.39532	-23.7624	-25.77701	-37.6308

Participant four, session one:

WS004 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.92139	-17.79388	-19.44865	-23.04383	-24.74125	-35.65965
3 degrees	-16.4536	-17.67893	-19.53757	-22.88883	-24.96887	-35.51155
6 degrees	-17.00373	-17.8687	-19.47675	-22.87887	-24.88274	-35.55289
0 degrees	-16.72534	-17.19431	-19.15736	-22.65653	-24.91486	-36.03571
3 degrees	-16.64908	-17.84084	-19.9931	-22.86081	-24.81644	-36.14382
6 degrees	-17.90392	-17.3517	-19.508	-22.82384	-24.91018	-35.45769

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.7289	-17.85089	-19.54414	-22.637	-25.06754	-36.03091
3 degrees	-17.25498	-17.73197	-19.61037	-22.91929	-25.08785	-35.97887
6 degrees	-16.9886	-17.47737	-19.47614	-22.37412	-25.3796	-36.63921
0 degrees	-17.22702	-17.62458	-19.91865	-23.06827	-24.71652	-35.86095
3 degrees	-17.7514	-17.83796	-19.59531	-22.7831	-24.65317	-35.50824
6 degrees	-16.63958	-17.77906	-19.20561	-22.7411	-24.78705	-35.87458

Participant four, session two:

WS004 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-20.11225	-17.88171	-20.78477	-23.59948	-25.5634	-36.56508
3 degrees	-19.60323	-17.60787	-21.08002	-23.1441	-25.15426	-36.15268
6 degrees	-19.64208	-17.61889	-20.64583	-23.14952	-24.91945	-35.8731
0 degrees	-19.67314	-16.99698	-21.09928	-23.39643	-25.42801	-36.55444
3 degrees	-19.05218	-17.89982	-20.05333	-23.74019	-26.03523	-36.79113
6 degrees	-20.06794	-17.42959	-21.22182	-23.58824	-25.01551	-36.00913

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-19.3276	-18.21185	-20.37367	-23.49319	-25.58631	-36.53939
3 degrees	-20.22497	-18.14501	-21.01696	-23.53209	-25.69949	-36.84738
6 degrees	-20.22203	-17.25708	-21.20861	-23.76729	-26.33318	-37.41159
0 degrees	-20.28988	-18.23367	-20.71443	-23.621	-25.7235	-36.35994
3 degrees	-19.21096	-18.22058	-21.30245	-23.34182	-25.43791	-37.05997
6 degrees	-19.76576	-17.86441	-20.83628	-23.69633	-25.95708	-36.97724

Participant five, session one:

WS005 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-9.875713	-11.73499	-16.2084	-18.9742	21.02099	-34.02478
3 degrees	-9.841653	-12.25085	-16.28174	-19.35786	-21.15575	-34.24942
6 degrees	-9.88279	-11.76359	-16.80952	-19.40954	-21.2263	-33.60613
0 degrees	-10.5249	-11.78948	-16.57046	-19.43365	-21.27753	-33.6797
3 degrees	-9.760796	-11.93128	-16.65879	-19.23704	-21.4325	-34.05261
6 degrees	-10.23264	-11.82263	-16.80725	-19.13459	-21.24976	-34.10658

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-10.18753	-11.97756	-16.61678	-19.07306	-21.1277	-33.6947
3 degrees	-9.724545	-11.69948	-17.09938	-18.48444	-20.93006	-33.73245
6 degrees	-10.05475	-11.90858	-16.54748	-18.94967	-21.16744	-34.26144
0 degrees	-9.823614	-11.93496	-16.62032	-18.90782	-21.0516	-33.8524
3 degrees	-10.55237	-11.77103	-16.52268	-18.65417	-21.08036	-34.05888
6 degrees	-10.49326	-11.82733	-17.07091	-19.41409	-21.18569	-34.1578

Participant five, session two:

WS005 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.48347	-12.3365	18.68877	21.64496	24.08447	35.86612
3 degrees	-11.70895	12.48339	-18.5392	22.22802	24.22459	35.49804
6 degrees	-12.38306	12.55677	18.76816	21.24319	23.79872	35.31258
0 degrees	-11.94154	-12.257	18.78511	21.81888	24.17928	35.46256
3 degrees	-12.12514	12.64514	19.39502	21.72414	24.20913	36.07943
6 degrees	-12.1832	12.38806	-18.331	21.13536	23.82403	35.40082

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-11.84616	-12.82283	18.13481	21.30435	23.85818	34.89683
3 degrees	-12.58431	12.50929	18.47575	20.72909	23.53495	34.84185
6 degrees	-12.03179	-12.8465	18.60846	21.96299	24.03635	-35.0145
0 degrees	-12.29463	12.71152	18.23859	20.98332	23.53322	34.96778
3 degrees	-11.78546	12.64228	17.68161	21.36301	23.80135	35.16812
6 degrees	-12.42526	12.92902	19.11957	21.37854	-24.1499	35.98756

Participant seven, session one:

WS007 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-7.240785	-10.15567	-14.09538	-14.98808	-16.32223	-32.57544
3 degrees	-7.205763	-10.20086	-14.82417	-15.11647	-16.49147	-32.62954
6 degrees	-6.941132	-9.911592	-14.39629	-14.70934	-15.91674	-32.81685
0 degrees	-7.200423	-10.102	-14.08127	-14.85625	-15.69023	-32.84296
3 degrees	-7.0858	-9.677894	-15.09088	-14.81431	-15.29246	-32.90576
6 degrees	-7.206025	-9.720115	-14.49634	-14.83414	-16.29425	-32.79237

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-7.462662	-9.711307	-14.04394	-14.55997	-15.96442	-32.80268
3 degrees	-7.209775	-9.514509	-13.81787	-14.66637	-15.75818	-32.79759
6 degrees	-7.302865	-10.10495	-13.72358	-15.14276	-16.02527	-32.94783
0 degrees	-7.396519	-9.695397	-14.91561	-15.13528	-16.53787	-32.78487
3 degrees	-7.543922	-9.187044	-13.22192	-14.74697	-16.50105	-32.79651
6 degrees	-7.534323	-10.40941	-13.71528	-14.91453	-16.05677	-32.69733

Participant seven, session two:

WS007 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.57147	-15.65396	-16.88973	-17.80967	-18.72657	-36.18466
3 degrees	-12.53171	-15.84015	-16.38444	-18.14478	-19.20201	-36.1438
6 degrees	-12.55006	-16.05471	-16.41032	-17.91124	-19.10851	-36.34754
0 degrees	-12.3008	-15.55414	-16.48909	-17.86467	-18.85914	-36.47271
3 degrees	-12.40683	-15.60584	-16.35654	-17.30074	-18.68802	-36.31851
6 degrees	-12.68734	-15.79844	-16.67485	-17.77586	-18.98274	-36.29551

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.59947	-15.87169	-16.4797	-18.10962	-19.23515	-36.30058
3 degrees	-12.25791	-15.75681	-16.73157	-17.82908	-19.16154	-36.27575
6 degrees	-12.78923	-15.54217	-16.80122	-18.0599	-19.16974	-36.36694
0 degrees	-13.05041	-15.53281	-16.89252	-18.34042	-19.05939	-36.1618
3 degrees	-13.30826	-16.18192	-17.74538	-18.57465	-18.85166	-36.61751
6 degrees	-12.94156	-15.22387	-16.48772	-17.66327	-19.23166	-36.15661

Participant seven, session three:

WS007 (3)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.28517	-13.22564	-17.39309	-17.19	-19.51076	-36.5617
3 degrees	-12.93989	-13.09963	-18.16099	-16.57728	-19.79814	-36.53154
6 degrees	-12.36327	-13.30194	-18.4679	-16.86658	-19.54918	-36.43072
0 degrees	-12.3445	-13.61943	-18.93382	-17.09053	-19.52873	-36.61171
3 degrees	-12.37554	-14.18884	-18.83208	-17.06192	-19.77006	-36.30124
6 degrees	-12.66801	-13.54114	-18.40806	-16.42375	-19.58154	-36.58134

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.49326	-14.07865	-19.71351	-17.407	-19.38111	-36.9022
3 degrees	-12.50804	-13.73372	-18.85337	-17.68705	-19.07349	-36.55508
6 degrees	-12.8509	-13.86925	-18.90079	-17.46209	-19.52187	-36.62379
0 degrees	-11.79186	-13.40884	-18.84598	-16.914	-19.48188	-36.52676
3 degrees	-12.81604	-14.09809	-19.22712	-18.08471	-19.01842	-36.88266
6 degrees	-12.67481	-13.49055	-18.77565	-17.74895	-19.49588	-36.90517

Participant nine, session one:

WS009 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-11.25478	-13.2417	-17.48113	-19.80553	-23.89993	-36.36066
3 degrees	-10.90348	-12.96029	-17.32939	-19.5934	-23.99867	-36.44972
6 degrees	-9.54885	-12.77044	-16.80767	-19.20722	-24.01168	-36.25918
0 degrees	-11.25264	-12.5052	-17.74331	-19.74664	-24.09211	-36.34412
3 degrees	-10.51741	-13.18512	-17.00463	-20.05035	-24.16879	-36.14384
6 degrees	-11.03606	-12.8325	-17.01026	-19.26298	-23.45463	-36.76563

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-11.54862	-12.71781	-17.40717	-19.54852	-23.79555	-36.38232
3 degrees	-11.6123	-13.01222	-17.61389	-20.09007	-23.82878	-36.57493
6 degrees	-11.11595	-13.0797	-18.04745	-20.58511	-23.59338	-36.26558
0 degrees	-11.43593	-13.01965	-17.82473	-19.8033	-23.98701	-36.47589
3 degrees	-11.08162	-12.9961	-17.34563	-19.82701	-23.56851	-36.21307
6 degrees	-11.52679	-13.20152	-16.74753	-19.94461	-23.22619	-36.07508

Participant nine, session two:

WS009 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-22.65987	-25.85432	-26.89333	-27.52934	-29.09566	-39.72257
3 degrees	-22.25816	-25.80231	-27.13759	-27.42644	-29.01749	-39.80772
6 degrees	-21.80886	-25.58899	-27.55646	-27.64423	-29.29223	-39.89811
0 degrees	-22.05253	-26.48608	-25.93356	-27.47754	-28.91859	-39.76036
3 degrees	-22.87979	-25.22226	-26.79551	-27.49913	-28.89146	-39.74337
6 degrees	-21.46586	-24.95236	-26.44807	-27.42456	-28.60369	-39.17275

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-21.22096	-26.217	-26.68761	-27.9553	-29.08122	-39.54332
3 degrees	-22.34083	-26.10298	-25.85188	-27.76691	-28.83534	-39.77708
6 degrees	-22.7126	-25.98396	-26.65967	-27.82083	-28.99856	-39.5761
0 degrees	-22.41509	-25.84481	-26.40452	-27.59068	-29.11091	-39.72635
3 degrees	-21.50606	-25.95224	-26.9848	-27.41187	-29.1347	-40.09805
6 degrees	-23.39547	-26.34352	-26.18547	-27.65095	-28.4244	-39.57255

Participant ten, session one:

WS010 (1)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.02425	-13.00915	-15.52275	-19.37827	-23.31932	-35.58893
3 degrees	-12.736	-12.69632	-14.8311	-19.08424	-23.21496	-35.81634
6 degrees	-13.36599	-12.49827	-15.24288	-19.57805	-23.61362	-35.61146
0 degrees	-13.63596	-13.78549	-15.59131	-19.38545	-23.77517	-35.50351
3 degrees	-12.734	-13.34899	-15.32282	-19.04314	-23.4526	-35.40978
6 degrees	-13.368	-13.29859	-15.48089	-19.05813	-23.4342	-35.43926

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.56696	-13.18305	-15.69049	-19.43608	-23.36972	-35.76686
3 degrees	-13.05164	-13.27633	-15.39619	-18.95632	-23.43891	-35.37349
6 degrees	-13.35742	-13.35049	-15.52582	-18.89414	-23.42729	-35.5025
0 degrees	-12.21181	-13.16381	-15.03714	-18.55484	-22.84811	-35.61803
3 degrees	-13.3787	-13.0171	-15.23804	-19.01195	-23.39641	-35.85571
6 degrees	-13.54597	-12.89517	-15.26895	-19.1079	-23.25948	-35.59575

Participant ten, session two:

WS010 (2)

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.97576	-14.89709	-18.91305	-22.8258	-25.79066	-39.64335
3 degrees	-16.14581	-14.10629	-18.69354	-22.24664	-25.83154	-39.6442
6 degrees	-16.31652	-14.37329	-18.65358	-22.52345	-26.0762	-39.59465
0 degrees	-16.4197	-14.13004	-18.52446	-22.4275	-25.97352	-39.6411
3 degrees	-16.5525	-14.72738	-18.27095	-22.40442	-26.13526	-39.65841
6 degrees	-16.03979	-13.96988	-17.75431	-22.56626	-25.92282	-39.73085

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.16732	-14.11167	-18.60223	-22.54798	-26.14596	-39.80579
3 degrees	-17.04278	-14.40557	-18.0701	-22.35964	-26.51057	-39.86455
6 degrees	-17.51613	-14.06128	-17.87946	-22.60848	-26.59887	-40.25446
0 degrees	-16.70852	-14.79957	-18.05677	-22.20383	-26.05611	-39.83015
3 degrees	-15.98765	-14.3203	-18.18341	-22.53314	-26.04719	-40.39203
6 degrees	-16.8814	-14.64484	-18.43333	-22.51898	-26.45773	-40.08918

Participant eleven:

WS011

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.58582	-13.92081	-15.71407	-15.92721	-21.21786	-31.86661
3 degrees	-14.69088	-14.48075	-15.51949	-15.8883	-21.51798	-32.78011
6 degrees	-14.24534	-13.50081	-15.89475	-16.33144	-21.50865	-32.75773
0 degrees	-13.73877	-13.91926	-15.51723	-16.00492	-21.25179	-32.90223
3 degrees	-12.48734	-13.53506	-15.10404	-15.82931	-21.97782	-33.48811
6 degrees	-13.82171	-13.87902	-15.74835	-16.39534	-21.56631	-32.3814

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.84694	-12.84414	-16.19661	-16.09333	-21.65401	-31.86323
3 degrees	-14.20542	-13.43555	-15.19262	-16.08876	-21.21599	-32.96546
6 degrees	-13.51275	-14.04688	-15.56545	-15.73702	-21.39676	-32.7418
0 degrees	-13.99712	-13.80635	-15.67649	-15.87158	-21.58092	-32.92893
3 degrees	-15.33971	-13.78582	-15.75867	-16.00733	-21.14296	-32.65491
6 degrees	-14.80799	-13.38375	-15.27808	-15.89734	-21.35916	-33.144

Participant twelve:

WS012

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.0946	-17.35481	-22.00932	-24.8307	-27.65615	-38.94877
3 degrees	-15.4516	-17.29729	-20.64459	-24.60737	-27.51807	-38.79167
6 degrees	-15.68279	-16.40592	-20.50994	-24.46453	-27.59779	-39.03456
0 degrees	-15.61472	-16.60377	-20.05166	-24.88952	-28.01366	-39.47836
3 degrees	-15.70215	-16.69201	-20.34153	-24.56606	-27.83876	-39.01193
6 degrees	-15.4105	-16.18855	-19.82646	-24.79479	-27.62771	-38.92997

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-14.78865	-16.87149	-20.43407	-24.47364	-27.7987	-39.17466
3 degrees	-15.66527	-16.46477	-20.78748	-24.90154	-27.76122	-39.30111
6 degrees	-15.24795	-16.94804	-20.67411	-24.71709	-27.63927	-38.99441
0 degrees	-15.27596	-16.44281	-21.1313	-24.66154	-27.41416	-38.94721
3 degrees	-16.19513	-17.37452	-21.24049	-24.87444	-27.56817	-39.17894
6 degrees	-16.05824	-16.52375	-21.07129	-24.99207	-27.57747	-39.18448

Participant thirteen:

WS013

INHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-9.399694	-12.24074	-13.95101	-16.63009	-18.0617	-28.9628
3 degrees	-10.35844	-12.0506	-13.25424	-16.93188	-18.02203	-29.04236
6 degrees	-10.0797	-12.42561	-12.70724	-15.97014	-17.96935	-29.13679
0 degrees	-10.13282	-12.10343	-14.3653	-17.69587	-18.26429	-28.90355
3 degrees	-10.53054	-12.87455	-14.8986	-17.12789	-17.85532	-28.62801
6 degrees	-10.13611	-11.46806	-13.0227	-16.67413	-17.99404	-29.15639

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-10.3547	-11.9039	-13.34512	-16.78864	-17.88478	-28.85072
3 degrees	-9.582077	-11.5868	-12.81229	-16.47737	-18.20164	-28.96447
6 degrees	-9.876451	-11.14797	-13.45692	-16.75852	-17.69944	-28.62857
0 degrees	-10.4722	-11.13951	-13.05304	-16.33468	-17.83981	-29.56212
3 degrees	-10.06067	-12.09232	-12.59564	-16.65492	-18.13163	-28.73199
6 degrees	-9.372416	-11.83003	-13.30502	-16.68701	-18.00738	-28.82525

Participant fourteen, session one:

WS014 (1)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.46501	-15.63692	-17.73471	-19.94294	-22.47175	-33.99282
3 degrees	-13.38614	-15.80173	-18.36773	-20.09919	-22.52209	-33.92926
6 degrees	-13.22295	-16.44166	-17.6753	-19.8952	-22.442	-33.8758
0 degrees	-13.35194	-16.12458	-17.8638	-20.11892	-22.28595	-34.15472
3 degrees	-13.6086	-16.12421	-18.13782	-20.24959	-22.67514	-34.05757
6 degrees	-13.29972	-15.94601	-17.93146	-20.11972	-22.37542	-34.06377

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-13.50752	-16.22684	-18.0495	-19.94805	-22.38856	-33.8206
3 degrees	-13.31931	-15.97526	-17.99142	-19.93431	-22.46458	-34.0299
6 degrees	-13.7226	-16.0406	-17.57327	-19.94821	-22.56655	-34.09066
0 degrees	-13.55196	-16.24403	-17.42555	-19.71326	-22.75535	-33.9597
3 degrees	-13.70227	-15.99131	-18.04202	-20.13068	-22.32155	-33.92938
6 degrees	-13.40234	-15.91271	-17.85795	-19.77211	-22.72591	-33.79506

Participant fourteen, session two:

WS014 (2)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.42641	-15.6291	-20.06964	-20.28254	-21.28464	-35.0159
3 degrees	-16.09412	-16.06092	-20.30403	-20.17263	-21.53577	-35.08171
6 degrees	-15.98442	-16.15669	-20.11655	-20.36506	-21.498	-35.04081
0 degrees	-15.20653	-15.60107	-20.40024	-20.44113	-21.62829	-35.0846
3 degrees	-15.47115	-16.00271	-20.28941	-20.34612	-21.52903	-35.24168
6 degrees	-15.33632	-16.30277	-20.22311	-20.55061	-21.55174	-35.23558

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.34477	-16.01631	-20.26531	-20.20789	-21.42718	-35.2212
3 degrees	-15.23532	-15.21419	-20.16373	-20.34475	-21.77747	-34.99585
6 degrees	-15.76875	-15.7931	-20.09505	-20.27043	-21.13967	-35.26958
0 degrees	-15.26478	-16.12064	-19.81545	-20.31245	-21.51993	-35.27309
3 degrees	-16.14097	-15.84991	-19.80948	-20.40422	-21.51669	-35.18026
6 degrees	-15.90673	-15.90319	-19.957	-20.08495	-21.5601	-35.33137

Participant fourteen, session three:

WS014 (3)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.33012	-16.60477	-20.80139	-20.17498	-22.32098	-34.53799
3 degrees	-15.09076	-16.86275	-20.56799	-19.83053	-22.57021	-34.4213
6 degrees	-15.40758	-16.85392	-21.57336	-19.80617	-22.74924	-34.43464
0 degrees	-15.20628	-17.01718	-20.22016	-20.25389	-22.48562	-34.44282
3 degrees	-15.12426	-16.48408	-20.2974	-20.14028	-22.52699	-34.58775
6 degrees	-15.03587	-16.81914	-20.15905	-20.12296	-22.87231	-34.48454

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-15.1794	-16.97669	-20.38243	-20.14412	-22.65352	-34.52991
3 degrees	-15.2225	-16.74537	-20.47564	-20.00624	-22.8558	-34.55819
6 degrees	-14.60025	-16.6236	-20.17946	-20.26628	-22.63531	-34.74632
0 degrees	-14.90872	-16.53956	-20.651	-19.9585	-22.49709	-34.49056
3 degrees	-14.66841	-16.74997	-20.23016	-19.63721	-22.73407	-34.68919
6 degrees	-15.23875	-16.79579	-20.22735	-20.10217	-22.49991	-34.76049

Participant fifteen, session one:

WS015 (1)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-9.903847	-12.70297	-15.14251	-18.64856	-20.04001	-31.8228
3 degrees	-9.865841	-12.55454	-14.98795	-17.99281	-20.16881	-32.10754
6 degrees	-11.35198	-12.35704	-15.33428	-17.86143	-20.38596	-32.06707
0 degrees	-10.4775	-13.02352	-15.56154	-18.43823	-20.67745	-32.91726
3 degrees	-10.23432	-12.60227	-15.53289	-18.09526	-20.36645	-32.71195
6 degrees	-10.37174	-13.03707	-15.07599	-18.88391	-19.95553	-31.33984

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-10.06381	-13.86619	-15.89041	-18.83962	-20.17299	-32.57855
3 degrees	-9.960649	-13.11349	-15.20603	-18.36289	-19.7579	-32.53907
6 degrees	-10.21541	-13.09271	-15.26443	-19.33697	-19.96839	-32.48185
0 degrees	-10.18032	-12.35546	-15.08378	-18.68296	-20.34034	-32.71724
3 degrees	-10.64343	-12.98722	-15.40631	-18.51839	-19.74863	-32.27084
6 degrees	-9.175401	-12.75091	-14.77251	-17.65963	-20.15876	-33.42562

Participant fifteen, session two:

WS015 (2)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.80005	-14.91586	-19.94764	-21.18033	-24.38309	-35.56166
3 degrees	-13.1467	-15.21251	-19.97541	-21.29799	-24.47651	-35.5398
6 degrees	-12.66981	-14.72265	-19.40957	-20.52418	-24.72663	-35.65855
0 degrees	-12.68561	-15.35735	-20.56585	-21.51659	-24.8115	-36.10301
3 degrees	-12.40128	-15.67378	-19.76822	-21.35279	-24.72255	-35.86097
6 degrees	-11.92187	-15.14862	-20.32691	-21.0903	-24.73762	-35.16505

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-12.85358	-14.75099	-20.29207	-21.21632	-24.80423	-35.72311
3 degrees	-12.18927	-14.34578	-20.52599	-21.13465	-24.55141	-35.84867
6 degrees	-11.39814	-15.3129	-20.50646	-21.2253	-24.91793	-35.80773
0 degrees	-12.27989	-14.42956	-19.6932	-21.39063	-24.96564	-36.22448
3 degrees	-13.11507	-14.6847	-20.18619	-21.62999	-24.74067	-35.47979
6 degrees	-12.36632	-13.61826	-20.33012	-21.79214	-25.0307	-36.34425

Participant fifteen, session three:

WS015 (3)

INHALATION 1

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.31077	-21.23595	-25.11554	-27.81616	-29.62952	-40.54876
3 degrees	-17.31634	-21.30089	-24.99497	-28.0581	-29.92581	-40.79429
6 degrees	-18.18309	-21.47722	-24.68478	-27.56815	-29.8375	-40.36211
0 degrees	-17.26013	-21.86488	-25.0338	-28.15081	-30.16	-41.29993
3 degrees	-16.89884	-20.97092	-25.54531	-28.34502	-30.2103	-41.13494
6 degrees	-17.8936	-21.36711	-25.66944	-27.88711	-29.53849	-40.08881

EXHALATION

	Delta	Theta	Alpha	Low Beta	High Beta	Gamma
0 degrees	-16.70152	-21.74174	-24.52365	-28.237	-30.13893	-41.0718
3 degrees	-16.88208	-20.78786	-25.65638	-28.02069	-30.08631	-41.40717
6 degrees	-16.87415	-20.86248	-24.83958	-27.97255	-29.77001	-41.19449
0 degrees	-16.99187	-21.41165	-25.11225	-27.42186	-30.14902	-41.11369
3 degrees	-17.0449	-20.58441	-25.00913	-28.18204	-29.60113	-40.80034
6 degrees	-16.10641	-20.46007	-24.9233	-27.59757	-30.29077	-42.00865

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