Physiological Responses to Emotionally Charged Auditory Stimuli

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Key Terms: Auditory Stimulus, ElectroDermal Activity (EDA), Empathy, Heart Rate, Mirror Neurons, Pulse, Respiration, Sound, Yawn

Word Count: 4,000

Abstract:

Yawning in response to observing another's yawn is a natural reflex that is rarely contemplated, but recognized in this study as a consequence of mirror neurons firing and as a quantified indicator of human empathy. Mirror neurons in the premotor cortex appear to assist humans in relating to the actions of others by creating neural stimulation reflective of the actions observed or heard. Here, we explored whether this response can be evoked from auditory yawn stimuli alone and the possibility of predicting a participant yawn on the basis of deviation from physiological homeostasis during exposure to emotionally charged auditory stimuli. Thirty-one participants listened to a series of one minute neutral and emotionally evocative sound clips while respiratory rate, pulse, and EDA skin conductance were measured. It was hypothesized that if presented with an emotionally charged auditory stimuli, that a deviation from physiological homeostasis, which can be used as a proxy for empathetic response, could be measured. The term "emotionally charged" with regard to auditory stimuli is to express that the sounds presented are likely to cause a change in mental state from resting silence or wind, whether that be joy or stress. A T-test with a 95% confidence interval was used to compare the deviation from baseline for each auditory stimulus for each of the three physiological tests where $p<0.05$ is significant. The respiratory data did not show significance at any of the time points when compared to the baseline measurements. Still, the baby laughing and baby crying audio seemed to increase overall respiratory rate indicating that the auditory stimuli had some effect. The heart rate and EDA data also failed to show significance when compared to the homeostatic baseline measurements. However, in many participants, peaks in EDA were observed during the yawn, signifying a physiological response. Because of the lack of significance in the three physiological tests, the null hypothesis cannot be rejected. Although statistically insignificant, this research can be utilized to improve future studies surrounding the relationship between auditory stimuli and mirror neuron activation, as well as general methods of physiological data collection.

Introduction

According to *Alford et al.*, empathy, the ability to understand and share the feelings of another, is a characteristic imperative to success in many careers as well as in life. The concept of empathy has been studied to great extent in the fields of psychology and neuroscience with the discovery of mirror neuron evidence (Pitts-Taylor. 2013). Mirror neurons in the premotor cortex appear to assist humans in relating to the actions of others by creating neural simulation of the actions observed (Alford et al. 2014). In a sense, the observed actions of others are understood and limited by one's ability to perform said action. The presence of mirror neurons can be used as evidence that human brains are highly social (Pitts-Taylor. 2013). In addition, mirror neurons do not just simulate a particular action; they help to recognize the intention behind the action, which gives a person a deeper and more meaningful understanding of what they have observed (Alford et al. 2014).

A primary example of the effect of mirror neurons can be seen when one person yawns in response to someone else's yawn (Cooper et al. 2012). This psychological response is only seen in a few species other than humans, such as non-human primates, wolves, and dogs (Massen et al. 2015). Contagious yawning is indirectly related to empathy both behaviorally and neurologically; as a result, yawning is believed to be an evolutionary action that helps humans bond to one-another unconsciously (Arnott 2009). A majority of people will exhibit this mirroring tendency, though there are factors that influence the probability of a mirrored yawn response. One factor is being afflicted with autism, which affects the ability to empathize and may decrease the probability of a mirrored yawn; the overall mental and emotional state of the observer and their relationship with the person yawning also impacts their tendency to yawn (Cooper et al. 2012).

While there are studies that explore the response to seeing someone else yawn, there is very little published research available on human responses to the auditory aspect of a yawn. Auditory stimuli can be just as effective at provoking contagious yawning as visual stimuli (Evans et al. 2016). However, both gender and the social relationship between the trigger and person responding have an effect on the rates of yawn response (Norscia et al. 2016). The effectiveness of auditory stimuli was also shown in a study conducted by *Lang et al.* which related hearing sounds of pain and the presence of neural activity to empathy. Areas of the brain that are involved with feeling empathy for pain were activated, without actually feeling physical pain.

Although there is much evidence to believe that mirror neurons exist, the scientific community has not yet explicitly detected them using neuroimaging. This seemingly magical connection between two humans can, however, be quantified via physiological response. The three physiological measurements used in this study are heart rate, respiratory rate, and skin conductance. A study conducted in 2016 by *Chuen et al.* studied psychophysiological responses to auditory change, and found increased heart rate, respiratory rate, and skin conductance in response to high tempo music. Additionally, a study published on the Journal of Advanced Student Science and conducted by *Evans et al.*, showed listening to disturbing auditory stimuli increased heart rate and had some effect on respiratory rate in study participants. Knowing that these three physiological factors had potential to deviate from baseline, a variety of auditory stimuli were chosen to evoke varying effects on homeostasis in this study.

Although crying and laughing are not considered to be human language, these sounds have the potential to evoke significant physiological response because of their important role in human response and bonding (Lang et al. 2011). Using auditory stimuli such as a baby crying, a baby laughing and wind as controls, deviations from baseline can be measured. The positive control stimuli included a baby laughing and a baby crying. Both were expected to elicit a response that differed from baseline. The negative control stimulus, the sound of wind, was not expected to elicit a physiological deviance from baseline. These positive and negative controls allowed for the comparison of physiological responses to differing stimuli to baseline. Furthermore, they may enable a quantitative way to summarize mirror neuron behavior and the potential to measure empathetic response.

It is hypothesized that if presented with an emotionally charged auditory stimuli, there will be a deviation from physiological homeostasis which can be used as a proxy for empathetic response. The term "emotionally charged" with regard to auditory stimuli is to express that the sounds presented are likely to cause a change in mental state from resting silence or wind, whether that be joy or stress. In addition, the tendency to yawn in response to a simulated auditory yawn would also be an indicator of empathetic response.

Materials

The three variables that were tested for homeostatic deviance were heart rate, respiratory rate, and skin resistance (ElectroDermal Activity). Heart rate was tested using a Pulse oximeter and CO_2 detector (Model 9843, SN: 118102926, Nonin Medical Inc. Plymouth, MN) to measure beats per minute (BPM). Respiration rates were tested via a respiratory transducer Xdcr (Model:

SS51B, SN: 1602004165, Biopac Systems, Inc. Goleta, CA) with lung expansion and contraction data representing participant's breaths per minute. Skin conductance was measured using an electrode lead set Xdcr (Model: SS3LA, SN: 1602004165, Biopac Systems, Inc. Goleta, CA) that utilizes two BSL EDA gelled finger electrodes (Model: SS3LA). Recording and analyzing of the quantitative data was completed using Biopac Student Lab System (BSL 4 software, MP36). Biopac Systems, Inc. Student Manual (Biopac Systems Inc. ISO 9001:2008) was also utilized as a resource for equipment usage and direction.

In order to evoke emotional and empathetic responses, an auditory collage was created from seven sounds using iMovie software (version 10.1.4) downloaded onto a Mac Os Sierra processor. The neutral sound of wind, the sound of a baby crying, and the sound of a baby laughing were recorded and cited from Youtube sources. The last audio clip consisted of a student investigator reading from page one, section one of the Vander's Human Physiology 14th edition textbook. The investigator was recorded subtly yawning 45 seconds into the audio clip. The URL links to the three sounds used in this investigation are included below.

Baby Crying: https://www.youtube.com/watch?v=1UaJsxe3Lwg
Baby Laughing: https://www.youtube.com/watch?v=15q_K5r3RzU
Wind: https://www.youtube.com/watch?v=l17ZmCPYJDU

Methods

Procedure

Participants for this experiment were selected from the University of Wisconsin-Madison Physiology 435 course in the Spring of 2017. Participants received a consent form, which warned them of a potentially emotionally evocative experience. Upon collection of the consent forms, the investigator allowed the participant an opportunity to ask questions. Following their informed consent, participants were given a brief questionnaire inquiring about their experiences with young children, specifically whether they had extensive babysitting experience or have lost a child with whom they had a relationship with. Furthermore, participants were asked how many hours of sleep they received as well as how many caffeinated beverages they consumed in the 24 hours prior to the study.

Participants were then instructed to sit down and the devices required for physiological measurements were connected. The respiratory effort chest band was fit to the participants sternum and the transducer was connected to the acquisition unit. The EL507 electrodes (coated with electrode gel) were attached to the index and middle fingers on the participant's left hand. The electrodes were purposefully positioned over the finger pads. The two electrodes were then attached to the SS57L lead, which was connected to the Biopac Systems, Inc. Acquisition Unit. Electrodes were placed on the participant approximately five minutes before calibration. The pulse oximeter was placed on the index finger of the participant’s right hand. Participants were given headphones and asked to close their eyes while the auditory stimuli was played.

Following the calibration instructions provided by the Biopac Systems, Inc. Student Manual, all three devices were calibrated with the participant seated. Physiological measurements were recorded by the Biopac Systems, Inc. software throughout the duration of the auditory stimuli (fig. 5). For the first minute, the participants heard no sound. This allowed for a baseline measurement of heart rate, skin resistance, and respiratory rate. Next, they heard the sound of wind for one minute. This served as a neutral stimuli which was not expected to elicit any drastic physiological response. Immediately following, a sound typically associated with positive emotion, a baby laughing, was played for one minute. In order to return the participants to homeostasis, the neutral sound of wind was played for another minute. Next, the participant heard a baby crying, a sound typically associated with negative emotion, for one minute. Then, again, was followed by the neutral sound of wind for one minute. Finally, the participant listened to a one minute long monologue that contained a strategically placed yawn 45 seconds into it.

As the participant listened, they were observed by one investigator sitting 10 feet to their right. The investigator was responsible for ensuring that the participant's eyes remained closed throughout the duration of the experiment. Furthermore, the investigator observed whether the participant yawned in response to the recording of a yawn during the monologue portion of the recording. After hearing that portion of the recording which signalled the end of the experiment, the participant was instructed to remove the headphones and allow the investigator to assist in the removal of the equipment. At this point the participant answered one last question asking them to rate their own level of empathy on a 1-10 scale, 1 not being empathetic at all and 10 extremely empathetic.

Data Analysis

Pulse data was collected by recording the participants' pulse every 15 seconds for the duration of the study. The average pulse for each minute was calculated for each participant. The average of the first minute (the baseline measurement) was subtracted from each subsequent minute (the various auditory stimuli). Next, the average of the deviations for all of the participants was calculated, resulting in one average deviation for each auditory stimulus (Figure 6).

Breaths per minute were calculated from the respiratory data by manually counting the number of peaks, which represented breaths, for every minute of the study. The average of each minute was calculated, the first of which was the baseline. The average baseline value was then subtracted from minutes 2 through 7, resulting in the average deviation from baseline for each auditory stimulus represented in Figure 7.

EDA data was collected by recording the average over a time period of 0.8-1.08 seconds of the highest peak in each of the seven one-minute intervals, as well as at the time of the recorded yawn stimulus. Figure 8 was created by subtracting each participant's baseline data from each auditory stimulus and calculating the overall average change per auditory stimuli.

Positive Control

The change in respiration, heart rate and SpO_2, and skin conductance due to a stimulus could all be measured with Biopac Systems, Inc. devices, as portrayed by Figures 1-4 and the pulse oximeter data. Figure 1 and 3 display resting skin conductance and respiration, respectively, on a group member. The group member walked up and down stairs for 30 seconds to create a physiological change from the resting state. These changes are evident in Figures 2 and 4. Figure 2 shows peaks of conductance and Figure 4 displays a change in both wavelength and frequency of respiration. Pulse oximeter data was also affected by the performed activity. Resting pulse was 80 beats per minute and SpO_2 was 98%. After activity, pulse was 110 beats per minute and SpO_2 was 97%. Evidence of this positive control data proved that physiological data applicable to the experiment could be measured after a stimulus was applied.

Negative Control

In our experiment, physiological baseline measurements of respiration, heart rate, and EDA were taken during the first minute while their eyes were closed and listened to no audio for each participant.

Results

Subject characteristics

A total of 31 participants underwent testing; however, only 25 participant results were used in the study (17 females and 8 males, age range of 19-25). Due to a faulty EDA recording device, 6 participants were excluded from the data analysis because of incomplete physiological measurement data. All of the participants were enrolled in Physiology 435 at the University of Wisconsin-Madison. Prior to participating, each subject signed a consent form informing them about the basic features and potential triggers of the study. Each participant was assigned a number, ensuring that their information remained confidential.

Survey Results

Prior to beginning the study, participants were asked to self-report the amount of sleep they received the previous night and the number of caffeinated beverages consumed the day of the study. Evidenced by Figure 9, 60% of participants had 6-8 hours of sleep. Figure 10 shows that the majority of participants (56%) had zero caffeinated beverages. After completion of the study, participants were asked to rate their perceived level of empathy on a scale of 1-10 and a mode of 7 was observed as shown by Figure 11.

Physiological Data Results

A T-test with a 95% confidence interval was used to compare the deviation from baseline for each auditory stimulus for each of the three physiological tests.

The heart rate data failed to show significance when compared to the baseline measurements. Figure 6 portrays the changes in average pulse for every minute of the study.

The respiratory data did not show significance at any of the time points when compared to the baseline measurements. Although not significant with p-values of 0.119 and 0.176 respectively, the baby laughing and baby crying audio clips have slightly increased respiratory rates (Figure 7).

No significance was found in the EDA data at any of the time points when compared to homeostasis. Figure 8 shows the average EDA for every minute of the study. Because of the lack of significance at all time periods of the three physiological tests, the null hypothesis cannot be rejected.

The pulse, respiration, and EDA data were then split into male and female groups and T-tests were done to analyze whether there was any significance in these sample data. Figures 12-17 represent deviation from baseline for each group respectively for the three physiological measures studied. None of the groups showed statistical significance.

Discussion

After determining that the collected physiological data was statistically insignificant, it was concluded that various factors may have influenced the validity of the results. These factors resulted from various actions of the researchers as well as general equipment sensitivity issues.

Overall, the study content and data collection methods should be used in future research with suggested modifications in order to produce a study with stronger validity.

The objective of the study was ultimately to determine if a mirrored yawn could be predicted if specific physiologic measures deviated from homeostasis. Unfortunately, as a result of numerous variables, study participants failed to mirror the auditory yawn, although the sample population scored themselves high on the self reported empathy scale (7.72/10), the data produced by the study implies that the sample population tested had a lesser level of empathy than they had scored themselves.

After conducting the research following the outlined methods, it has been determined that some improvements in lab equipment and analysis methods would result in a future study that more accurately reflects the goals of our research. Testing the equipment at the beginning of each laboratory time in order to insure that all information recorded was accurate and useable could improve accuracy. Using other available measurements, such as blood pressure, would allow for more analytical comparisons to be made in a new study and would have potentially helped to compensate for less accurate measures by some of the flawed EDA results in this study. As mentioned below, a more accurate conclusion as to why our results were inconclusive could have been reached if more questions were included in the participant survey.

The participants used in the research also self evaluated the hours of sleep they received on the night prior to participation, as well as the number of caffeinated beverages they consumed throughout the day. Over 80% of participants slept at least the minimal recommended amount of hours for their age group (Figure 9). Additionally, 84% of participants recorded drinking one or less caffeinated beverages (Figure 10). Well rested participants are less likely to yawn and also less likely to consume multiple caffeinated beverages throughout the day.

There are several factors that potentially influenced the likeliness that a participant in the lab setting would yawn. Previous research has shown that many elements such as setting, social factors, and emotional and physical states may affect the likelihood that one mirrors a yawn. Factors that may have affected this study include having, or lacking, a relationship to the trigger yawner, being under direct observation, or being in an unfamiliar lab setting (Norscia et al. 2016). Some of these factors, such as the existence of a relationship with the person yawning, are inalterable, as not everyone will feel the same towards the voice yawning. Other variables such as setting may be controlled for in future studies in order to induce a more realistic environment for participants.

In future research it may be advantageous to change some aspects of the environmental setting in order to make the participant more comfortable. Although the number of researchers in the testing room was limited to two in order to run equipment accurately and efficiently, possible benefits could be seen by having a camera or double sided mirror to improve the comfort of the participant. Previous research has shown that participants are less likely to yawn when being observed by the researchers (Massen *et al.* 2015). Although no yawns were observed, several participants made comments after completion of the study about feeling tired or having an urge to yawn. Improving the lab setting in a way that makes participants feel more at ease could lead to more accurate readings and potentially significant data.

A study conducted by Dr. Arnott at the Rotman Research Institute also researched the relationship between auditory yawing and recorded mirror yawns. Similarly, it established that auditory stimuli alone may not be enough to elicit a yawn. Dr. Arnott's team only used yawn stimuli without using other stimuli for comparative measure as conducted in this more current research. With access to technology such as MRI, the team at Rotman Research Institute was able to measure significant brain activity in areas that would be normally stimulated during mouth movement and auditory stimuli. In future research, using more accurate techniques such as MRI are imperative in order to be able to compare the effects of the four auditory stimuli presented to each participant. It is very probable that the results of an MRI in this research methodology would have provided more detailed information on the effects of different stimuli and how neurological measures can be used to predict an empathetic yawn.

Additionally, future studies would benefit from including additional follow up questions on the participant survey. Specifically, the study could have been improved with an immediate question about the nature of the participant's response to the baby laughing and crying. It was not appropriate to simply assume that participants would demonstrate a strong response to a baby's laughing and crying. Furthermore, more conclusions about the relationship between physiological data and participant state could be drawn if questions pertaining to mood, tiredness, and overall well being were answered after participating in the study.

Interestingly, a spike was observed in EDA conductance at the exact time of the yawn in the majority of participants. Additionally, other neural reactions could be potentially detected via MRI. Figure 8 depicts the change in EDA post-yawn as a lower value than the baseline EDA. This could result from the increased anxiety felt by the participants during the first few minutes of participating in the research study environment (Levitt et al. 2007). Additionally, the EDA results show the largest deviation from baseline during the audio clips of the baby laughing and crying.

Respiratory rate showed a positive increase from baseline during the baby laughing and baby crying stimuli and a smaller increase during the voice auditory stimulus; however, none of the deviations were significant. Near baseline respiratory rates were measured during the wind stimuli. These results reflect a change in physiological status during emotionally evoking stimuli and evidence the return to to baseline during the wind stimuli.

The data collected during heart rate measurements show less pattern than respiratory or EDA measurements. Heart rates increased during the first wind audio clip and then plateaus over the next four auditory stimuli. It is suspected that the baby laughing increased the heart rates of the participants and that this higher heart rate was maintained over the next few minutes. The heart rates eventually slowed when participants concentrated on the voice they were hearing during the last audio clip and returned to a rate near baseline.

Conclusion

After failing to reject the null hypothesis, the results of the research were analyzed to determine any additional relationships between physiological measurements and auditory stimuli. After the data was analyzed, it was found that the data implied correlational relationships between the different auditory stimuli and a change in baseline for each of the physiological measures. Although it was not possible with the above research methods to formulate a way to predict empathetic yawn based on physiological deviations, the results and methods obtained will be advantageous to scientists doing future neurological research.

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Appendix

Figure 1-4: Proof instruments are sufficient for the desired measurements

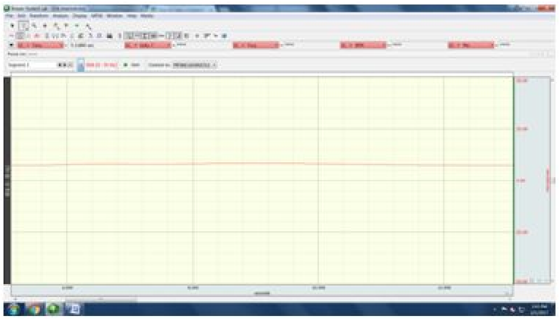

Figure 1. EDA data of person at rest

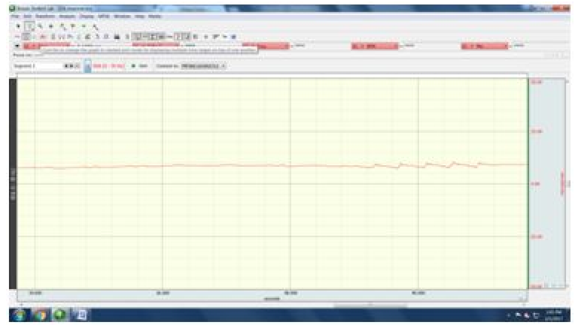

Figure 2. EDA data of person during stimulus

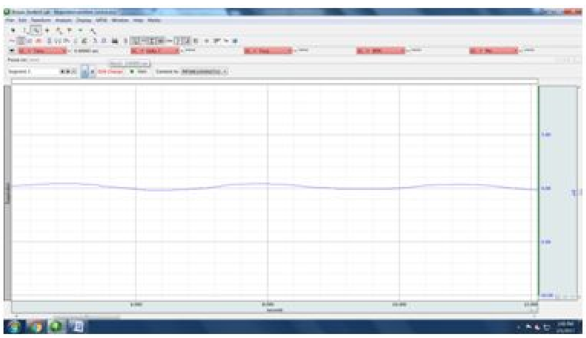

Figure 3. Respiration data of person at rest

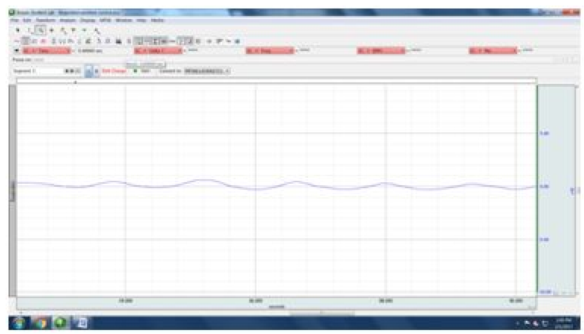

Figure 4. Respiration data of person after stimulus

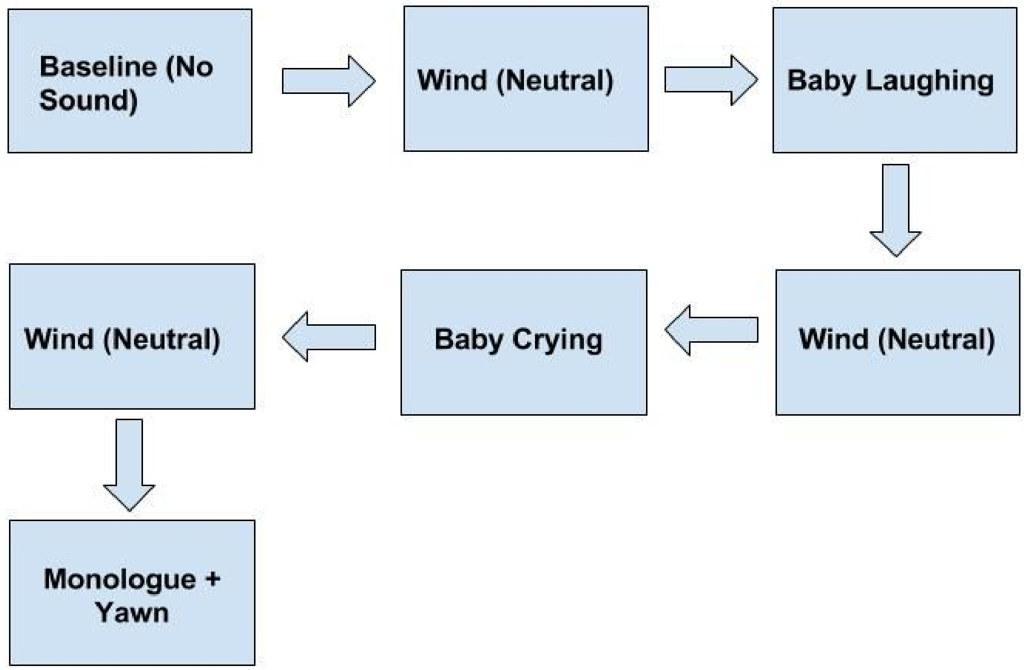

Figure 5. The baseline measurement consisted of the subject connected to all of the devices that measured physiological responses with no audio playing. Next, the neutral sound of wind was played. This acted as a negative control because no deviation from homeostasis was expected. The sound of a baby laughing was played next to observe the physiological response to what is usually perceived as a pleasant experience. This was followed by the neutral sound of the wind to return the subject to homeostasis. The sound of a baby crying was played next to observe the subjects physiological response to what is usually perceived as a negative and stressful experience. Again, this was followed by the sound of the neutral wind returning the subject to homeostasis. Lastly, the subject was exposed to a monologue that included the sound of a discrete yawn

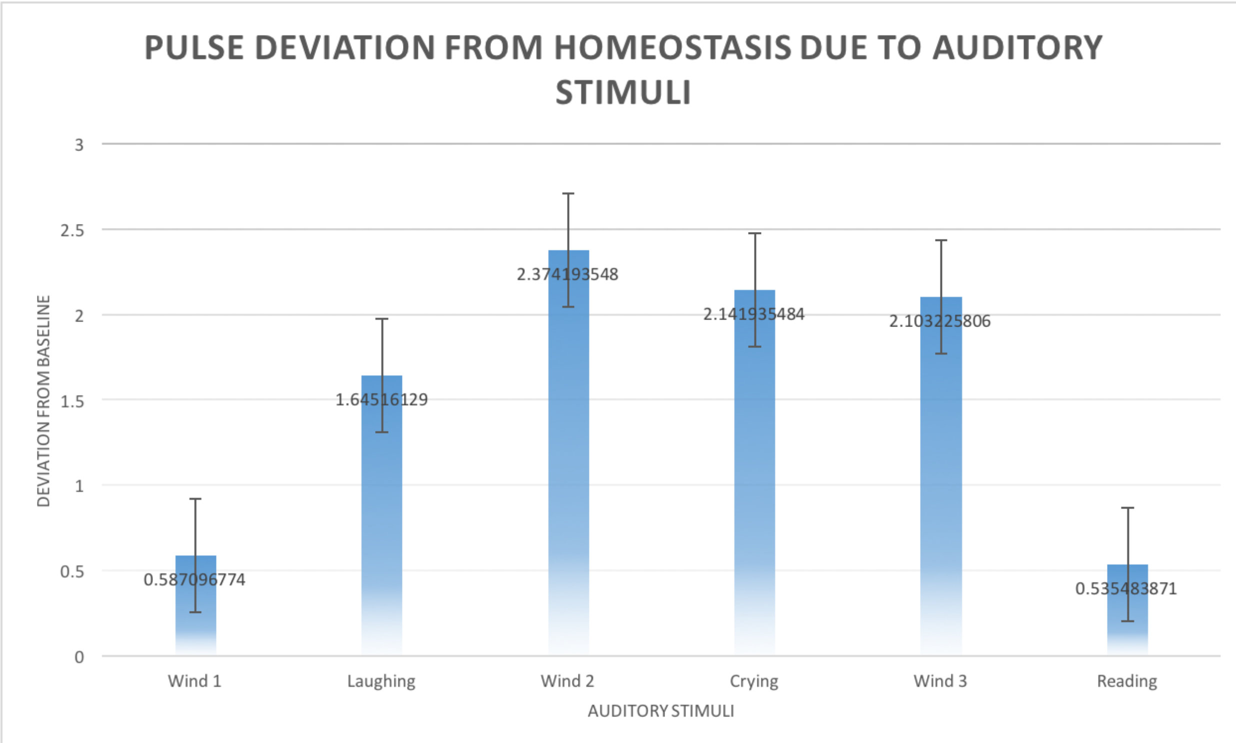

Figure 6. Positive values represent an increase in pulse compared to the baseline measurement.

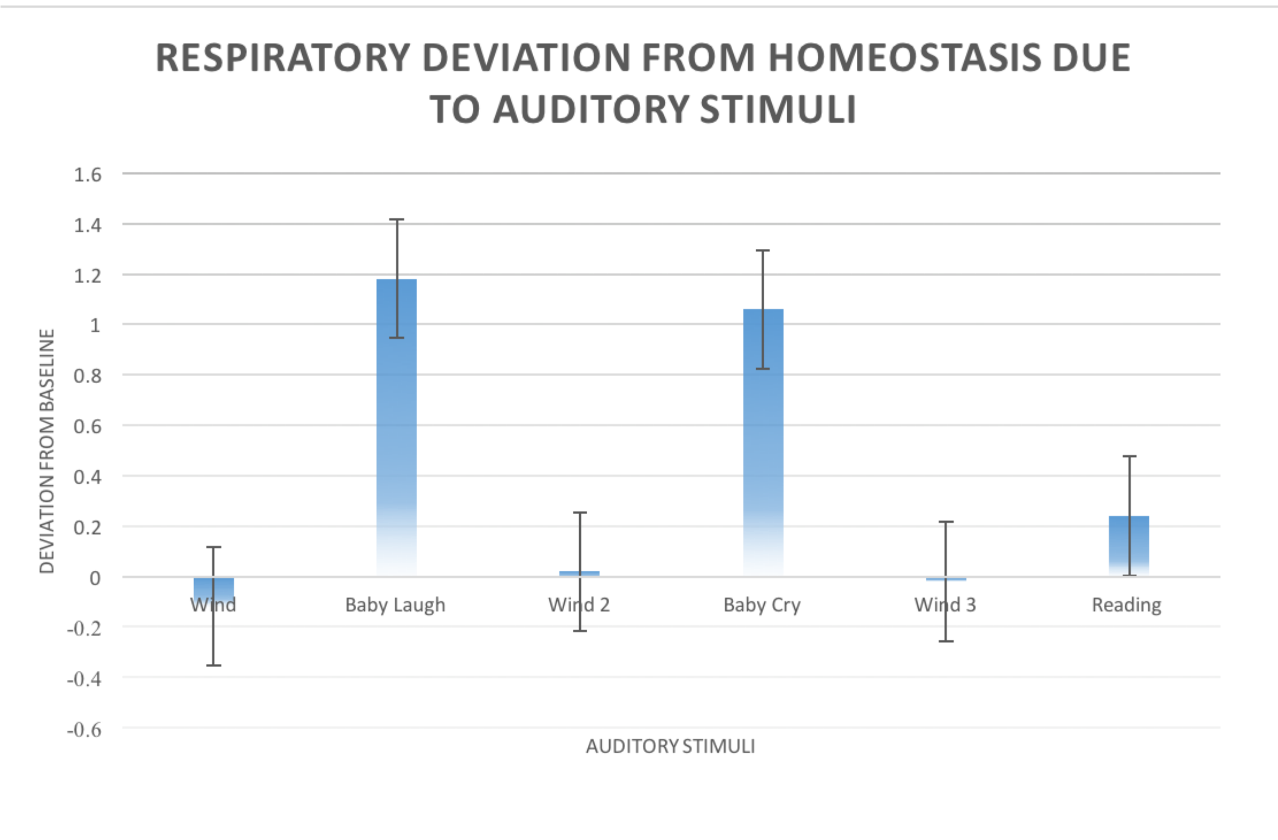

Figure 7. Positive values represent an increase in respiratory rate while negative values represent a decrease in respiratory rate compared to the baseline measurement.

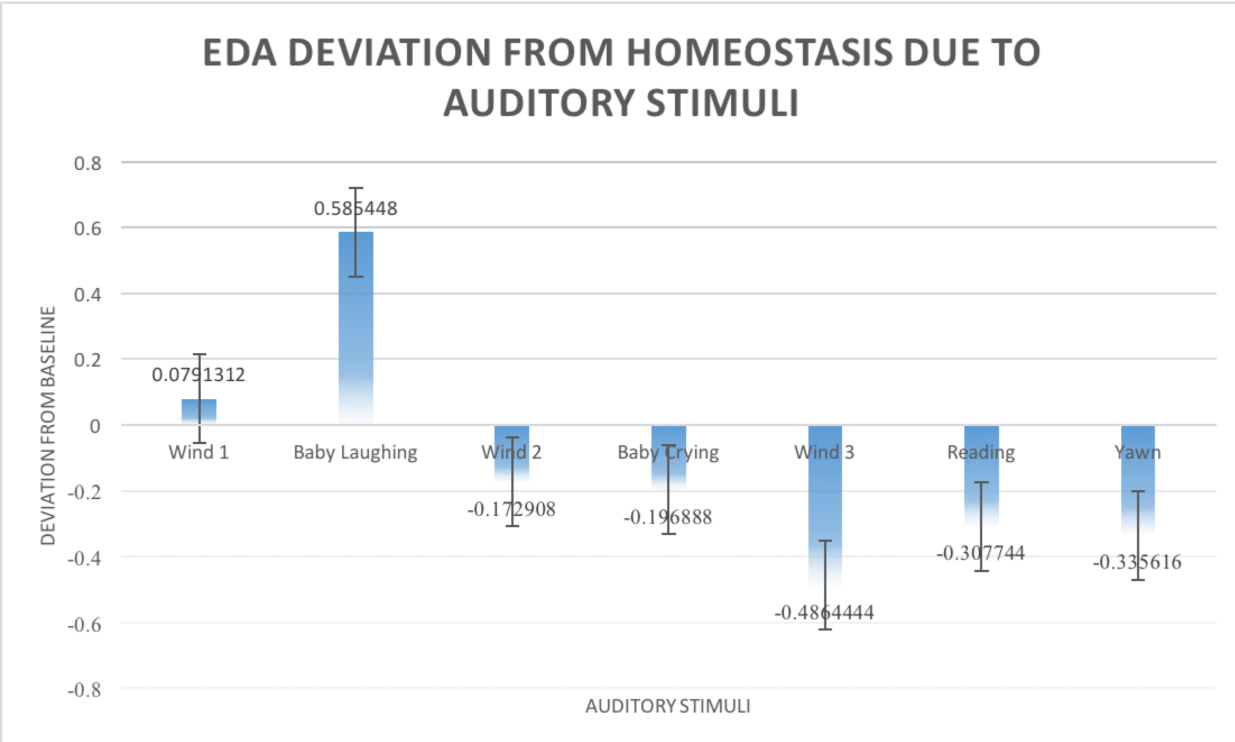

Figure 8. An increase in average EDA data from baseline was seen in Wind 1 and Baby Laugh, as evidenced by the positive value. The data from the remaining auditory stimuli showed a decrease from baseline, as evidenced by the negative values.

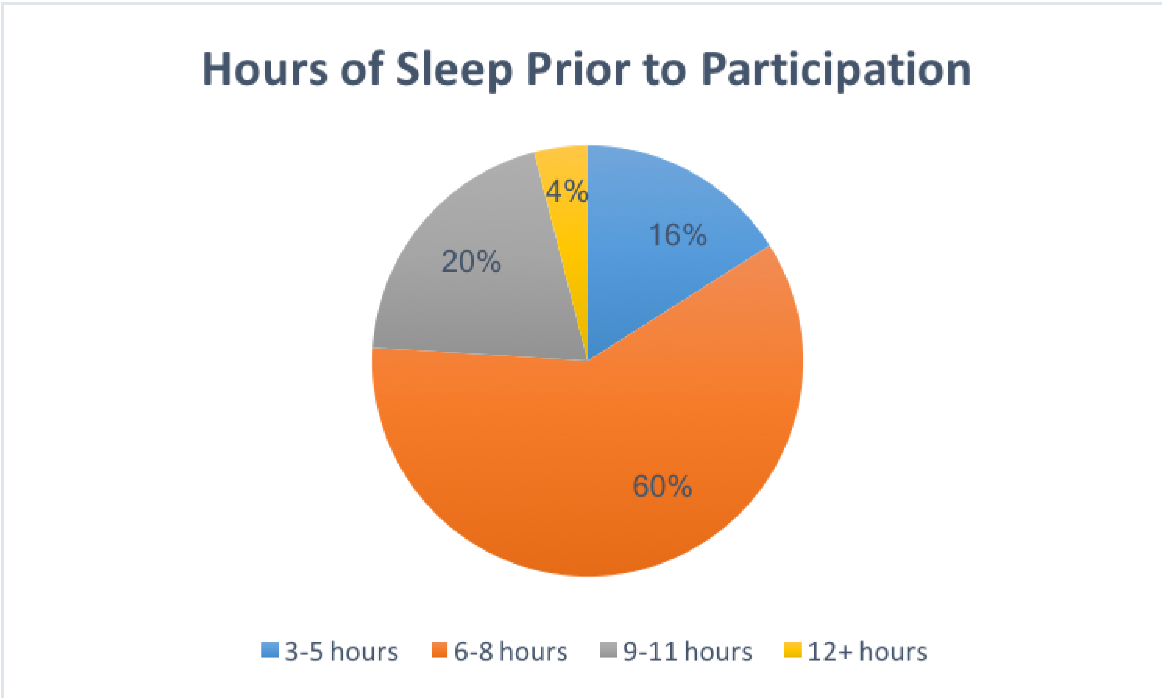

Figure 9. Participants self-reported the number of hours of sleep they received the night before the study (n=25).

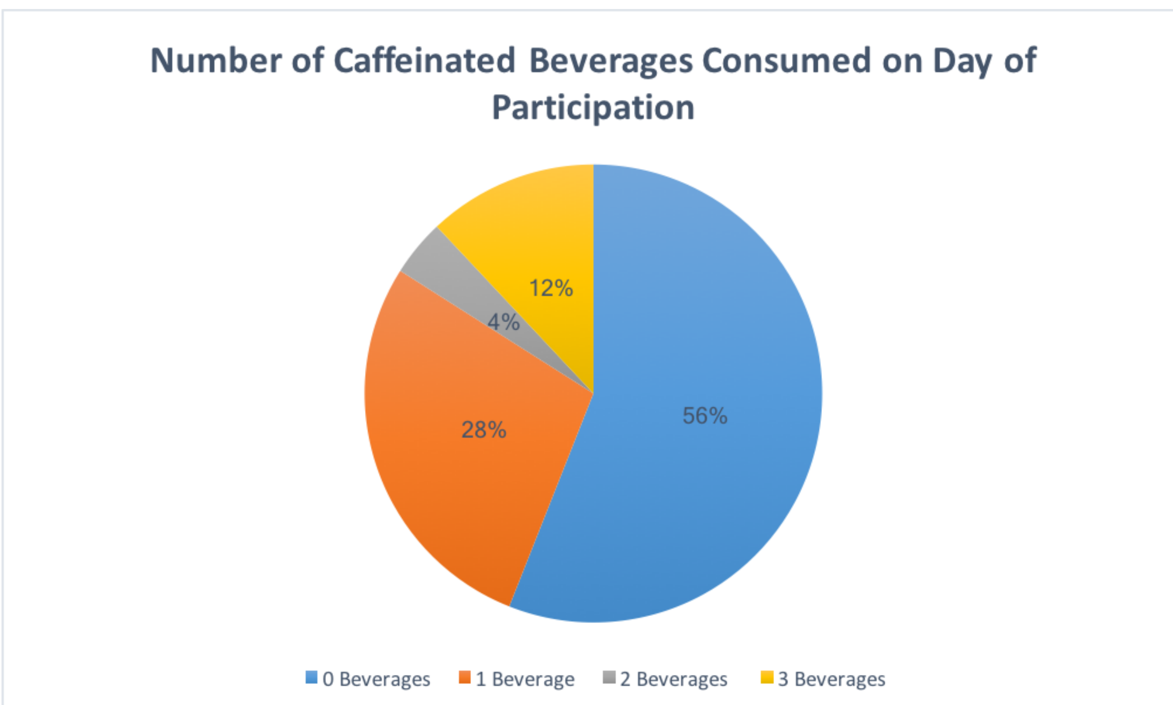

Figure 10. Participants self-reported the number of caffeinated beverages they consumed the day of the study (n=25).

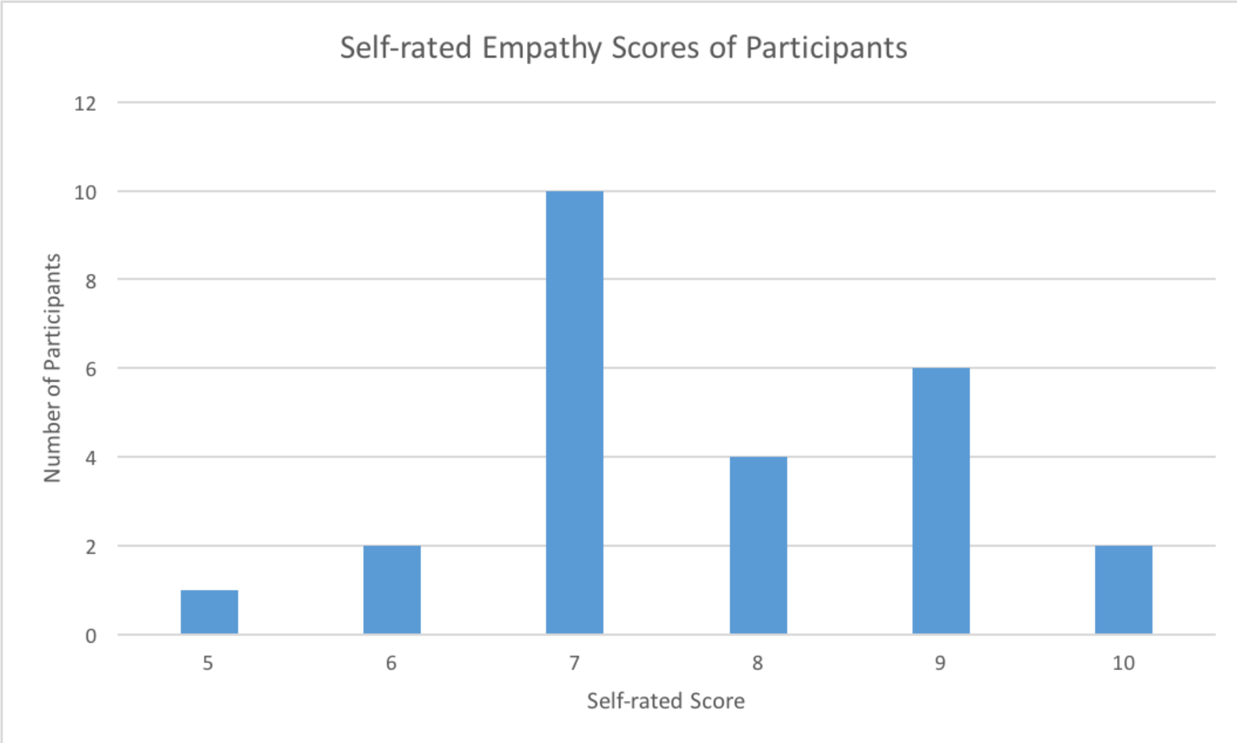

Figure 11. After participation, each subject rated their levels of empathy on a scale of 1-10, with one being the lowest level of empathy and ten being the highest (n=25).

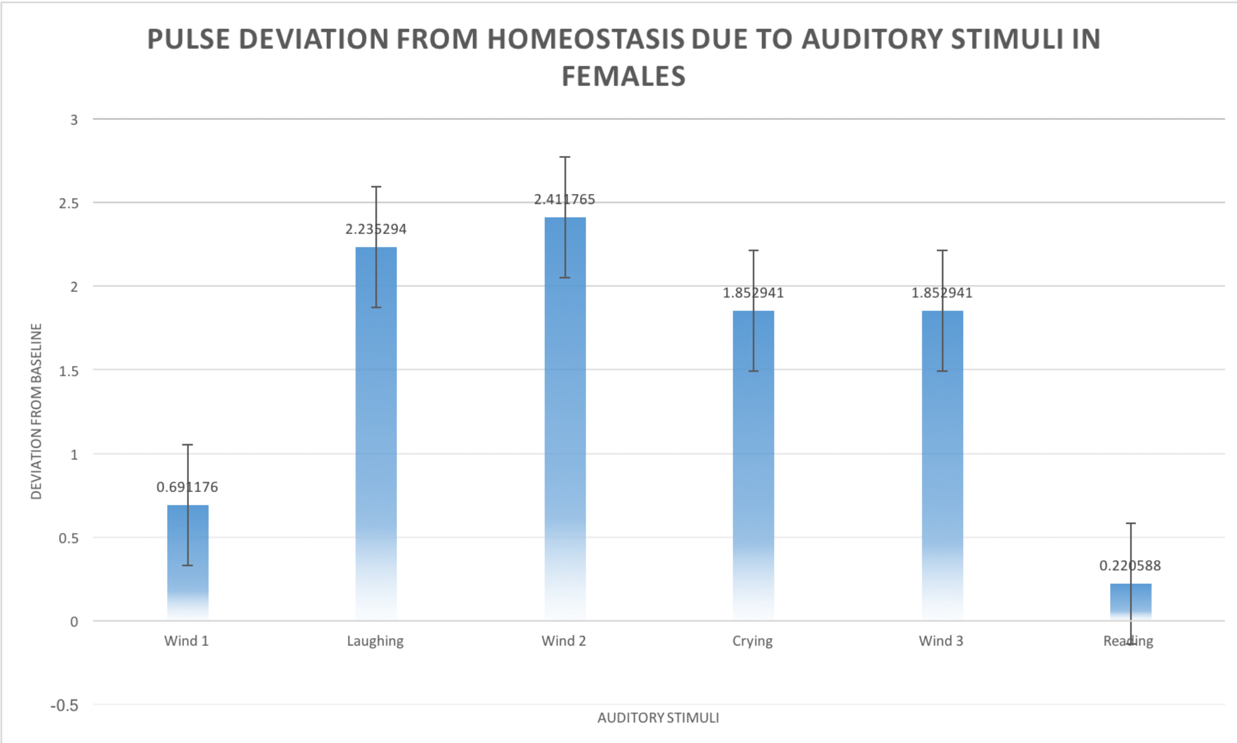

Figure 12. Pulse deviation from baseline for females (n=17).

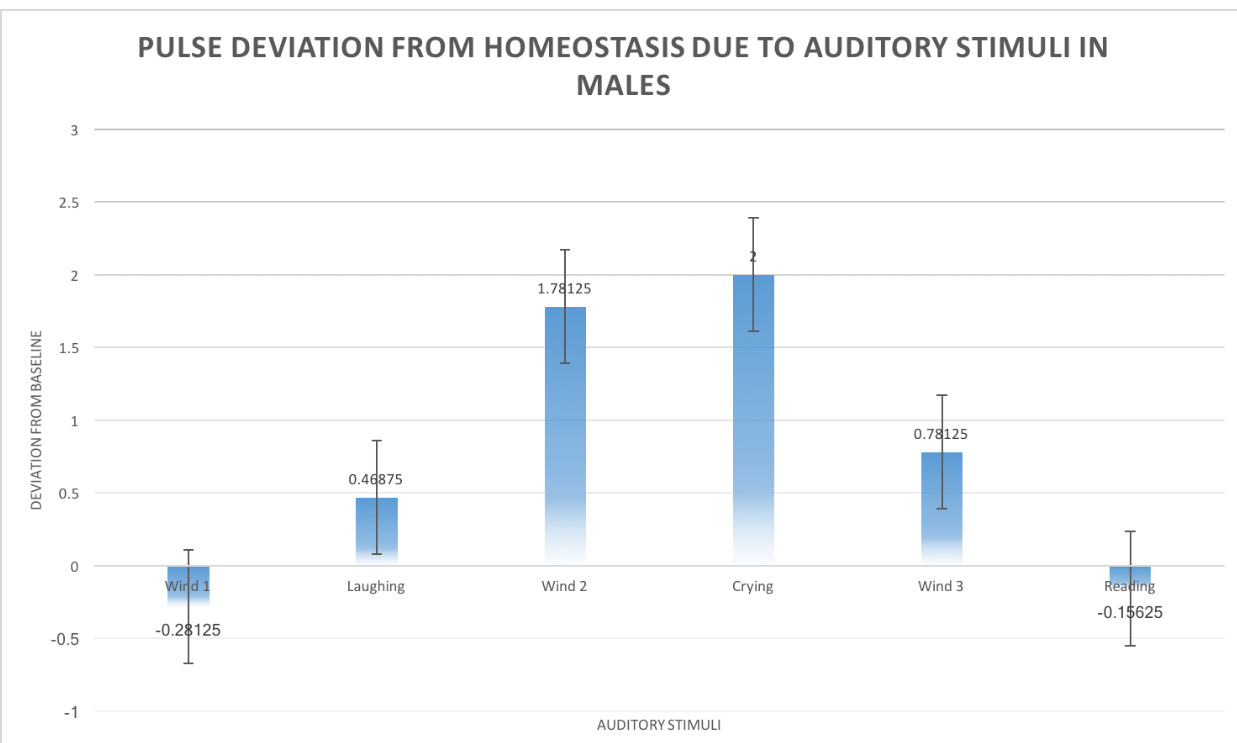

Figure 13. Pulse deviation from baseline for males (n=8).

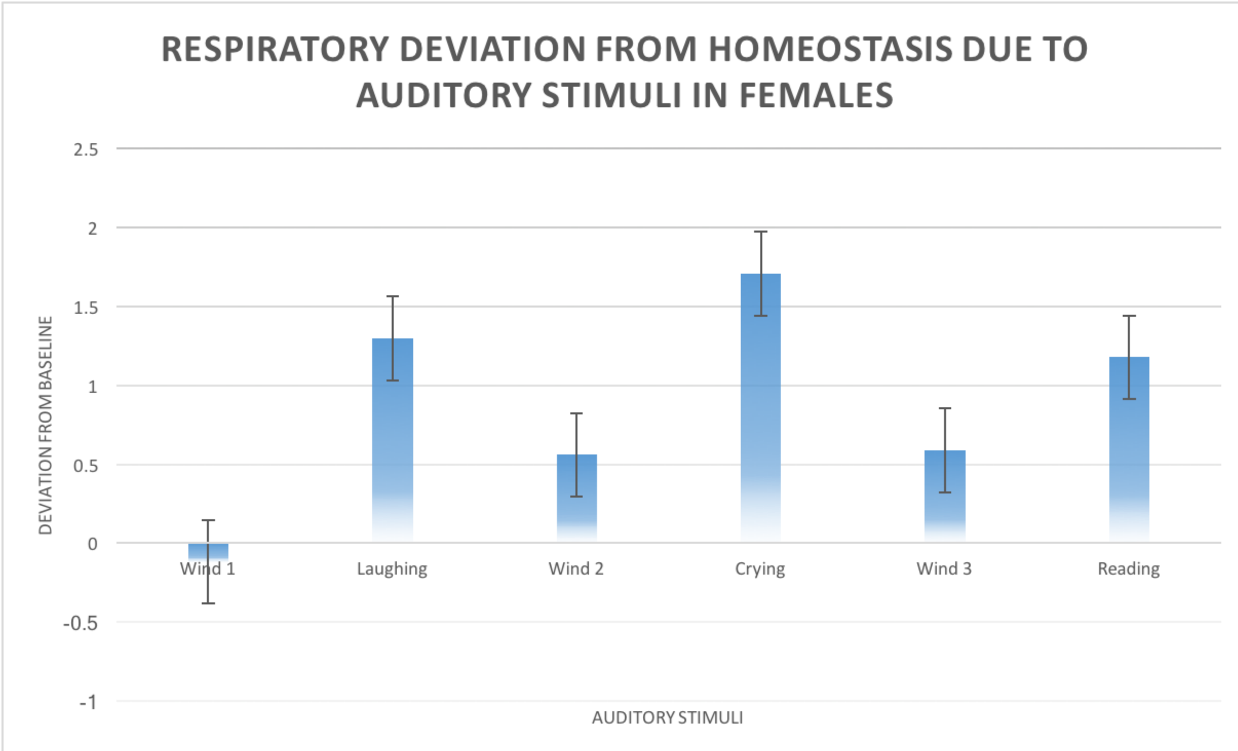

Figure 14. Respiratory deviation from baseline for females (n=17).

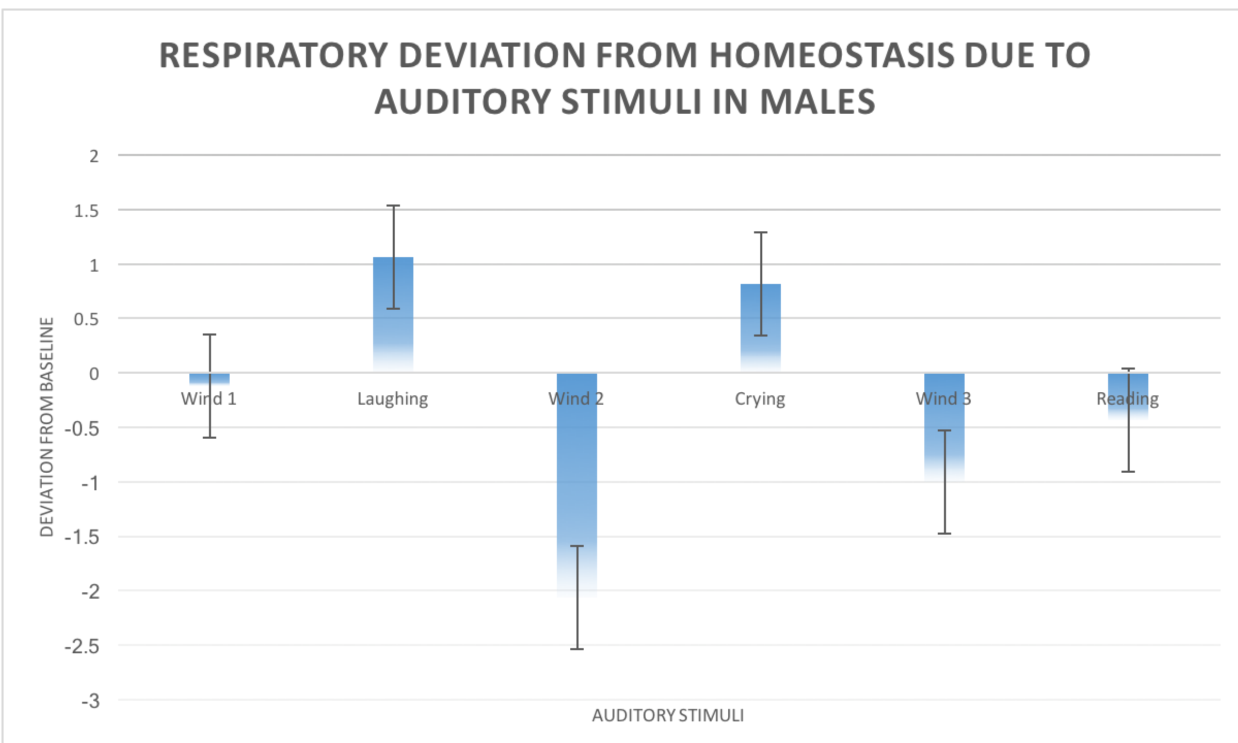

Figure 15. Respiratory deviation from baseline for males (n=8).

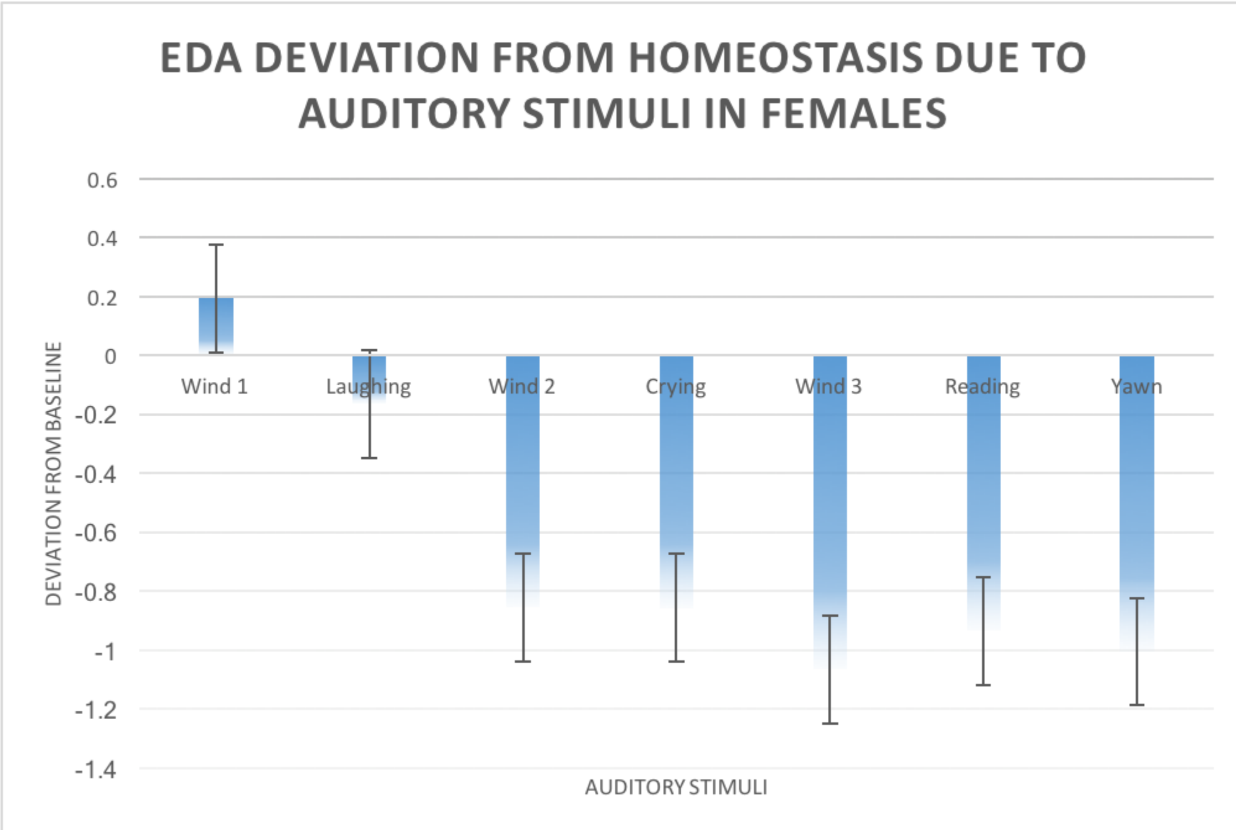

Figure 16. EDA deviation from baseline for females (n=17).

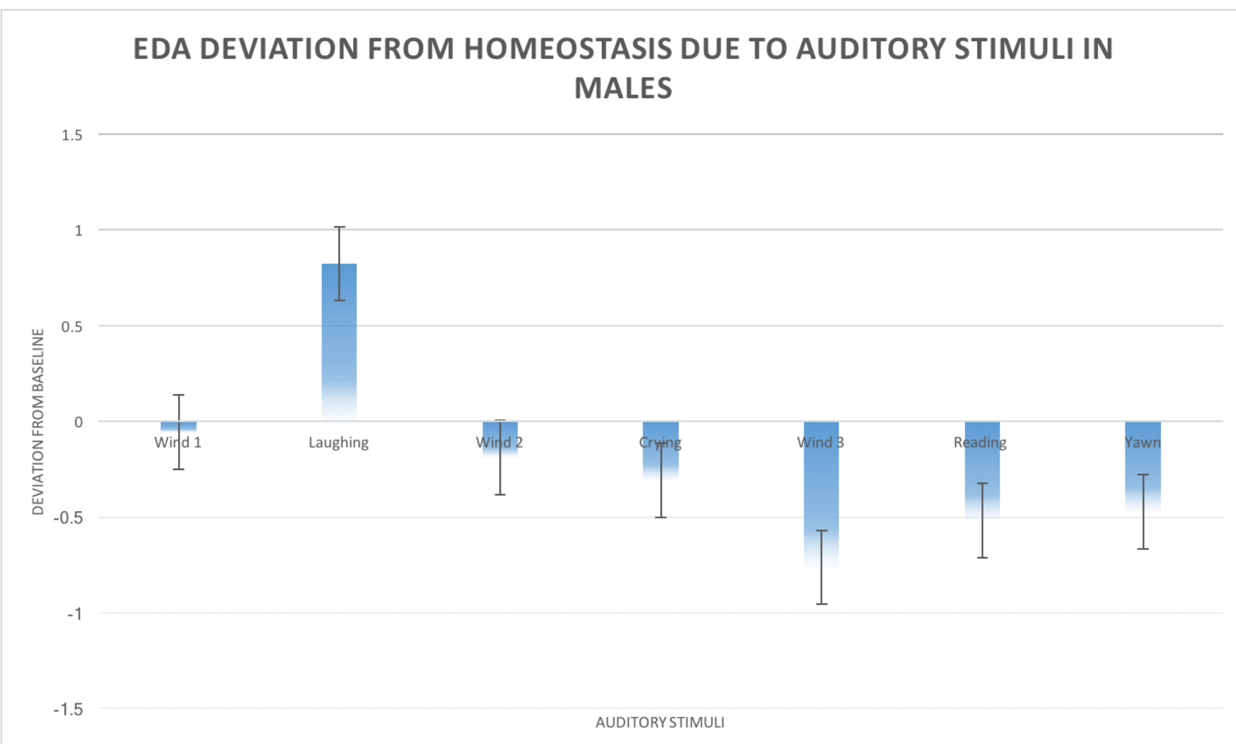

Figure 17. EDA deviation from baseline for males (n=8)