# THE EFFECTS OF NOISE ON AUTONOMIC AROUSAL AND ATTENTION AND THE RELATIONSHIP TO AUTISM SYMPTOMATOLOGY

by

**Ann Marie Alvar**

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# THE PURDUE UNIVERSITY GRADUATE SCHOOL
# STATEMENT OF COMMITTEE APPROVAL

**Dr. Alexander L. Francis**

Department of Speech, Language, and Hearing Sciences

**Dr. Brandon Keehn**

Department of Speech, Language, and Hearing Sciences

Department of Psychological Sciences

**Dr. Anne B. Sereno**

Department of Psychological Sciences

Weldon School of Biomedical Engineering

**Dr. Hari Bharadwaj**

Department of Speech, Language, and Hearing Sciences

Weldon School of Biomedical Engineering

**Approved by:**

Dr. Preeti M. Sivasankar

*Dedicated to*

*God and my Family*

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# ABSTRACT


## Experiment One: The Effect of Noise on Autonomic Arousal

In response to the growing demand for research that helps us understand the complex interactions between Autonomic Arousal (AA) on behavior and performance there is an increasing need for robust techniques to efficiently utilize stimuli, such as sound, to vary the level of AA within a study. The goal of this study was to look at the impact of several factors, including sound intensity, order of presentation, and direction of presentation on skin conductance level, a widely utilized technique for approximating levels of AA. To do this we had 34 young adults ages 18- 34 listen to a series of 2-minute blocks of a sound stimuli based off a heating, ventilation, and air conditioning system (HVAC). Blocks included 5 single intensity conditions each block differing in 10 dBA steps ranging from 35-75 dBA. We presented blocks in both rising and falling level of intensity, with half the participants hearing them in a rising order first and half in a falling order first. The evidence found by this study suggests that increasing the sound level plays an important role in increasing AA and habituation is an extremely important factor that must be accounted for as it, in the case of typical young adults, quickly dampens the response to stimuli and subsequent stimuli. These findings suggest that researchers can best efficiently maximize the range of AA they can use while keeping their participants comfortable by starting out with the most intense stimuli and proceeding to the less intense stimuli, working with habitation instead of against it.

## Experiment Two: The Effect of Autonomic Arousal on Visual Attention

The goal of this study was to better understand how various levels of autonomic arousal impact different components of attentional control and if ASD-related traits indexed by Autism Quotient scores (AQ) might relate to alterations in this relationship. This study had 41 young adult participants (23 women, 17 men, 1 prefer not to say), ages ranging from 18 to 38 years old. Participants listened to varying levels of noise to induce changes in AA, which were recorded as changes in skin conductance level (SCL). To evaluate attentional control, participants preformed pro and anti-saccade visual gap–overlap paradigm tasks as measures of attentional control. The findings of this study suggest that increased levels of autonomic arousal are helpful for improving performance on anti-saccade tasks, which are heavily dependent on top-down attentional control. Additionally, increases in AQ scores were related to having less of a benefit from increasing levels of arousal on anti-saccade tasks. Additional interactions were also found and are discussed in this paper.

# CHAPTER 1: THE EFFECT OF NOISE ON AUTONOMIC AROUSAL

## Background

There is a growing interest in conducting studies that look at how autonomic arousal (AA) induces changes in human behavior (Bellato et al., 2020; Critchley, 2005; Diamond et al., 2007). To design such studies, researchers must employ methods to alter AA that are suitable to use with diverse populations such as individuals with mental illness, developmental differences, and children. These populations are particularly important to include as variations in autonomic response may help explain some of the behavioral differences observed in these populations (Bellato et al., 2020; Keith et al., 2019; Orekhova & Stroganova, 2014; Stroganova et al., 2013)

Typically, researchers utilize sensory stimuli to induce changes in AA, varying the "dose" of this stimuli to vary the magnitude of autonomic response in the individual. In this context, dose refers to a quantitative characteristic of the stimulus, which when varied induces a measurable change in a physical or behavioral response (Wickens, 1954). For example, past research has employed electric shocks to elicit changes in AA. Researchers found that they can vary the levels of AA (a response) by varying the electric shock intensity (dose), thus inducing multiple levels of AA (Dodson, 1915; Kyle & McNeil, 2014; Yerkes & Dodson, 1908). Inducing multiple significantly different levels of autonomic response is key to this line of research, as it has been found that the relationships between the amount of AA and the change in task performance or behavior have nonlinear relationships (Diamond et al., 2007; Dodson, 1915; Yerkes & Dodson, 1908). To study complex nonlinear relationships, researchers need to induce multiple levels of AA to adequately increase the power in the model, so they can accurately describe the true pattern of the relationship.

However, as the focus of this research shifts towards understanding the effect AA has on behavioral differences observed in vulnerable populations, the use of electric shock and other novel stimuli are falling out of favor. Instead, researchers are looking for stimuli that are more suitable for vulnerable populations, such as children, and are moving towards using stimuli that are more akin to what is typically experienced in day-to-day life, so that findings can better relate to lived experiences.

Sounds and their effects on AA are a stimulus type of growing interest. Unlike electric shocks, sound is not a novel stimulus for the average individual, and it is easy to develop sound stimuli that are akin to the natural fluctuations in sensory information one would experience throughout the day. Initial studies have found that sounds such as white noise, beeps, and vowels are suitable and effective to use in populations such as typically developing children, children with attention deficit hyperactivity disorder (ADHD) and children with high functioning autism spectrum disorder (ASD) (Keith et al., 2019; Kleberg et al., 2020).

However, there is still one major gap in the methodologies that these studies employ that needs to be resolved. As noted earlier, to best describe the true relationship between AA and behavior, it is important that these experiments explore multiple levels of AA, induced by multiple levels of stimuli. Yet, the cited studies have all relied on experimental designs that only use 2 arousal conditions a high arousal noise "on" condition and a low arousal noise "off" condition. Future studies should include more levels of arousal, which would require multiple doses of sound.

Psychoacoustic research has found that sounds presented at high levels of intensity, or its perceptual correlate, loudness, alter many types of physiological responses, including skin conductance level (Keith et al., 2019). This would suggest that varying sound intensity may be an ideal method of creating differential dosages of sound to get more variable levels of AA response.

Before we can use sound intensity to dose AA in an experiment, we need to map sound dosages and their typical corresponding AA responses. Mapping sound intensity to AA response may sound simple, but the stimulus response literature shows that there are multiple factors which can affect this relationship, such as time of exposure and order of stimuli (Podoly & Ben-Sasson, 2020; Thompson, 2001). The goal of this study is to establish the pattern of the stimulus (dose) response relationship between sound level and autonomic response, while also accounting for other factors such as time of exposure and order of exposure; creating a reference that can be used when designing future studies.

Next, we will discuss autonomic arousal, and our methods for measuring it as well as important factors to consider when quantifying sound intensity, and characteristics that impact human perception of it; that need to be taken into consideration when designing this experiment.

**The response: What is Autonomic Arousal and how can we measure it**

Autonomic Arousal (AA) is the body's unconscious response to stimuli. Historically researchers have often used the term AA or arousal when referring to responses produced in and related to a particular division of the autonomic nervous system, the sympathetic nervous system (Keith et al., 2019; Kyle & McNeil, 2014; Lee et al., 2012; Mather & Sutherland, 2011; Orekhova & Stroganova, 2014; Tracy et al., 2000). This may be in part due to the fact that sympathetic responses are related to general arousal. For this study references to changes in AA will relate specifically to activity in the sympathetic branch of the autonomic nervous system. Sympathetic activity results in measurable physiological changes such as increases in heart rate, vasoconstriction and vasodilation, pupil dilation, and increased eccrine sweat gland activity (Boucsein, 2012; Karemaker, 2017; Szabadi, 2018). One of these changes, increased activity in the palmar eccrine sweat glands, is particularly useful to researchers. This activity increases levels

of sweat within the eccrine ducts and on the surface of the skin which in turn increases the electrical conductance across the palm. Using these properties researchers can quantify these changes through a measure called skin conductance level (SCL). Measures of SCL are particularly useful, as they are highly correlated with autonomic arousal, relatively easy to obtain, and inexpensive (Boucsein, 2012; Boucsein et al., 2012) making SCL measurement a widely used method to approximate degree of sympathetic response (Boucsein, 2012; Keith et al., 2019; Tracy et al., 2000); due to these factors and its wide use in the field we utilized this technique to measure AA in our participants.

**The Stimuli What is sound and what factors impact our perception of it?**

***Physical characteristics of sound: Sound intensity***

Sound is a longitudinal wave of pressure that propagates through a medium, causing molecules to vibrate. The strength or intensity, of this wave is describe mathematically by the amount of power or pressure (Watts) over an area (meters squared) which can be represented with the following simplified equation:

$$Intensity = \left(\frac{Pressure}{area}\right)$$

The range of sound pressure that humans typically can hear ranges from 1 x 10-12 W/m$^2$ to 12 W/m$^2$. Due to the size of this range a common way to describe sound pressure levels (SPL) is to use a unit called a decibel (dB SPL). The decibel (dB) system is a referential unit that uses the equation

$$dB = 10\ log\left(\frac{Observed\ Intensity}{Reference\ Intensity}\right)$$

For sound pressure level, the reference intensity for 0 dB SPL is standardized and set to 20μ Pascal, which is around the average hearing threshold of hearing for young healthy adults. This compacts the range to 0-140 decibels (Martin, 1929). It is important to note that utilizing this logarithmic scale means that the actual sound pressure doubles every 3 decibels (dB) and that the unit 3dB is not an absolute measure but one that is referential.

## ***Psychoacoustics***

### *Loudness*

Most stimulus response relationships do not have a simple one-to-one linear relationship. This is because an organism's response to a stimulus is directly influenced by characteristics of the perceptual system that alter the how a stimulus is weighed (*American National Standard Psychoacoustical Terminology*, 1973; Wickens, 1954). The perceptual correlate of sound intensity is loudness. Our perception of sound intensity is influenced by two main factors, the physical characteristics of the human ear and how the human brain interprets the signals transmitted from the ear. These factors greatly affect how we perceive and interpret the quantity of change in intensity (Fletcher & Munson, 1933b; Peeke & Petrinovich, 1984; Podoly & Ben-Sasson, 2020; Schmid et al., 2015; Stevens, 1955, 1956) which may then affect the degree of autonomic response.

### *The Ear*

The human ear both amplifies the sound wave and transduces it into neural signals. Due to its physical characteristics, the ear is limited in what frequencies it can transduce, typically around 20 Hz to 20 kHz, and biased in which frequencies get more amplification. To account for these factors, researchers developed a weighting system (Fletcher & Munson, 1933a, 1933b) to create equal "loudness" levels for all frequencies called "A weighting". When A weighting has been

applied to the dB SPL scale, we denote this on the measure using the abbreviation "dBA". When designing a study that looks at an individual's response to sound intensity that includes a sound stimulus with multiple frequencies, it is important to measure the sound stimuli in dBA to better represent the experience of the listener.

*The Brain*

The second part of this system involves psychoacoustics, or how the brain perceives signals. For this study, we must consider three factors that affect the magnitude of response to sound stimuli. The first directly impacts how we think about quantifying the "dose" of sound. Humans' perception of the degree of change in sound intensity is not linear even when using the dBA scale. Although, due to its logarithmic scale, it takes 3dB to double the actual intensity of a sound, on average it takes around 10 dBA before a person perceives a sound as doubling in loudness (Stevens, 1955, 1956). This is important to consider in the efficient design of a psychoacoustic study, as it is vital that the sound stimuli should be designed to be significantly different to the listener on some level. The value of only using significantly different stimuli becomes more pronounced when we consider the next two phenomenon.

The second two factors relate to how time and order of exposure to a sound stimulus change our perception of it. The first phenomenon, habituation, is an organism's diminishing response to sensory stimuli after a period of continued or repeated exposure. Habituation is not due to adaptation of the sensory receptor (ear), but a neurological phenomenon (Peeke & Petrinovich, 1984; Schmid et al., 2015). Habituation can be used to describe a decrease in a behavioral or physiological response; for example, skin conductance level, a correlate of AA, will drift back to baseline resting levels over time if the exposure to a non-painful stimulus continues (Podoly & Ben-Sasson, 2020). Once the stimulus stops there can be a recovery from the effects of habituation

over time, increasing responsiveness back to the levels seen before habituation (Thompson, 2001). Knowing that habituation alters stimulus response relationships, our models will be directly related to exposure time and may vary over time. To account for this, we have included exposure time as a factor in our model.

It is very important that the findings of this study are applicable to the experimental contexts of studies where the effects of AA would have a great benefit to increasing our understanding of human behavior. A length of experimental blocks utilized in previous behavioral studies and in studies we planned on replicating with the addition of AA manipulation is 2 minutes (Keehn, Westerfield, et al., 2019), Because this is the block length used in these studies, in this initial study we looked at responses to sound exposure at a set level over 2 minutes.

Secondly, habituation not only applies to the magnitude of response to the current stimulus but may alter the degree of response to following stimuli. This is called a sensory context effect. For example, response to a high intensity noise (say 75 dBA) may be weaker following a 65 dBA stimuli vs. silence (Behler & Uppenkamp, 2021). Since experiments that use stimuli to dose sound need to utilize multiple levels of stimulus intensities in a single experiment, we will factor this into our study by comparing the effects of order of stimuli presentation on the stimulus response relationship. We factored this into the study by having half of the participants hear the stimuli in a rising order of intensity first and the other half of the participants hear the stimuli in a falling order of intensity first. Each group then heard the stimuli in the opposite order to look for interaction effects. Additionally, order of presentation was factored into our model and its implications for experimental design will be discussed.

## Conclusion

Incorporating factors such as habituation and order of presentation, the following study aims to model the stimulus response relationship between sound intensity (dBA) and level of autonomic arousal, as indicated through changes in skin conductance levels.

# Methods

## Participants

Experiment 1 had 34 young adult participants (26 women, 8 men), ages ranging from 18 to 34 years (M = 21.88 years; SD = 3.42 years). All participants passed a hearing screening with a threshold of 20 dB at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz in both ears. Because the autonomic nervous system measurements of interest in this study are sensitive to health conditions and medications, all participants needed to meet the following criteria to participate in this study. None of the participants could have a history of neurological disease or impairment (e.g., head injury, seizure disorder, neuropathy, or neurological diseases such as Parkinson's disease) or other medical/health conditions or behaviors including smoking, substance abuse, heart disease, or diabetes known to affect variables relevant to the current study. Additionally, those who reported experiencing psychological or psychiatric problems such as depression or anxiety disorder within the last 6 months, or who received a score higher than 50% on a standard anxiety screener, the Geriatric Anxiety Inventory (GAI) (Pachana et al., 2007) or depression screeners, the Geriatric Depression Scale (GDS) (Yesavage et al., 1982) were excluded as these conditions have been shown to impact ANS function (Dieleman et al., 2010) and these scales have been utilized in past studies for a similar population (Francis et al., 2016; Love et al., 2021). In addition, individuals were excluded if they were currently on or had recently taken medications that can affect cognitive, motor, or autonomic function (e.g., selective serotonin reuptake inhibitors (SSRI), medications for

attention deficit disorder and muscle relaxants), or that might affect their performance on any experimental tasks. Individuals with pacemakers or other implanted electrical medical devices were also excluded because the use of skin conductance measurements is contraindicated in such cases.

## Materials, Stimuli, and Apparatus

### *Stimuli*

The auditory stimuli were designed to be akin to the sound produced by a commercial heating, ventilation, and air conditioning (HVAC) system with additional 333 Hz and 666 Hz harmonic components. This stimulus was selected as HVAC-like noises are experienced in day-to-day life of individuals on the college campus (Love et al., 2021). The additional tonal component was included as it increases levels of ANS activity related to AA responses (Bienvenue et al., 1990). Each stimulus was played at 5 different intensity levels ranging from 35 to 75 dBA and increasing in 10 dBA steps. The sound level remained relatively constant throughout a block to keep the dose consistent and to limit the number of potential factors to control (Zwicker & Fastl, 1999).

The presentation of the auditory and visual stimuli was controlled using Presentation software (nbs.neuro-bs.com; version 11.8) using scripts written by the experimenters.

## Procedure

Before coming in for the study, all participants were instructed to make sure that they got a good night's sleep. They were also instructed to not eat or drink anything for one hour before coming into the lab and to have not consumed any caffeine for 2 hours before coming into the lab to avoid the influence of caffeine on ANS response (Barry et al., 2008). On the day of the study,

they were asked to use the restroom before the start of the experiment to make sure they would be able to sit comfortably for the duration of the study.

After the participants were consented, screened, and had the SCL electrodes applied to the palm of their non-dominate hand, they were seated in a comfortable chair in a single-walled sound booth (IAC Inc) between 2 speakers that were used to present the auditory stimuli to the participants. The speakers (Hafler M5 Reference) were located 1.5 meters on the left and right side of the participant. All measures of dBA were measured with an audiometer (Larson Davis model 824) at the center between the 2 speakers, at the approximate level as the participant's head when seated.

### *Experimental design*

#### *Baseline tasks*

Before and after the experimental paradigm, participants had a 5-minute resting block, during which they watched a silent relaxation video of waves on a beach. The video was displayed on a 50" LED TV monitor mounted on the wall about 2 m directly in front of the participants at head level. These 2 periods were averaged to get baseline measurements of skin conductance levels (SCL), the mean SCL of these periods was later used to norm the SCL levels in the experimental conditions so that individual participant levels could be better compared across participants using the formula depicted below.

$$Normed\ SCL = \left(\frac{Sample\ SCL}{Mean\ Baseline\ \ SCL}\right)$$

*Experimental Tasks*

The participants were asked to bring reading materials to read during the study. During the sequence participants read the materials they brought, as they were listening to the stimuli in 2-minute intervals. This was to avoid boredom and have them engaged in a consistent activity throughout the experiment. After the baseline condition and before the experimental blocks began, participants were asked to open their book and begin reading. This was done to minimize the amount of movement during the experimental paradigm, as movement can add noise to the SCL signals. For the entirety of the experimental paradigm, the participants were asked to sit comfortably but relatively still and read silently as the noise played in the background. The experiment was made up of ten 2-minute experimental blocks. The stimuli were played at a single intensity level throughout the block; these levels were 35, 45, 55, 65, and 75 dBA. Half of the participants first heard the blocks in a rising order of intensity followed by a falling order (condition one, in Figure 1) The other half heard it in a falling order followed by a rising order (condition two, see Figure 1). This resulted in each participant being exposed to each level two times. There was a 12-second period of silence between each block.

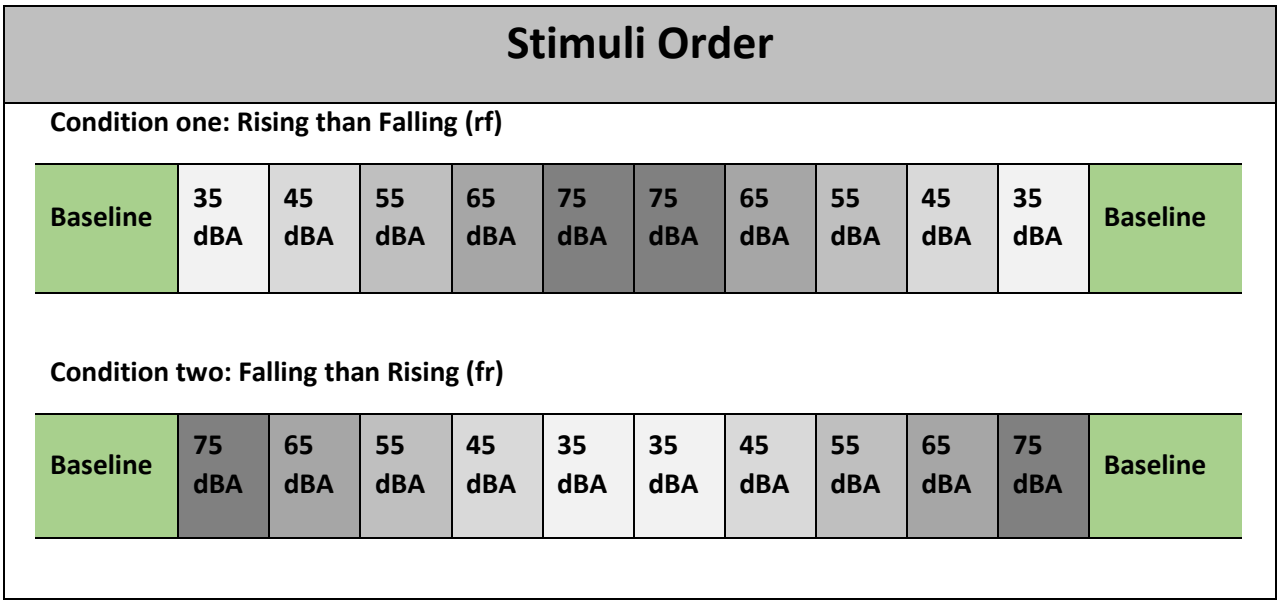


Figure 1. The figure above depicts the two possible conditions. Baseline blocks were 5 minutes in length. Each sound block was 2 minutes with 12 seconds of silence between them.

## Measurements

### Physiological measures

Physiological data was collected using the Biopac MP150 system (hardware) and the Biopac Systems, Inc.'s AcqKnowledge 4.3 (software) using the following module and configurations.

#### *Electrodermal activity/ Skin Conductance*

Recordings of skin conductance were collected using the Biopac GSR100C amplifier module. Two standard-size (8 mm contact area) Ag/AgCl surface electrodes (Biopac's model EL507) were placed on the palm of the participants non-dominate hand with adhesive tabs and additional Biopac's GEL101 isotonic gel. Prior to placing electrodes, the skin was wiped with a paper towel dampened with distilled water to standardize hydration. Recordings were obtained using a constant voltage system in which a very small (0.5 V) voltage was applied across the

electrodes as described in Biopac's Application Note AH-187. The electrodes were left in place for at least 5 min before data collection began (Potter & Bolls, 2011).

Electrodermal activity was evaluated using AcqKnowledge 4.3 software (BiopacSystems, Inc.) Mean tonic SCL was calculated from the average SCL in the two baseline conditions. This mean was used to normalize the experimental block measurements (henceforth "Normed SCL").

## Analysis

To analyze the data, we first ran a mixed effects model using the lme4 library (Bates et al., 2015) in R to run a multilinear analysis to get parameter estimates. Next, we ran an ANOVA using the car library (Fox & Weisberg, 2018) which included Type II Wald F tests with Kenward-Roger df to test the significance of these factors and interactions. In these models Sound Intensity Level (in dBA), Direction (rising or falling), and Condition (rising first vs. falling first) were fixed effects and participant was set as a random effect. The response of this model was the mean Normed SCL for the block. All effects were set as factors and the alpha level was set at $p < 0.05$. Plots were created using ggplott2 library for R (Wickham, 2016).

## Results

The results of our ANOVA found one independent factor and several interactions had statistically significant effects on SCL. The only factor that was independently statistically significant was Sound Level ($F(4, 279) = 3.656$, $p = 0.006$). There was a general trend of blocks with greater sound level intensities inducing larger responses with the highest mean SCL response being for 75 dBA (mean 0.19015) and the 35dBA with the lowest (mean, -0.09351). 75 dBA (mean 0.19015) and the 35 dBA with the lowest (mean, -0.09351).

Additionally, there were three, interaction effects that were significant, which included Sound Level and Direction, ($F(4, 279) = 2.825$, $p = 0.025$), Sound Level and Condition ($F(4, 279) = 2.656$, $p = 0.033$), and Direction and Condition ($F(1, 279) = 18.316$, $p > .001$). Full results of the ANOVA can be found in Table 1.

Table 1. ANOVA table for Normalized Skin Conductance Levels.

**Response: Normed Skin Conductance Level**

| **Factor** | **F value** | **Degrees of freedom** | **Residual degrees of freedom** | **Pr(>F)** |
|---|---|---|---|---|
| Sound Intensity Level (dBA) | 3.6556 | 4 | 279 | 0.006388 * |
| Direction (Rising or Falling) | 0.4140 | 1 | 279 | 0.520453 |
| Condition (rising first vs. falling first) | 0.1259 | 1 | 31 | 0.725148 |
| Sound Intensity Level by Direction | 2.8245 | 4 | 279 | 0.025304 * |
| Sound Intensity Level by Conditions | 2.6562 | 4 | 279 | 0.033287 * |
| Direction by Condition | 18.3158 | 1 | 279 | 2.575e-05 * |
| Sound Intensity Level by Direction by Condition | 1.2453 | 4 | 279 | 0.291972 |

*Note: An asterisk * indicates a statistically significant finding (p value < .05).*

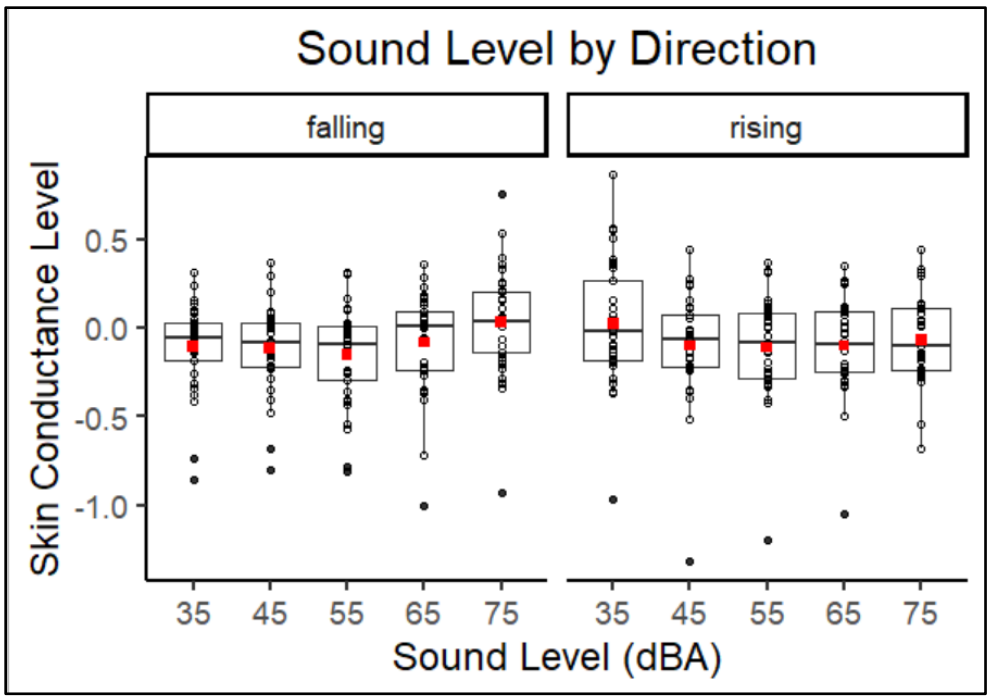


Figure 2. These box plots allow us to compare the interaction of Sound Level by Direction (rising vs. falling). It is important to note that the order of presentation is different between the two conditions. In the falling condition level 75 dBA is the first block and in the rising condition 35 dBA is the first condition. The red circles indicate the mean values.

When we look more closely at the interaction between Sound Level and Direction, depicted in Figure 2, we see an interesting effect. The largest response comes from the first stimuli whether it be the 35 dBA stimuli, in the rising direction, or the 75 dBA stimuli in the falling direction, showing that the effect of noise level is superseded by an effect of order. The largest response comes from the first stimuli whether it be the 35 dBA stimuli, in the rising direction, or the 75 dBA stimuli in the falling direction, showing that the effect of noise level is superseded by an effect of order. We then see another unique difference between these 2 conditions on sound level where there is a greater range in mean SCL in the falling condition.

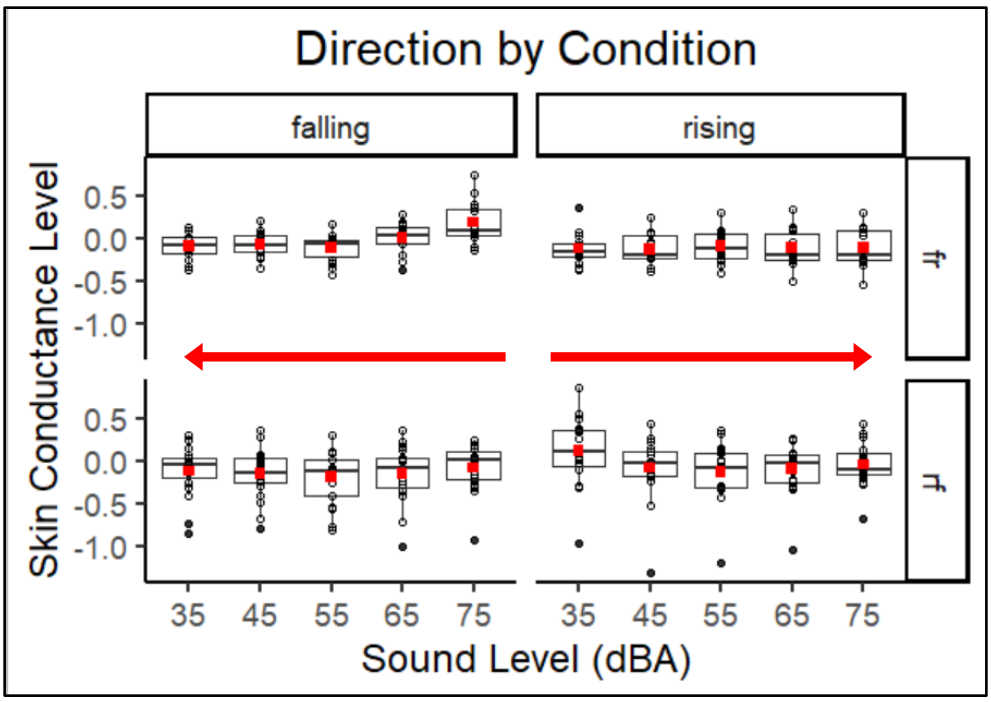


Figure 3. These Boxplots show the interaction between the Direction of the stimuli and the Condition, falling than rising (fr) vs. rising than falling (rf)). The red circles indicate the mean values. Arrows have been included to illustrate the order of presentation of the stimuli in the given condition.

The results depicted in Figure 3 also help us to better interpret the effects seen in the last 2 interactions Sound level by Condition and Direction by Condition. Condition (rf vs. fr) is very similar to order as by knowing if it is a rf or fr condition you know the order of presentation for each stimulus and that is apparent in its effect with Sound Level. In Figure 3 we see a continuation of the primary stimuli effect but on a larger level as we can see all ten blocks for each condition. Here we see in the fr condition the largest response belongs to the 75 dBA block in the falling direction (the first stimuli in the condition) and this is also seen in the rf condition where the first stimulus is the 35 dBA condition in the rising direction.

The last statistically significant interaction is between Direction (rising or falling) and Condition (rf vs. fr) illustrated in Figure 3. Here it seems that the second grouping within a condition for example, the falling order in the rf condition (see bottom left chart in Figure 3) has

less variability than in the first order in that condition. For example., the rising order in the rf condition (see the bottom right chart in Figure 3)

## Discussion

The goal of this study was to investigate the impact of sound level on AA response while trying to account for the possible effects of participants habituating/adapting to a sound stimulus. With the larger goal of using these findings to better maximize the range of AA used in experimental conditions.

### Sound Level

As was expected our ANOVA found that Sound Level on its own was a significant contributor to normed SCL. This is consistent with the literature for other stimuli that reports that increases in stimuli intensity increases AA and its physiological correlates (Kyle & McNeil, 2014). However, although Sound Level was a significant factor for manipulating SCL this study found several statistically significant interactions that must be taken into consideration if one is looking to utilize Sound Level to manipulate AA within a study. As we will discuss there were several factors that can diminish or negate the effects of Sound Level on SCL. These effects most likely are the result of the same phenomenon.

### Adaption and Habituation

The most likely interpretation of the significant interaction effects seen in this study, which included Sound Intensity Level by Direction, Sound Intensity Level by Condition, and Direction by Condition is that they are all coming from the same phenomenon, sensory adaptation which leads to habituation of ANS responses. In both interactions that involved Sound Level, we saw

that response was highly influenced by the initial stimulus, whether that stimulus was at 35 or 75 dBA it induced the greatest response. After this response the difference in the magnitude of response was diminished for all future stimuli. When we set the experiment to start with a 35 dBA block in the rf condition we see that there can be little change from that point forward, making "rising" conditions not as advantageous for a researcher looking to maximize the range of AA within an experiment.

## Conclusion

Although Sound Level, in the range utilized by this study, significantly affected SCL it was clear that habituation/adaptation greatly impacted autonomic response throughout the course of the experimental paradigm. The implications of these findings are significant and should be considered in the design of future studies that use sound stimuli to induce various levels of arousal. This study found that participants quickly responded to the onset of auditory stimuli before adapting to sound level in the range of 35-75 dBA. From these findings we can see that to get a maximal effect of Sound Level, the first condition needs to use the most intense stimuli, unless methods for inducing rapid recovery from habituation can be found and implemented.

The finding that the greatest level of AA occurs with the first stimulus shows several disadvantages in using this type of stimuli. Such weaknesses could create several issues with research designs that need to control for confounds by counterbalancing order, for example if there are concerns about a learning effect for a task or fatigue making the sound stimuli used in the present study unsuitable for this type of work. To better address these issues future studies should investigate methods to speed recovery from habituation and focus more on factors that affect response recovery. Another possible solution that may help prolong and increase AA that should

be explored are methodologies to induce sensitization. Sensitization is the opposite phenomenon of habituation, where increased exposure to a stimuli increases response.

Another limitation in this methodology that became apparent was that the changes in the block may not represent the full range of AA response that could be safely elicited. Possible ways of addressing this, though it may be harder to quantify the "dose", would be to use sound stimuli that have a more variable signal as this may increase AA and make the sound harder to habituate to (Zwicker & Fastl, 1999) and knowing the exact dose may not be as large of an issue if researchers move away from more blocked dose designs. Overall, it appears unlikely that a block design with block level analysis is the best methodology for getting a wide range of distinct AA levels. Fortunately, when the goal of a study is to index the effects of varying levels of AA on a behavior or on task performance, the block itself is of little theoretical importance. For studies that have trials within a block, discrete trial by trial measurements of AA could be a good way of breaking down blocks for more granular data. In this way, researchers can utilize these methodologies to increase the numbers of unique levels of AA to better understand these relationships.

# CHAPTER 2: THE EFFECT OF AUTONOMIC AROUSAL ON VISUAL ATTENTION

## Introduction

There is a growing interest in Autonomic Arousal (AA) and its impact on attention (Bellato et al., 2020; Critchley, 2005; Diamond et al., 2007; Lee et al., 2012; Mather & Sutherland, 2011). Autonomic Arousal (AA) has traditionally been studied in relationship to the function of the peripheral sympathetic nervous system. However, there is a growing body of work that suggest that increases in sympathetic activity not only influences the sympathetic nervous system, but also influence performance on multiple cognitive and behavioral tasks improving task performance in some conditions and hurting it in others (Dodson, 1915; Lee et al., 2012; Mather & Sutherland, 2011; Yerkes & Dodson, 1908). There are multiple factors hypothesized to contribute to these changes but the predominate hypothesis is that this is mediated through changes in attention (Lee et al., 2012; Mather & Sutherland, 2011; Robbins, 1997; Tracy et al., 2000). Yet, there is still a large gap in the understanding of the exact nature of this facilitation, how these changes interface with task demands and why some behaviors continue to improve with increased arousal while others fall apart at high levels of AA. Gaining a better understanding of this relationship would have many implications and could not only help us to develop methods to improve task performance for the general population but also help us better understand the etiology behind conditions in which individuals have the triad of autonomic, attentional, and behavioral differences, such as autism spectrum disorder (ASD) attention-deficit/hyperactivity disorder (ADHD), and schizophrenia among other conditions (Bellato et al., 2020; Carter et al., 2010; Corrigan et al., 1990; Elsabbagh et al., 2013; Keehn et al., 2013; Morris et al., 2013; Orekhova & Stroganova, 2014; Strauß et al., 2018; Zwaigenbaum et al., 2005).

## Attention

Attention is the allocation of one's explicit cognitive resources. As with most resources, our mental capacities are not unlimited. An organism only has so many neurons they can devote to a task and a limited amount of metabolic resources such as oxygen and glucose available (Scalf et al., 2013). Due to these limitations, we need systems and principles that guide these resources to behaviorally relevant stimuli, so hopefully they can be appropriately attended to.

### *Biased competition*

The allocation of attention is not random; our neural networks are predisposed to have a greater response to certain features/objects, giving them a competitive advantage in the fight for neural representation. This principal is known as biased competition (Desimone, 1998; Desimone & Duncan, 1995). These biases can stem from top down or bottom up and make some stimuli more likely to be attended to while potentially blinding us to other stimuli that do not receive these resources. This preference towards certain stimuli is known as a bias, and we refer to the features or objects that we show a bias towards as being salient. Biases can lie on a spectrum with very strong biases recruiting more resources, which can increase the likelihood it will be remembered and allow for more detailed perception of that object.

A stronger bias towards one stimulus can not only prioritize that stimulus but it can also actively suppresses the perception of less salient stimuli which, can result in an individual becoming perceptually "blinded" to it (Macdonald & Lavie, 2011; Mack, 2003; Raveh & Lavie, 2015; Scalf et al., 2013). Having these biases and the strength of biases has its tradeoffs; we may not perceive everything, but we can prioritize important stimuli and devote a sufficient amount of resources to allow us to process them.

Changes in attentional bias can directly alter behaviors and task performance. Improved biasing to task relevant stimuli can result in quicker reaction times, better working memory, and better memory consolidation (Desimone & Duncan, 1995; Lee et al., 2012; Mather & Sutherland, 2011).

On a behavioral level this biasing influences our seemingly "automatic" interactions with our environment, such as initiating and directing eye movements which can help us to prepare for further interactions with the environment (Desimone, 1998).

However, we live in an ever-changing world and the optimal degree of biasing, or of attentional "focus" may need to change. For example, if you are walking across an open campus, it may be better to be scanning and consistently reorienting your attention to allow you to be more aware of multiple objects in your environment that you may need to navigate around. In contrast, when you need to study you might prefer to focus on very specific materials so that you will be able to retain the information so that you can pass an exam.

Knowing that context may be an important signal for indicating changes in the needed degree of focus of attention it would make sense that there may be responses that occur when there are changes in the environment that help an individual adapt to the changing attentional demands. As discussed above one possible mechanism for this could be autonomic arousal.

**Arousal**

Like the brain the rest of the body works with a limited number of resources to support physical needs and activities. At any given time, the optimal allocation of these resources may fluctuate based on changing environmental demands. For example, if a threat such as an angry bear appears it may be more useful for blood and oxygen supplies to be prioritized to your limbs, which can help you respond to this threat, than to your digestive track, which would not provide

immediate support in the given situation. The body regulates these resources through a response called Autonomic Arousal (AA). Arousal will be defined in this paper as "the physiological and cognitive response to stimulation" (Lacey, 1967; Orekhova & Stroganova, 2014). Although many papers use the term "autonomic arousal" or arousal to describe this phenomenon in reality these studies report the response of only one of the three divisions of the autonomic nervous system, the sympathetic division (Keith et al., 2019; Lee et al., 2012; Mather & Sutherland, 2011; Orekhova & Stroganova, 2014; Tracy et al., 2000). The sympathetic nervous system responds to stimuli in ways that prioritize systems that prepare the body for immediate action such as prioritizing blood flow to skeletal muscles and suppressing digestive functions such as gastrointestinal peristalsis. These changes are often described as a "fight, flight, or freeze" response (Karemaker, 2017; Stefan Bracha et al., 2004; Waxenbaum et al., 2021).

These are spurred on from a cascade of neurological and chemical activity which can be challenging to measure in real time. Fortunately, researchers can measure increases in AA in the peripheral activity of the sympathetic nervous system through the changes it produces such as blood pulse volume, heart rate, and sweat to name a few (Boucsein, 2012; Goodwin et al., 2006; Keith et al., 2019; Tracy et al., 2000). Of these techniques one of the methods that is particularly useful is the measurement of palmer electrodermal activity.

This change in electrodermal activity is due to sweat rising within the eccrine ducts and its excretion onto the skin. Since sweat is largely made up of salt and water these changes increase the conductance, the ability for electric current to flow, across the palm. The measure of this electrodermal property is known as skin conductance level (SCL). Measures of SCL are highly correlated with autonomic arousal and are easy and inexpensive to collect (Boucsein, 2012; Boucsein et al., 2012); these properties make it a commonly used method to approximate degree

in sympathetic response (Boucsein, 2012; Keith et al., 2019; Tracy et al., 2000). Due to these factors and its wide use in the field we will be utilizing this technique to approximate AA in our participants.

Although much of our basic and current classification of autonomic arousal is based on its effects on efferent changes produced by the sympathetic nervous system, there is a growing body of evidence that there are cognitive changes that occur in concordance with this activity (Lee et al., 2012; Mather & Sutherland, 2011). These changes can be seen in measures of cognitive and behavioral performance. Though we don't fully understand the mechanisms behind these changes there is a growing body of literature that describes the changes in performance for different tasks at various levels of AA, which are helping researchers get to the basics of this relationship.

### *Attention and Arousal*

As alluded to in our discussion of attention, our attentional demands are ever changing, and we need efficient automatic mechanisms to help us to quickly adapt to changing environmental demands. Sometimes we need a stronger "filter" for information to devote cognitive resources more efficiently to more critical information. As we discussed, AA seems to help the body to quickly adjust the allocation of resources to best adapt to changing needs. But is there evidence that AA may effect attention? This kind of relationship had been hypothesized as early as 1959 when Easterbrook first theorized that arousal limits the number of cues available for the individual to use, like a narrowing of a spotlight, to help us to better focus on task demands (Easterbrook, 1959).

Many years later this interaction between attention and arousal was then directly applied to the biased competition theory in what Mather and Sutherland call "arousal-biased competition"(Mather & Sutherland, 2011). They noted in 2011 that several studies have found that

arousal heightens the bias for goal relevant stimuli and improves memory consolidation for those stimuli. However, arousal does not indiscriminately boost general cognitive ability as it also decreases the perception of task irrelevant stimuli. Combined, these processes may help to "focus" attention. This arousal-biased competition has been shown to have the dual effect of both boosting perceptual learning of salient stimuli while impairing learning for non-salient stimuli (Lee et al., 2012).

Researchers who look at the attentional systems level (as opposed to the more cellular level approach used in the biased competition research) have describe the same phenomena: multiple arousal systems "modulate" attention by "narrowing the spotlight" on the task relevant stimuli (Orekhova & Stroganova, 2014).

However, looking at this as a perfect focusing of the spotlight may be too simplistic of an approach, especially as many researchers argue that we should think of attention more as a series of filters that are applied then a spotlight that can be directed (Wimmer et al., 2015). Findings from behavioral research suggests that this relationship maybe more complicated than just a simple tuning into the correct stimuli but more of an extreme filtering, which could result in important information being lost, just as the researchers of biased competition and attentional blindness have described (Desimone & Duncan, 1995; Mack, 2003). This is important to consider as we look at the behavioral evidence of this effect, where we see mix results on the benefit of arousal on task performance.

### *Cognitive Task Performance and Arousal*

Performance researchers have long known that there are various relationships between task performance and levels of AA. Many studies have shown that increases in AA and factors known to increase AA such as stress, excitement, and fear among others alter performance on cognitive

tasks (Diamond et al., 2007; Dodson, 1915; Keith et al., 2019; Yerkes & Dodson, 1908). The most commonly cited interaction is described as an "inverted U shape" by many authors (Arent & Landers, 2003; Rietschel, 2006) and was popularized by Donald Hebb's interpretation and illustration of Yerkes and Dodson's work where Hebb depicted an inverted U-shaped relationship between arousal and task performance (Hebb, 1955). In this model initial increases in autonomic arousal increase task performance until an optimal level of arousal is reached, after which additional increases in AA begin to have an inverse effect on task performance, see Figure 4.

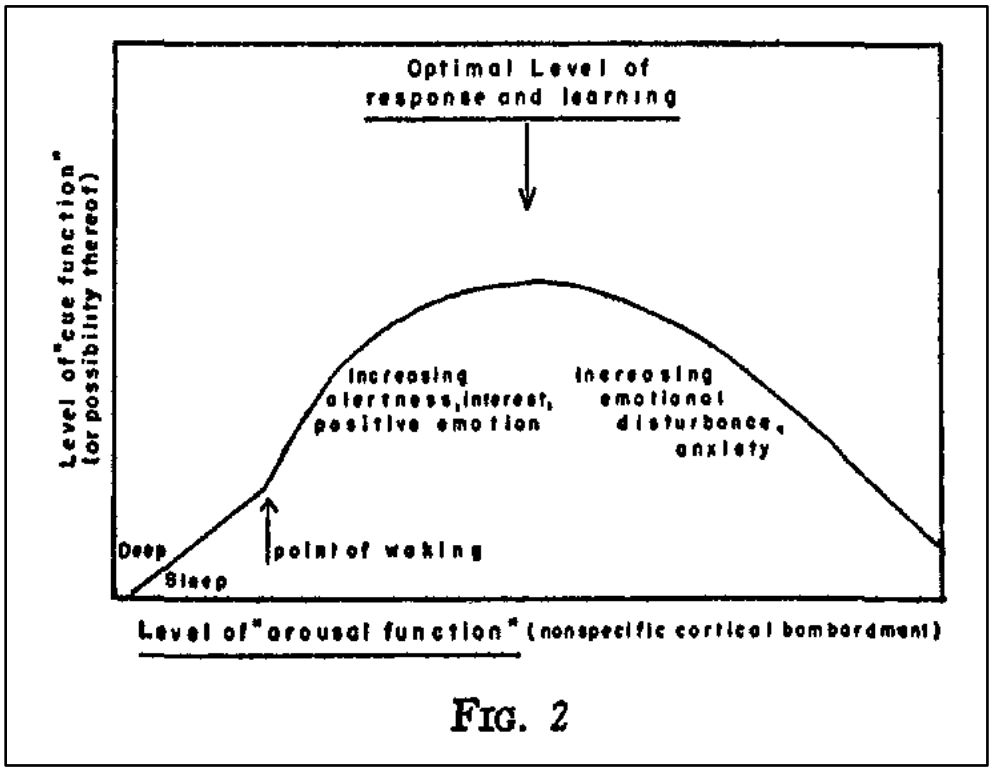


Figure 4. This figure depicted above is from Hebb's 1955 paper (Hebb, 1955) which is often researchers' reference point for describing Yerkes and Dodson's findings which may explain the widely cited "inverted U shape" to describe Yerkes Dodson's findings (Yerkes & Dodson, 1908).

This depiction is not completely dissimilar to the findings in Yerkes and Dodson's 1908 paper for which this relationship is named, Yerkes and Dodson did report that performance on

difficult tasks was similar to what Hebb later described, and they noted that there was a v shaped relationship where initial increments of AA increased task performance until an optimal level was reach with additional levels of AA decreasing performance. However, Hebb and much of the research community overlooked the other relationship, described in that and subsequent work, for what were described as simpler tasks. For these tasks, there was more of a dual linear relationship where task performance improves with increasing AA until performance hits a peak level before leveling off with any additional increases in AA (Dodson, 1915; Yerkes & Dodson, 1908). This relationship is illustrated in the Figure 5. Yerkes and Dodson's 1908 findings and Hebb's interpretations of it are commonly referred to as the Yerkes-Dodson Law (Cole, 1911; Corbett, 2015; Hebb, 1955).

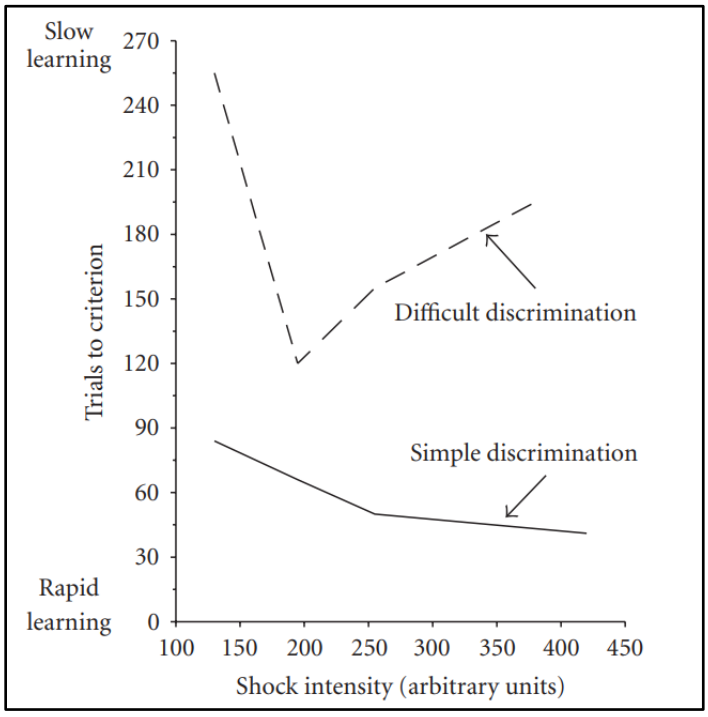


Figure 5. This image is Diamond et. al.'s illustration of the findings from Yerkes and Dodson's 1908 study (Diamond et al., 2007).

These findings of different relationships between task performance and arousal depending on the task were the first indication that the impact of arousal my carry its own biases in what systems it may be supporting. A key to understanding which systems may be involved is by looking at what features are commonly used to separate difficult task and simpler tasks in human studies of the Yerkes Dodson law and what features make these tasks different. In more recent studies meant to replicate these findings the difference in difficulty between "simple" and difficult task are qualitatively and not quantitatively determined, where difficult task are ones that require split attention and working memory and "simpler" task are more automatic such as a fear condition response or simple n- back tasks (Diamond et al., 2007; Keith et al., 2019). These tasks that have been labeled as simple or difficult may rely on different attentional systems to efficiently execute the task demands. By looking more closely at the different response patterns to arousal and task performance and the different features of these task we may be able to better understand the mechanisms behind these relationships and how AA helps or hinders performance on these responses. To look at this in the context of attentional control one would need to utilize a task that can be employed to compare different components of attentional control to better understand which attentional component AA could be bolstering.

**Attentional Task**

A highly validated tool that has been used to study the automatic properties of attention in many populations, including those with autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and schizophrenia, is tracking an eye movement called a saccade (Keehn et al., 2013; Kleberg et al., 2020; Mosconi et al., 2009; Sereno & Holzman, 1995). A saccade is the quickest type of eye movement (around 200 ms or less) (Purves et al., 2001) and is often a result of the automatic "visual grasp reflex" which is an automatic orienting response

(Hess et al., 1946). These movements can give us insights on the more automatic orienting of attention as they can be facilitated or inhibited by competition between multiple attentional systems which results in differences in the reaction time and directions of the eye movement.

One task developed to study the interaction between these systems is called a gap-overlap paradigm. In this type of study, a participant is often asked to stare at an object that appears in the center of the visual field called the "central stimulus". Focusing on this central stimulus activates visual fixation neurons which fire to hold attention on this target, thus inhibiting saccades. The subject is then instructed that at some point another object will appear to the left or right and when it does, they are to look at this "peripheral stimuli"/ target without moving their head. Although instructions are given this is not something that even necessarily requires a voluntary response as novel stimulus often illicit the "visual grasp reflex" (Hess et al., 1946). The neurons that facilitate this response ("saccade neurons") are in competition with the fixation neurons for control of the subject's visual attention. Not only are they in competition but they have a reciprocal innervation where the activity of one group can directly suppress the other group (Munoz & Everling, 2004). The experimental manipulation comes in a difference between conditions. In some conditions there is a short gap where the central stimulus disappears at least 200 ms before the peripheral stimulus appears (the gap condition) and in another condition the central stimulus does not disappear (the overlap condition). Typically, it is found that the reaction time (RT) which is the amount of time from when the peripheral stimulus appears until the eye first initiates the saccade to the peripheral target (called a pro-saccade) is longer in the overlap condition than it is in the gap condition. This difference in RTs, sometimes called a gap-overlap effect, is thought to be due to the extra difficulty a participant has with disengaging with the central stimulus (stopping/out competing the fixation neurons) in the overlap conditions. Additionally, some researchers include a third trial type called

a “step” or “baseline” trial that is halfway between these two trial types. In these trials the target stimulus appears at the same time the central stimulus disappears (Keehn, Kadlaskar, et al., 2019) and typically the RT for these trials lies somewhere between the RT for gap and overlap trials. These tasks have been found to be a little bit more challenging for some of the populations as mentioned earlier, especially those with ADHD and ASD and these difficulties may give us some insight into the differences in attentional control between populations (Keehn, Kadlaskar, et al., 2019; Kleberg et al., 2020). For example in some studies individuals with ASD have been reported to have a harder time disengaging from the central stimulus, even in the gap conditions. This difficulty disengaging with the central stimuli slows down their ability to reorient their attention to the peripheral target slowing down their reaction times and increasing errors such as “no-shift trials” where the participant does not look away from the central stimulus. Some individuals with ASD even seem to receive less benefit from the 200 ms release from the central stimulus in the gap conditions. (Elsabbagh et al., 2013; Keehn, Kadlaskar, et al., 2019; Kleberg et al., 2017). Children with ASD have a harder time disengaging in a gap overlap task when compared to typically developing (TD) children and children with downs syndrome (Landry & Bryson, 2004) so much so that latency for looking away from the central stimulus at 14 months was found to be predictive of whether a child would later be diagnosed with ASD (Elsabbagh et al., 2013).

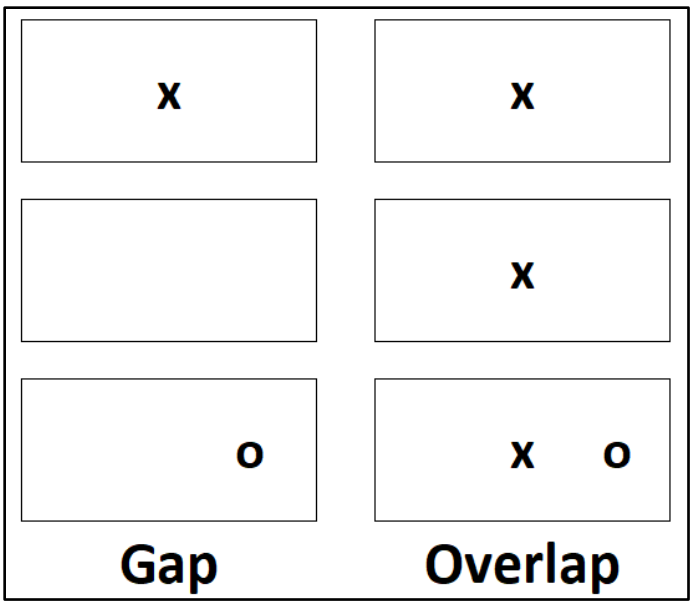


Figure 6. This figure depicts the differences in stimuli presentation in Gap vs. Overlap trials. Each trial starts off with a central stimulus, depicted as an "x" in the figure above. In Gap trials this central stimulus disappears at least 200 ms before the peripheral stimulus, depicted as an "o" in the figures above, appears. In the Overlap trials the central stimulus remains visible when the peripheral stimulus appears, thus the presentation of the two stimuli overlaps with one another.

An alternate version of this task adds a few more competitive factors which have been found to be helpful in discovering other attentional differences between populations with reported attentional issues. This paradigm is called an "anti-saccade" task. In this paradigm individuals are given similar instructions as they were in the pro-saccade task but with one key difference. They are instructed that they must look in the opposite direction of the peripheral stimulus once it appears; this eye movement is referred to as an anti-saccade (Munoz & Everling, 2004). Successful execution of this task requires other mechanisms of attentional control that compete with the systems utilized in the pro-saccade task. The first is a top-down inhibitory response, because a saccade is such a quick response and individuals are prone to look towards a novel peripheral stimulus and therefore it often takes preemptive suppression to successfully inhibit a pro-saccade eye movement before the participant is able to quickly plan and execute the anti-saccade (Coe &

Munoz, 2017; Everling et al., 1998; Munoz & Everling, 2004). Individuals who struggle with suppressing the "visual grasp reflex", will be much more prone to an erroneous pro-saccade movement before the correct anti-saccade. These pro-saccade error rates are very informative measures of top-down inhibitory control between populations and other factors. A meta-analysis also showed that individuals with ASD are also more error prone in anti-saccade tasks (Johnson et al., 2016).

Consequently, this task is thought to relate to cognitive flexibility. Because there are a variety of mechanisms at play in this condition, a combined analysis of the, step, gap and overlap conditions in both the anti-saccade and pro-saccade conditions are necessary to get a broader picture of the attentional control. A comprehensive analysis includes a comparison of the conditions, which can help disentangle where differences lie within and between populations. Ultimately, this allows us to test whether differences between individuals come from the voluntary saccade, the strength of the pull to a central stimulus, or the strength of top-down control. Researchers have found a variety of differences in patterns of responses. Again, the same populations such as those with ADHD, schizophrenia, and ASD (among many others) have difficulty with this task but the exact levels of where this difficulty is seen varies between populations (Gooding & Basso, 2008; Mosconi et al., 2009; Munoz & Everling, 2004; Optican et al., 2008; Terao et al., 2011; Walton et al., 2015).

What is still not known is how or if the relationship between these attentional mechanism (fixation, orienting, top-down control) respond to increases in arousal and how potential differences in these interactions may relate to ASD related behavioral traits which can be quantified using tools such as the Autism Quotient (AQ).

**Populations Where it May be Important**

Individuals with Autism spectrum disorder (ASD) have documented differences in regulating arousal, (Goodwin et al., 2006; Orekhova & Stroganova, 2014) attention, (Keehn et al., 2013, 2016; Keehn, Westerfield, et al., 2019) and responses to sensory input (Leekam et al., 2007).

We know that attention and arousal guide how we respond to sensory stimuli and that the neural systems that govern attention and arousal are highly interconnected, with arousal modulating attention (Mather & Sutherland, 2011; Tracy et al., 2000).

Although differences in attention and arousal are well documented in ASD and are among the earliest ASD symptoms to manifest (Elsabbagh et al., 2013; Zwaigenbaum et al., 2005), ASD is diagnosed based on behavioral differences that deviate from "typical" behaviors to an extent where they are deemed "clinically significant". These behavioral differences include "stereotyped or repetitive motor movements, insistence on sameness, highly restricted, fixated interests that are abnormal in intensity or focus, and hypo or hyperreactivity to sensory input or unusual interests in sensory aspects of the environment." (DSM-5). A key symptom listed in the DSM-5, is that individuals with ASD have a high propensity to become hyper focused on topics or objects but it is also well documented that individuals with ASD often also have difficulty attending to task relevant stimuli when compared to their typically developing (TD) peers and can become easily distracted (Keehn et al., 2016; Liss et al., 2006).

At first these attentional and sensory symptoms may seem contradictory. How can one be hypo and hyper reactive to stimuli and both easily distracted but also at times, hyper focused? Although this may seem like a peculiar paradox, this is actually a common phenomenon in populations with documented issues with attention. For example, individuals with attention deficit disorder (ADHD) or with schizophrenia may have difficulty maintaining attention but also have a propensity for hyper focus at times (Ashinoff & Abu-Akel, 2019; Hupfeld et al., 2019; Ozel-Kizil

et al., 2016) and the parallels between these three diagnoses have led to direct comparisons (Ashinoff & Abu-Akel, 2019). Additionally, all three conditions have been documented to have differences in sensory processing (Ausderau et al., 2016; Carter et al., 2010; Liss et al., 2006; Morris et al., 2013) and arousal when compared to age-matched peers (Corrigan et al., 1990). The key to understanding why individuals present with seemingly paradoxical symptoms, may be because attention is not a singular measurable trait. Attention requires a complex balancing of input that is impacted by environmental needs. Difficulties in maintaining this balance may be a reason why individuals with ASD do not seem to maintain the same attentional equilibrium as "neuro-typical" peers.

**Attention and ASD traits across the population**

This is not to say that those with ASD are completely different from their peers who are considered "neuro typical". Research has found that the behaviors associated with ASD are found throughout the population using validated tools such as the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001; Lundqvist & Lindner, 2017) and The Social Responsiveness Scale–Second Edition (SRS-2) (Bruni, 2014). These scales have found that ASD traits do exist to varying degrees throughout the population who do not have a diagnosis of ASD. This makes sense as even within the population that receives a diagnosis of ASD these traits lie on a spectrum. To receive an official diagnosis of ASD these differences must be seen to a degree that is clinically significant, as defined by the DSM-5. Importantly, the diagnosis must also include social communicative differences and stereotyped/ repetitive behaviors. This means that it is possible for neurotypical peers to exhibit similar attentional deficits as those with ASD, but not to have all the behavioral traits needed for an official diagnosis of ASD. Likewise, those who have the behavioral traits seen in ASD may not have them to a degree that is clinically significant enough to result in a diagnosis.

This line of research has also found that the traits captured in these scales correlate with performance in other non ASD specific tasks such as mathematical aptitude (Baron-Cohen et al., 2001) indicating that variability in ASD related traits may relate to variability in general behaviors. Since these ASD traits may reflect attentional and/or arousal differences in ASD and likely fall along a spectrum, it is helpful to use tools like the AQ instead of using an ASD diagnosis.

**Manipulating Arousal**

To better understand the possible effects of AA on attention and how ASD like traits may affect this relationship we needed to utilize a methodology that could manipulate levels of AA in participants during an experimental paradigm. Although the goal of this study is to look at subjects in the young adult population, we wanted to implement an experimental paradigm that can later be applied to young adults and children with ASD. Past studies have shown that noise played at 75 dBA was an effective method to induce a heightened level of AA in children with ASD (Keith et al., 2019). As discussed in Experiment 1 we found that playing a relatively steady state HVAC like auditory stimuli at 75 -35 dBA can induce autonomic responses in young adult participants and that if we manipulate the noise level we can get a range of AA levels. With this information we designed our experiment to utilize the same sound stimuli that was used in Experiment 1 in this study. More information on the properties of this stimuli can be found in the Stimuli section of the Methods section below.

**Objective**

With this knowledge, we wanted to evaluate the relationship between AA level on task performance for step, overlap, and gap trials in both anti and pro-saccade tasks, as past studies have not aimed to directly measure the relationship between specific attentional behaviors and AA.

To manipulate AA, we used a sound stimulus played at different intensity levels. Additionally, we looked at how this relationship maybe altered by ASD related traits as indexed by AQ scores.

## Methods

### Participants

Experiment two had 41 young adult participants (23 women, 17 men, 1 prefer not to say), ages ranging from 18 to 38 years (M = 25.02 years; SD =5.06 years). All participants passed a hearing screening at 20 dB at 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz in both ears. Participants needed to meet the same criteria as was set for Experiment 1 which includes the following criteria. They could not have a history of neurological disease or impairment (e.g., severe head injury, seizure disorder, neuropathy, and neurological diseases such as Parkinson's disease) or other medical/health conditions or behaviors including smoking, substance abuse, heart disease, or diabetes as these factors are known to affect variables relevant to the current study. Additionally those who reported experiencing psychological or psychiatric problems such as depression or an anxiety disorder within the last 6 months or who received a score higher than 50% on a standard anxiety screener, the Geriatric Anxiety Inventory (GAI) (Pachana et al., 2007) , the Geriatric Anxiety Inventory (GAI) (Pachana et al., 2007) or depression screener, the Geriatric Depression Scale (GDS) (Yesavage et al., 1982), were excluded as these conditions have been shown to impact ANS function (Dieleman et al., 2010) and have been used in other ANS studies with a similar population (Francis et al., 2016; Love et al., 2021). In addition, individuals were excluded if they were currently on or had recently taken medications that can affect motor, autonomic function, cognitive performance, or the autonomic responses of interest (e.g., medications for attention deficit disorder, or selective serotonin reuptake inhibitors (SSRI), etc.). Individuals with pacemakers or other implanted electric medical devices were also excluded

because the use of skin conductance measurement is contraindicated in such cases. Additionally for this study, Experiment 2, participants had to also have normal or corrected to normal vision. This criterion was included to ensure that the participants could see the visual stimuli in the visual attention task included in this study. Individuals also took the Autism Quotient questionnaire which has a range between 0 - 50. (Baron-Cohen et al., 2001). Participant scores ranged from 4-31 (M=17.32 SD= 5.898).

Participants were asked to get a good night's sleep the night before the study. They were also asked to not eat or drink anything for one hour before coming into the lab and to not consume caffeine for 2 hours before coming into the lab. We ask the participants to not schedule their time for a period when they would typically have had consumed caffeine as to not have them in a state of caffeine withdrawal in the lab.

## Stimulus and Apparatus

### *Stimuli*

*Visual*

The experiment took place in a darkened single-walled sound booth (IAC Inc). During the study participants sat in a comfortable chair which was located approximately 1.5 m from each of the stimuli displayed. The stimuli were arranged in a semicircular display where the LEDS (light emitting diodes) displays were positioned at 0° (i.e., directly in front of the participants) and at -30° and 30° to the left and right of participant (see Figure 7.). LED (light emitting diode) displays were created using a 3D printer with an embedded Trinket micro controller (Adafruit Industries). The Trinket microcontroller was programed to interface with the Presentation script with the LED that comes mounted on the microcontroller. The LEDS were positioned at eye level when the participant was seated in the sound booth and programed to produce a white light when turned on.

*Audio*

The speakers (Hafler M5 Reference) that presented the audio stimuli were located at – 90 degrees and + 90 degrees, 1.5 meters away from the participant. The auditory stimuli were the same HVAC-like stimuli with the additional 333 Hz and 666 Hz harmonic component as was used in Experiment 1 (Love et al., 2021). The stimuli were set to play at 3 different levels, 75 dBA, 65 dBA, and 35 dBA. The sound levels were calibrated using a sound level meter (Larson Davis model 824) which was positioned between the 2 speakers at the level of the listener's head.

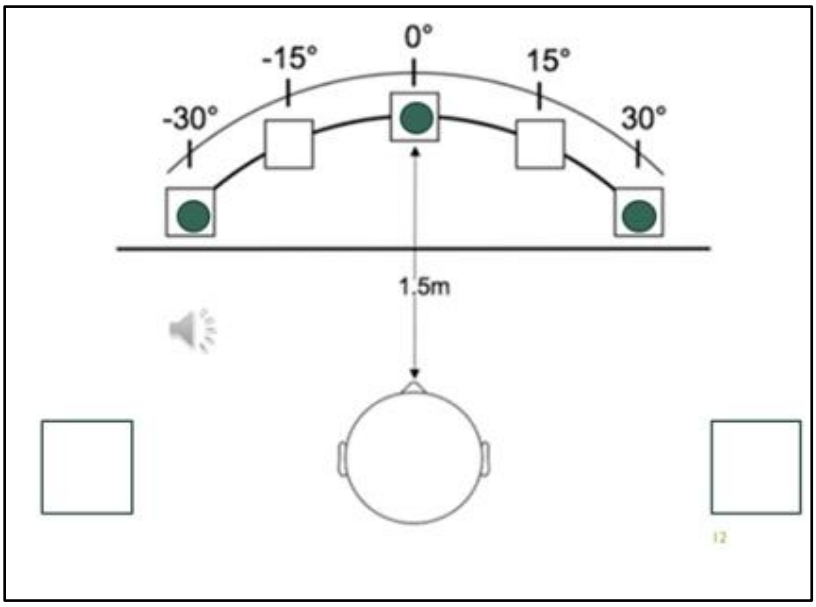


Figure 7. This image depicts the room set up. The green dots represent the location on the LED lights in respect to the participant. The central stimulus is at 0 ° and the peripheral stimuli are to the left and right at -30 ° (left) and 30 ° (right). Speakers are located at 90 ° (right) and -90 ° (left) in reference to the participant. This image is a modified version of an image originally published in Keehn, Kadlaskar et al., 2019 (Keehn, Kadlaskar, et al., 2019).

***Other Apparatus***

Additionally in the sound booth we had a 50" LED TV monitor mounted on the wall about 2m directly in front of the participant at head level. This screen was used to display a 5-minute

video of waves on a beach for our baseline task as well as display instructions. Except for when the relaxation video played during the two base line conditions the screen remained on and black and when instructions were given, the font appeared white. When instructions were given participants scrolled through them using a button-box (Cedrus RB-730).

To remind the participants to not move their head 2 metal bars constructed from rulers were positioned to the back sides of the participants' head. They were not meant to be constraints and did not directly touch the participants head unless they moved their head. These were meant to provide tactile feedback incase the participant began to lean during the experiment. These bars did not obtrude the participants' peripheral vision.

The presentation of the audio and visual stimuli was controlled using Presentation software (nbs.neuro-bs.com; version 11.8) using scripts written by the experimenters.

### ***Physiological measures***

Electrodermal activity and Electrooculography was collected using the Biopac MP150 system (hardware) and the Biopac Systems, Inc.'s AcqKnowledge 4.3 (software) using the following modules and configurations.

#### *Electrodermal activity/ Skin Conductance*

Recordings of skin conductance were collected using the Biopac GSR100C amplifier module. Two standard-size (8 mm contact area) Ag/AgCl surface electrodes (Biopac's model EL507) were placed on the palm of the participants non-dominate hand with adhesive tabs and additional Biopac's GEL101 isotonic gel. Prior to placing electrodes, the skin was wiped with a paper towel dampened with distilled water to standardize hydration. Recordings were obtained using a constant voltage system in which a very small (0.5 V) voltage was applied across the

electrodes as described in Biopac's Application Note AH-187. The electrodes were left in place for at least 5 min before data collection began (Potter & Bolls, 2011).

EDA data was reformatted from the collected AcqKnowledge (.aqc) file type to. mat using the AcqKnowledge 4.4 software. The .mat file contained 2-time locked channels, one channel of the EDA data sampled at 500 Hz and one channel with the event marker channel data. Electrodermal activity was then analyzed using MATLAB software (MATLAB 2019a, The MathWorks, Inc., Natick, Massachusetts, United States.). Using the event markers in the mean tonic SCL were taken for each trial calculated from the 500 ms preceding the onset of the peripheral stimuli.

Our correlate for arousal was a normalized value of the SCL from the 500 ms preceding from the onset of the peripheral stimuli. SCL were normalized for each participant by taking the max SCL from a calibration task where the participant squeezed a hand grip as hard as they could for 5 seconds. Using a physical calibration task is recommended as a more robust baseline when there maybe differences between participant reactivity to stimuli. This was done to insure better between participant comparison as is common practice.

$$Normed\ SCL = \left(\frac{Sample\ SCL}{Max\ SCL}\right)$$

*EOG Data Acquisition*

Eye movement was tracked using a technique called Electrooculography (EOG). EOG data was collected alongside the ANS data using the Biopac MP150 system using the Biopac EOG100C amplifier module. The gain of the hardware was set to 5000 (corresponding to an input gain of ± 2 mV), and filter bandwidth was set to 0.05–35 Hz prior to digitization. As with the autonomic data the data was obtained using AcqKnowledge 4.3 software (Biopac Systems, Inc.).

We used two, 4 mm reusable Ag/AgCl shielded electrodes (Biopac EL254S). Each electrode was filled with conductive gel made up of 0.5% saline (NaCl) in a neutral base to create an isotonic, 0.05 molar paste. The electrodes were then put on the lateral canthi of the participants' left and right eye using adhesive disks (Biopac ADD204).

*EOG Data Analysis*

EOG data was converted from the collected AcqKnowledge (.acq) format to .mat using the AcqKnowledge 4.4 software. The .mat file contained two, time locked channels, one channel of the EOG data sampled at 500 Hz and one channel with the event marker channel data. A saccade was identified when there was a rapid negative or positive deflection in the EOG signal that had a peak velocity greater than 50 degrees per second for a duration of at least 20 ms for the duration of the visual stimuli (1200 ms). After the script identified the saccade onset, the marked waveforms of each trial were than looked over by the researcher to identify any possible errors. For a saccade to be marked as acceptable/ correct the EOG signal needed to be steadily fixated at the central stimuli for at least 200 ms prior to the onset of the peripheral light stimuli. Trials where the participant did not have a steady fixation towards the central LED, or in trials where the initial saccade went towards the incorrect target location (e.g., saccade to left with target on right) were labeled by error type and excluded from the standard SRT analysis.

Saccadic reaction times (SRT) were identified as the length of time between the onset of the peripheral LED and the onset of the first saccadic eye movement directed toward a peripheral target. In the pro-saccade trials the target location was the same as the peripheral light stimulus and in the anti-saccade trials it was the opposite side. Due to individual's natural inclination to look towards the novel stimuli (light onset) saccades are commonly made to the incorrect direction in anti-saccade trials. Additional types of errors included anticipation errors, where a saccade was

initiated less than 80 ms after stimulus onset, and no shift trials where participants-maintained fixation and no saccade was attempted. These errors were coded by the researcher to use for later analysis.

Overall, the number of trials that met this criteria for acceptability and were included were 7,871of a possible 8,856 trials. However, in additional analyses we looked at error rates of when participants looked at the incorrect target vs. correct trials which is covered in our error analysis in the following sections.

## Procedure

### *Design*

Each session began with an ANS calibration task. During this task the participant was asked to squeeze a hand grip to elicit an increase in skin conductance level (SCL). This was used later during the ANS analysis for maximal SCL. The participant was then asked to breathe in as much as they could, to peak lung capacity, and then instructed to breathe out until they reached their end expiratory level to calibrate respiratory measures (not reported here). After this the researcher left the sound booth and turned off the lights. From this point on the participants did not directly interact with the researcher but was given text instructions through the monitor.

### *The Experiment*

First the participants sat comfortably in the sound booth for 5 minutes to get baseline measures and so that they could relax before the experiment began. During this block the lights were off in the sound booth and a video of waves on a beach played on the TV screen.

Next the participant preformed an EOG calibration task. For this task the LED lights were turned on individually starting first with the LED located at the left at −30° then at the center

location 0°, and finally at the right at 30°. This sequence was repeated 5 times in a row and was later used to interpret the EOG signal.

Next began the experimental paradigms see Figure 6. The experiment was made up of 2 conditions (pro and anti-saccade) each with three blocks. Every participant did all three pro-saccade blocks and then the anti-saccade blocks. The order was kept the same to maximize the effect of the task; priming the participants with the pro-saccade to increase the need for top-down control in the anti-saccade task (Munoz & Everling, 2004). Each condition was made up of an instruction, six practice trials, and 3 blocks. After each block there was a one-minute period after where the word "RELAX" appeared on the screen in front of the participant.

Before both the set of pro-saccade and anti-saccade blocks Participants were given instructions. In the instructions for the pro-saccade task participants were instructed that they were going to play the 'find the light' game. They were instructed to look at the center LED, then to move only their eyes to the location of the peripheral LED once the light turned on, and then to look back towards the central location to wait for the LED. For the anti- saccade task, the participants were told they were going to now play the "opposite game". They were instructed that this time instead of looking at the LED when the light turned on, they needed to look in the direction of the opposite LED, moving only their eyes, and then back to the center. After the instructions for each task the participant then did 6 practice trials in silence.

**Experimental Design**

| | 5 minutes | | | 2 min | 2 min | 2 min | | 2 min | 2 min | 2 min | 5 minutes |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **EDA calibration** | **Baseline 1** | **EOG Calibration** | **Practice** | **75 dBA** | **65 dBA** | **35 dBA** | **Practice** | **75 dBA** | **65 dBA** | **35 dBA** | **Baseline 2** |
| | | | Pro-Saccade | | | | Anti-Saccade | | | | |

Figure 8. The figure above reflects the experimental design. Additionally, between each experimental block there was a one-minute rest period, where participants were instructed to relax.

***Block design***

*Design conditions*

Within each block there were three trial types that occurred gap, step and overlap, *see Figure 9*. Each trial began when the central LED turned on for a random duration between 1300 and 1500 ms next, one of the peripheral LEDs turned on for 1200 ms In an Overlap condition, the central LED remained on, in a Gap condition the peripheral LED turned on 200 ms after the central LED turned off, and in the Step condition the peripheral LED turned on simultaneous with the central LED turning off. Finally, after the trial there was a 2000 ms inter-stimulus interval during which time no LED was seen.

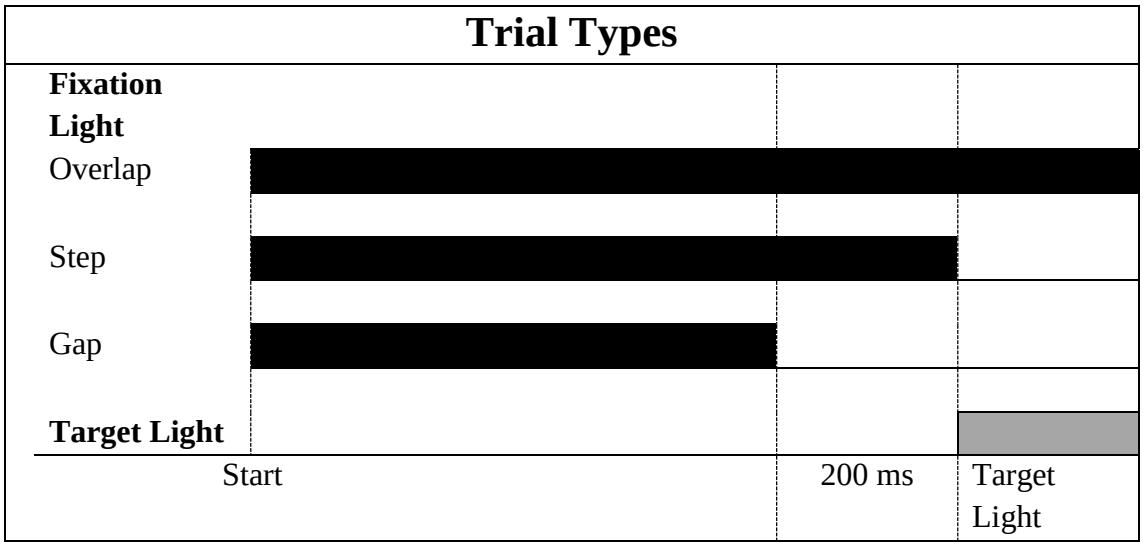


Figure 9. This figure shows the comparison between trial types. This figure is similar to one which can be found in Keehn et.al 2019 (Keehn, Kadlaskar, et al., 2019)

*Trials*

The two experimental conditions each consisted of three blocks of 36 trials for a total of 108 trials. Each block had 3 conditions (gap, step, overlap) with 2 sides where the peripheral light could appear (left, right). Conditions were varied in a pseudorandom order, each one appeared 6 times within the block. Each condition was presented an equal number of times within each block.

$$(\mathbf{2}\ \boldsymbol{Locations}\ \boldsymbol{x}\ \mathbf{3}\ \boldsymbol{Conditions} = \mathbf{6}\ \boldsymbol{trial\ types})\ \boldsymbol{x}\ \mathbf{6}\ \boldsymbol{times} = \mathbf{36}\ \boldsymbol{Trials\ per\ Block}$$

Figure 10. This formula summarizes the components of a block.

Each of the 3 blocks within a condition had a different level of background noise, starting from the loudest 75 dBA in the high autonomic arousal (AA) condition, 65 dBA in the medium AA condition and 35 dBA in the low AA condition each block lasted approximately 2 minutes.

## Measurements

### *Behavioral*

All participants completed several questionnaires to gain insights on related behaviors. Each participant completed the Autism Quotient scale (Baron-Cohen et al., 2001). To get measures of traits commonly seen in those who are on the autism spectrum, all participants completed the 50 question Autism Quotient (AQ) questionnaire (Baron-Cohen et al., 2001). Scores of this task were collected to be used as a possible covariate as numerous studies have found that AQ related traits may impact ANS responses (Lory et al., 2020; Vaughan Van Hecke et al., 2009). Higher AQ scores relate to a higher likelihood of an ASD diagnosis. Baron-Cohen et al.'s study of the adult version of the AQ found that individuals with a diagnosis of ASD scored 26 or above, but there is some overlap in AQ scores between those who do and do not have an ASD diagnosis. The same study found 80% of individuals with ASD scored 32 +, but only 2% of those without a diagnosis of ASD had a score of 32 or greater. The average score for non-autistic males is 17 and 15 for non-autistic females (Baron-Cohen et al., 2001)

## Analysis

### Saccade Reaction Time

To analyze the data, we first used a mixed effects model, we used the lme4 (Bates et al., 2015) library in R to run a multilinear analysis to get parameter estimates. Next, using the "car" library (Fox & Weisberg, 2018) we ran an ANOVA using Type II Wald F tests with Kenward-Roger df. In this model Task (pro or anti-saccade, Trial Type (gap, step, or overlap) and the normed SCL (from here referred to as SCL) were fixed effects and Participant was added as a random effect. The response of this model was saccade reaction time (RT). These models only included correct trials, excluding trials were there was an error such as a saccade made in the wrong direction, an anticipatory saccade (saccade occurring before 80 ms), and no shift trials (where no saccade was attempted). We set Participant, Task, and Trial Type as factors.

### Error rates

Another important indicator of task performance is error rates. To investigate the impact of these factors on error rates we compared correct trials with trials where participants made the error of looking in the opposite direction of the condition dependent target for example, looking to the peripheral light in an anti-saccade task instead of looking in the opposite direction. To look at the factors that could affect the proportion of correct trials we ran a Chi-square analysis using the "lmerTest" library in R. In this model we included the same fix and random effects as in the ANOVA model for reaction times and Participant, Task, and Trial Type were set as factors.

## Additional modeling and post hoc

### *ANOVA*

To better interpret findings of our ANOVA when significant factors included 3 or more groups, we conducted Tukey HSD Test for multiple comparisons using the emmeans package from the "cran" library in R. These tests were run with asymptotic degrees of freedom and significance was set to be $p < .05$.

### *Chi-square*

To better interpret findings of our Chi-square analysis when significant factors included 3 or more groups, we conducted a post hoc pairwise comparison with a Bonferroni correction with the significance level of $p < .05$. Results are reported using the log odds ratio scale.

### *Additional test of experimental design*

Additionally, we did an added planned ANOVA to learn more about our experimental design. We again used a mixed effects model, with the lme4 (Bates et al., 2015) library in R to run a multilinear analysis to get parameter estimates. Next, using the "car" library (Fox & Weisberg, 2018) we ran an ANOVA using Type II Wald F tests with Kenward-Roger df. In this model Task (pro or anti-saccade, and Block (first (74 dBA), second (65 dBA) and third (35dBA) were fixed effects and Participant was added as a random effect. The response of this model was Normalized mean Skin conductance level for the block. We also set Participant, and Task, as factors.

To better interpret and visualize statistically significant findings we plotted our data using the "ggplot2" library for R (Wickham, 2016).

## Results

### Initial confirmation of Block Design

The first ANOVA that looked at our study's design found that Block (Noise level) was highly significant ($F(2, 200) = [42.980]$, $p < .001$). In Figure 11. you can see that this had the intended effect where Block 1 (75 dBA condition), had the highest arousal and Block 3 (35 dBA) had the lowest. Although Task itself was not statistically significant on its own ($p=0.055$) it was approaching statistical significance. That along with a Significant Block by Task interaction: ($F(2, 200) =[ 4.967]$, $p = 0.009$ ) was something that we wanted to be careful about. However, after reviewing the data and because we are looking at trial level and not Block level data, we felt comfortable with this small yet statistically significant difference. The full ANOVA table can be found in the appendix Table 4. An additional HSD Test with Block as the factor test found that all 3 blocks were significantly different from one another first vs. second ($p = <.001$), first vs. third ($p = <.001$), and second vs. third ($p = <.005$) the full table (Table 5) can be found in the appendix.

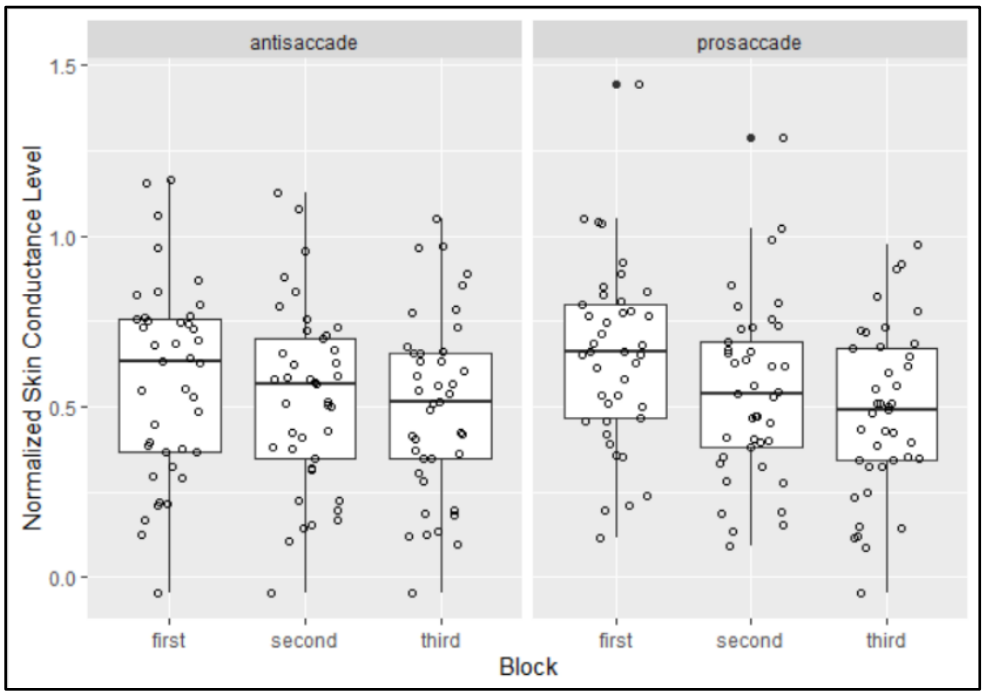


Figure 11. This Box plot shows the comparison for participants' mean Normed SCL between Task and Trial Type. The first Block had the sound level set to 75 dBA, the second, to 65 dBA and the third block was set to 35 dBA.

**Main Results**

Table 2. AVOVA Table for Normed Saccade reaction time.

**ANOVA results for Response Reaction Time**

| Factor | F | DF | DF.res | Pr(>F) |
|---|---|---|---|---|
| Normed SCL | 3.0894 | 1 | 584.4 | 0.0793278. |
| Task | 1384.7461 | 1 | 7770.4 | < 2.2e-16* |
| Trial Type | 140.5293 | 2 | 7811.6 | < 2.2e-16* |
| Autism Quotient score | 0.1875 | 1 | 35.5 | 0.6676263 |
| Normed SCL: Task | 93.6371 | 1 | 7828.5 | < 2.2e-16* |
| Normed SCL: Trial Type | 2.9209 | 2 | 7822.7 | 0.0539428 |
| Task: Trial Type | 8.5240 | 2 | 7812.7 | 0.0002005 * |
| Normed SCL: Autism Quotient score | 9.1884 | 1 | 430.0 | 0.0025827* |
| Task: Autism Quotient score | 19.6788 | 1 | 7838.3 | 9.286e-06* |
| Trial Type: Autism Quotient score | 0.2290 | 2 | 7812.8 | 0.7953047 |
| Normed SCL: Task: Trial Type | 0.9430 | 2 | 7815.9 | 0.3895010 |
| Normed SCL: Task: Autism Quotient score | 0.0160 | 1 | 7836.1 | 0.8992113 |
| Normed SCL: Trial Type: Autism Quotient score | 0.3191 | 2 | 7825.4 | 0.7267901 |
| Task: Trial Type: Autism Quotient score | 1.6484 | 2 | 7814.3 | 0.1924321 |
| Normed SCL: Task: Trial Type: | 1.0444 | 2 | 7820.1 | 0.3519488 |

*Note: An asterisk * indicate a statistically significant finding (p value <.05).*

**Consistent with the Literature**

From our ANOVA, for full results see Table 2, we found several significant factors. Consistent with previous literature we found that Task was significant (F(1, 7770.4) = [1384.746], p = 1384.746), with the RT for pro-saccade saccades being faster (mean 499.70 ms) than for anti-saccade (mean 552.83 ms) trials (Munoz & Everling, 2004). Also consistent with the literature Trial Type (F(2, 7811.6) = [140.529], p < .001) was found to be highly significant (Bekkering et al., 1996; Fischer & Ramsperger, 1984; Saslow, 1967). To further investigate the effects of Trial

Type we did a Tukey's HSD Test with Trial Type as the factor, which found that gap was significantly different (faster) from both step (p = <.001) and overlap (p = <.001) trials, but step and gap were not significantly different (p =0. 997).

Additionally, we found several significant interactions. For the Task by Trial Type interaction a Post Hoc Tukey was conducted and found all task by trial type comparisons were significantly different except for pro-saccade step and overlap (p=0.366) and the anti-saccade step overlap (p=0.325) comparisons. The findings of these Tukey test are similar to the findings from more traditional test for gap-overlap effects but are able to include more factors and allowed us to correct for multiple comparisons. For full results for these two Tukey HSD tests see the Appendix Tables 6 and 7.

**Novel Findings**

There were several novel significant interactions. One was between SCL and Task (F(1, 7828.5) = [93.637], p < .001). To better interpret this finding, we graphed Task Type and SCL faceted by Task see Figure 12. Here one can clearly see a difference in the slope of the relationship with increasing SCL having a much greater impact on reducing RT in the anti-Saccade Tasks than in the pro-saccade task.

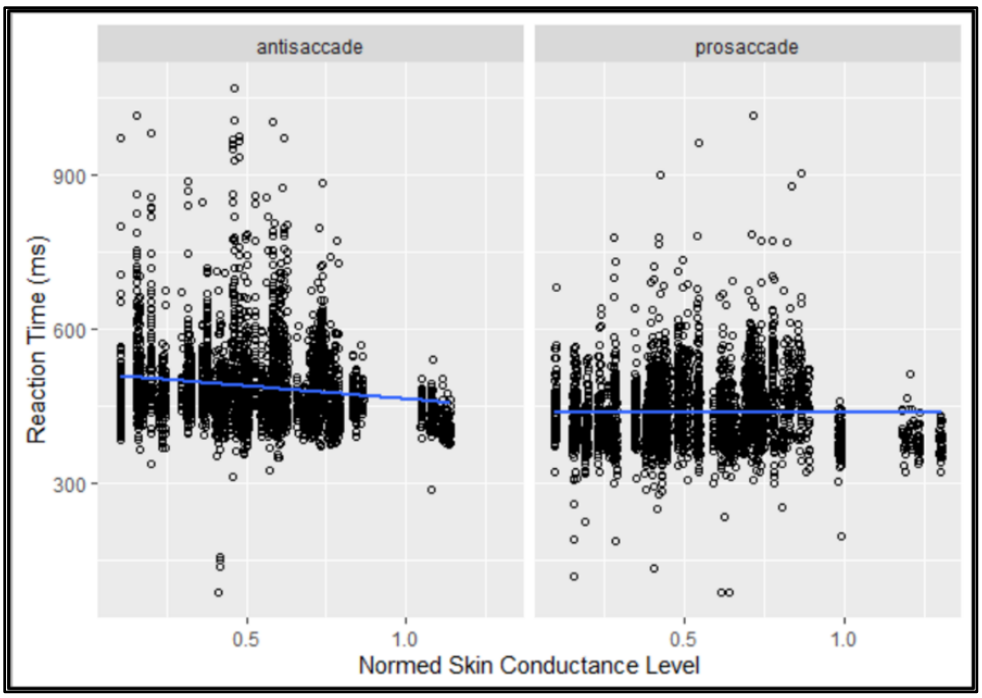


Figure 12. This plot illustrates the interaction between SCL, and reaction time split by Task Type.

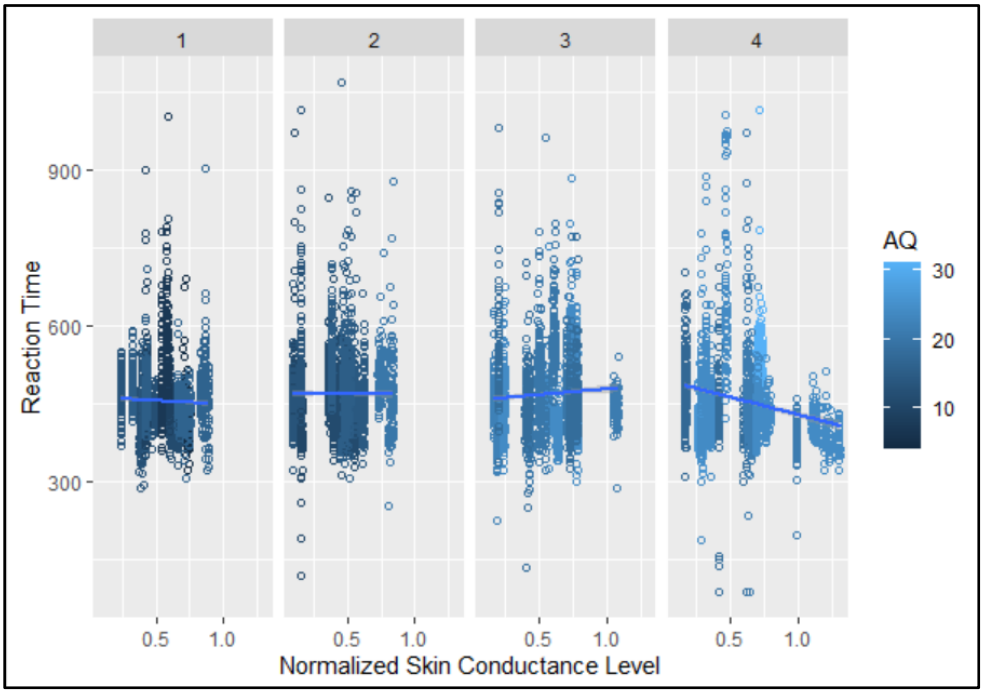


Figure 13. The effect of SCL and AQ on reaction times. Here AQ score is represented by the colors of the dots, with the lighter the dot the higher the AQ score. The grids are faceted by AQ quartiles ranging from low AQ scores on the left to the highest on the right.

SCL by AQ score also had a significant interaction with AQ (F(1, 430.0) = [9.188], p = 0.003). To better understand this interaction, see Figure 13. In Figure 13 we can see two trends that emerge in the 4th quartile of AQ scores. The first is that individuals in the 4th quartile, those with the highest AQ scores, have AA responses greater then what was seen in the calibration task (the 1 on the x axis) in contrast to the lower AQ quartiles where this is very rare. We also see a greater slope in this relationship for the fourth quartile.

Another significant interaction effect was seen between Task and AQ score (F(1, 7838.3) = [19.679], p >.001). To better interpret the direction of these effects we plotted the data.

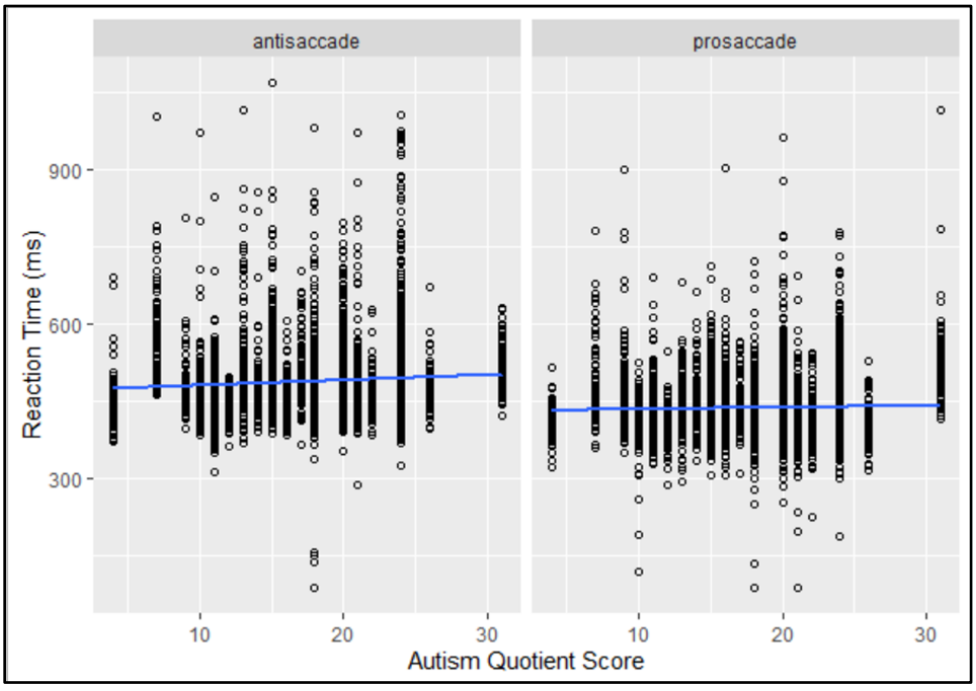


Figure 14. The figure depicts the relationship between reaction time and Autism quotient scores faceted by task.

Looking at Figure 14, we can easily see that there is a positive relationship between AQ scores and reaction time, where the higher the AQ score the slower the reaction time. We see when

we compare this relationship between task that degree of this effect is greater in the anti-saccade task than for the pro-saccade Task.

Additionally, it is important to note that there was an interaction that was approaching statistically significant, SCL by Trial: F(2, 7828.5) = 2.921 p= 0.054. This relationship is as depicted in Figure 14 and shows that the result appears to be greatest for the overlap condition.

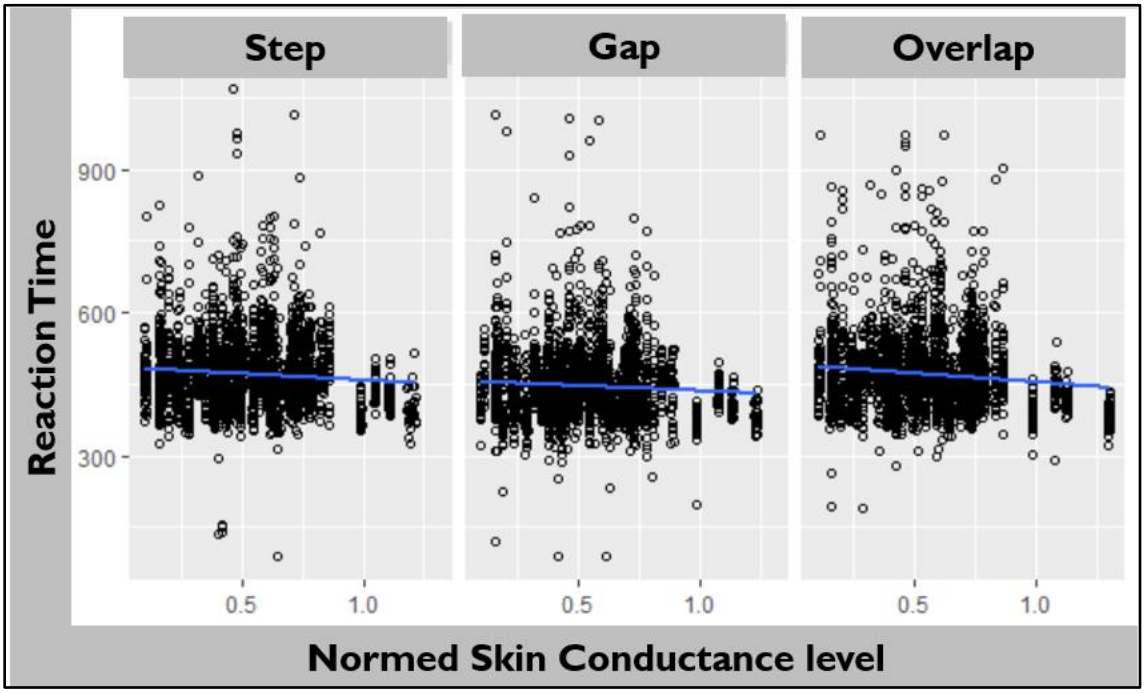


Figure 15. The figure depicts the relationship between reaction time and Normed Skin conductance level by Trial Type.

**Error rates**

Findings from the Chi-square task were consistent with previous literature

Table 3. Chi-square Table for Error Rates

**Chi-square table for Error Rates**

| Factor | Chi sq | DF | Pr (> Chi sq) |
|---|---|---|---|
| Task | 81.8204 | 1 | < 2.2e-16 * |
| Trial Type | 37.4925 | 2 | 7.221e-09 * |
| Normed SCL | 0.5568 | 1 | 0.4555 |
| Autism Quotient score | 0.1363 | 1 | 0.7119 |
| Task by Trial Type | 0.7970 | 2 | 0.6713 |
| Task by Normed SCL | 0.5664 | 1 | 0.4517 |
| Trial Type by Normed SCL | 0.8607 | 2 | 0.6503 |
| Task by Autism Quotient score | 1.5476 | 1 | 0.2135 |
| Trial Type: Autism Quotient score | 0.5861 | 2 | 0.7460 |
| Normed SCL by Autism Quotient score | 0.0271 | 1 | 0.8691 |
| Task by Trial Type by Normed SCL: | 1.1361 | 2 | 0.5666 |
| Task by Trial Type by Autism Quotient score | 0.3183 | 2 | 0.8529 |
| Task by Normed SCL by Autism Quotient score | 0.0026 | 1 | 0.9594 |
| Task by Normed SCL by Autism Quotient score | 0.5220 | 2 | 0.7703 |
| Task by Trial Type by Normed SCL by Autism Quotient score | 0.6871 | 2 | 0.7092 |

*Note: An asterisk * indicate a statistically significant finding (p value <.05).*

From these results we can see that overall Normed SCL did not independently have a statistically significant effect $X^2$ (1, N=41) =0.557, p = 0.456 . There was an effect of Trial type $X^2$ (2, N=41) =37.493, p < .001. Running a post hoc Tukey HSD test found that there was a statistically significant difference between gap and step (p < .001) and gap and overlap (p < .001), with gap trials having more errors (lower odds of correct). There was no statistically significant difference between step and overlap trials (p=0.715). See Appendix Table 8 for the full results.

There was also an effect of Task $X^2$ (2, N= 41) =81.821, $p < .001$ with more errors occurring in the anti-saccade task than in the pro-saccade tasks. This is in line with previous findings that have shown that directional errors, where participants look in the incorrect direction, occur more frequently in anti-saccade tasks (Munoz & Everling, 2004).

## Discussion

The goal of this study was to look at the effects of AA on attention and how that effect may differ based on the type of attentional parameters utilized for a task as well as the impact AQ may have on it. Our findings agreed with previous research that shows that individuals typically have faster RT in pro-saccade tasks than in anti-saccade tasks, have quicker RT in gap trials compared to other trial types and that there is an interaction between task and trial type (Munoz & Everling, 2004). Though some studies have also reported finding significant differences between step and overlap trials, we did not find a significant difference between these trial types (Keehn, Kadlaskar, et al., 2019).

Additionally, error rates, at the levels of AA we are studying do not seem to be impacted by changes in AA. This is an interesting finding as it suggests that the improvement in RT in the anti-saccade task are not due to a speed accuracy trade off and instead seems to be more purely due to improvements in overall task performance.

### Significant SCL/Arousal Interaction

A novel finding was that SCL, our analogue for AA, on its own did not have a statistically significant impact on RT or error rates, however SCL was involved in several interaction effects on RT, but not on error rates. The first interaction was between SCL and Task. When designing this study we theorized that performance on anti-saccade tasks would suffer at the highest levels

of AA as “top down” explicit attentional control is thought to be more vulnerable at high levels of AA (Diamond et al., 2007). Despite this initial hypothesis we saw that the effect of increasing SCL was beneficial for task performance on anti-saccade task while in contrast there seemed to be no significant effect of SCL on the pro-saccade task. This was surprising as most of the literature would predict, that there would be an increase in task performance for both tasks, but especially for the simpler “automatic” controls in the pro-saccade task. Another possible explanation is that for a basic pro-saccade task participants could be closer to their physiological ceiling so there is less potential of an effect of SCL. This could be supported by the findings of Kleberg et. al. who were able to normalize saccade reaction times in children who have ADHD and under preformed in the task, but the cue it’s self-did not have a statistically significant effect on RT for the general population who did not have impaired performance, though improvements were trending towards significant (Kleberg et al., 2020). If we interpret the pro-saccade task as falling into the category of what in the Yerkes-Dodson literature would be referred to as a “simple” task we would expect it to also be rather robust from any negative effects of increased AA after peak performance or “the ceiling” had been reached (Diamond et al., 2007; Dodson, 1915; Yerkes & Dodson, 1908), which could explain these findings of no effect. Along this line of research an interesting finding is that for the task that was more complex, and thus predicted to be more vulnerable to higher levels of arousal, the anti-saccade task, improved even with higher levels of arousal. There are two possible explanations for this finding the first and simplest would be that the levels of AA that are participants experienced may not be comparable to studies that found the eventual downturn in task performance, often these included stimuli that induced fear or pain which can have greater effects and be more robust to habituation.

However, we do not believe that this is the correct interpretation. Keith et. al., who used a silent low arousal condition and 75dB high arousal condition, reported that children did poorer on their harder task (a backwards number span task) in their high arousal condition (Keith et al., 2019). Having a high arousal condition similar to ours would indicate that all else being equal we should have seen a decrease in performance for our "harder task" which leads us to the other possible interpretation.

The second possible interpretation is that the attentional components of an anti-saccade task are not akin to these other tasks. A backwards number span task, or an equivalent digit span test is heavily reliant on working memory and the manipulation of that information (Cullum & Larrabee, 2010) and the body of work on arousal-biased competition predicts negative results in high arousal condition for a working memory intense task (Lee et al., 2012; Mather & Sutherland, 2011) so their findings are consistent with the literature. When designing the experiment, we initially thought that an anti-saccade task would be more vulnerable to AA since it included top-down control which we believed would be more vulnerable than the more "automatic" pull to the peripheral stimuli. However, our finding suggest that that may not actually be true. That overall increases in autonomic arousal my not default to more "basic" automatic control but help top-down control overcome the fixation and/or re-orienting responses.

**Autism Quotient Scores**

Another goal of our study was to look at how ASD related traits, indexed by AQ score, may impact the relationship between AA and performance. As reported in our participants section, our participant population had a rather restricted range of AQ scores. The scores of our participants ranged from 4-31 (M= 17.32 SD= 5.899) A histogram depicting the distribution of these scores can be found in Figure 16 in the appendix. There are several factors that may have contributed to

our reduced range. The first being that our main goal was to sample across the population, and we did not specifically target individuals with a diagnosis of ASD. Most of our recruitment materials were posted on a University campus and researchers have found that only .7 to 1.9 percent of college students meet the necessary criteria for an ASD diagnosis (White et al., 2011). Additionally, some of our recruiting criteria such as the anxiety screener may have unintentionally created a sampling bias against individual's with ASD as anxiety has a high comorbidity with an ASD diagnosis. A meta review conducted by van Steensel and colleagues found that the reported comorbidity of ASD and anxiety disorders ranges from 31.5 to 50.0 percent, with the estimated prevalence being around 40 percent (van Steensel et al., 2011) which is much higher than the estimated 18.1% of adults in the general population (Kessler et al., 2005). Additionally, Baron-Cohen et al.'s study mainly looked at individuals with ASD who were categorized as "high functioning", so our current study does not represent a majority of individuals who are diagnosed as being on the ASD spectrum. However, we do know that traits on the AQ lie on a spectrum and the use of the spectrum scores on a "typical" population can still provide useful exploratory information on the impact of these traits (Nummenmaa et al., 2012; Ruzich, Allison, Chakrabarti, et al., 2015; Ruzich, Allison, Smith, et al., 2015). Despite our relatively small range of AQ scores we did see some very interesting interaction effects.

### *AQ and SCL*

There was a significant interaction between AQ scores and SCL. This was a particularly interesting finding especially given that our population fell on the lower portion of the AQ scale. However, by splitting the data into quartiles to try and better understand this effect we saw several differences emerge in the highest quartile. Participants in this quartile seem to have a higher range of SCL then participants in other quartile, which could in part be driving this interaction. Although

not definitive this is an interesting observation to note as it suggests that some of the individuals in this quartile were highly responsive to the sound stimuli, often superseding the level of arousal seen during the calibration task. This was interesting as studies of children with ASD often report mix findings of both hypo and hyper EDA responses (Ferguson et al., 2019; Panju et al., 2015; Vernetti et al., 2020). Future work that directly addresses the topics of AQ, overall response to auditory stimuli, and other possible explanatory variables are needed to better interpret these findings.

### *Task and AQ score*

Another interesting finding relating to AQ score was that individuals with higher AQ scores had slower RT in anti-saccade tasks as depicted in Figure 14. Although the work done investigating the performance on anti-saccade task and ASD is more limited than information on the pro-saccade task it has been reported that poorer performance (error rates) on anti-saccade tasks relates to higher disinhibition scores (Mosconi et al., 2009). Although these findings do not directly relate to AA's impact on attention, we still know that the anti-saccade tasks are highly dependent on top-down inhibition and explicit orienting of attentional control both of which have been reported as being more difficult for individuals with a diagnosis of ASD which could be a possible explanation of these findings, though follow up work must be done before we can reach any conclusions.

# CHAPTER 3: CONCLUSION

## Future direction

Overall, there are several important takeaways that can be gleaned from a synthesis of these two studies and how these findings can be applied to future research. The goal of our first study was to look at how we can use sensory stimuli to manipulate AA. One of the biggest takeaways from this study was the clear evidence of the great impact that habituation/ adaptation has on AA response, at least in typical healthy young adults. While the quick and stable habituation of AA in the presence of sound stimuli may be a hurdle for researchers wishing to manipulate AA in their participants it seems like it is a relatively common, and most likely necessary ability that allows individuals to maintain balanced levels of arousal and not become overly effected by stimuli when it does not actually affect what responses maybe needed from them at that time.

Knowing this, our current research designs maybe missing out on a key feature of the stimulus AA response relationship, that it is based on our needs to adapt to changing environmental demands and perhaps in the absence of a clear goal even highly intense sensory stimuli is easily habituated to. Additionally future research on experimental design will need to try and find ways of attaching meaning to AA inducing stimuli in ways that either do not affect their experimental task or find ways to incorporate this into their design strategy.

The second study of this thesis looked at the interaction between AA and performance on different visual attention tasks and how AQ scores may relate to that relationship. Performance on these tasks has been documented to be biased by different components of the visual attention system. We hoped that AA would induce different types of changes in task performance which would give us better insight to what attentional systems benefited the most from increased levels of AA. The findings that increased SCL were correlated with a statistically significant

improvement in RT for anti-saccade task with no change in error rates appears to indicate that AA may have a beneficial impact on explicit cognitive control.

These findings have greatly impacted our view of future directions of this research by showing that while AA may narrow the number of cues one can utilize it does not inhibit top-down control or favor basic bottom-up attentional control.

The other important take away from this study was the different effects AQ scores, even in a more neurotypical range had on task performance. Of particular interest was the finding that individuals with higher AQ scores seemed to not receive as great of a benefit from increasing AA levels for the anti-saccade task, the only task that seemed greatly influenced by increasing levels of SCL (AA). Future research should look more closely at the etiology of this trend, perhaps looking to see if these findings can be replicated in individuals with a ASD diagnosis.

Synthesizing these findings from experiment one and two it appears that though in different ways both studies found that participants interaction with AA seemed highly adaptive to the context they were in; helping them return quickly to baseline in the first experiment and keeping them focused on the needed stimuli in the second. Given this evidence, we can see that typical autonomic regulation plays an important role in helping us to adapt when the world around us becomes noisy and helping us increase performance in an attentionally demanding task. Seeing this key role autonomic regulation plays in helping us adapt to our daily needs, future research must take a closer look at how autonomic responses differ in populations such as those with ASD and how this may impact their ability to adapt to the world around them.

# APPENDIX

## Tukey Tables

Table 4. AVOVA Table for mean Skin Conductance Level by Block

**Experiment 2 Mean SCL by Block**

| Factor | F | DF | DF.res | Pr(>F) |
|---|---|---|---|---|
| Block | 42.9803 | 2 | 200 | 2.967e-16* |
| Task | 3.7289 | 1 | 200 | 0.054891 |
| Block: Task | 4.9674 | 2 | 200 | 0.007845* |

*Note: An asterisk * indicate a statistically significant finding (p value <.05).*

**Experiment 2 Block**

Table 5. Tukey Test Block

| Trial Type | estimate | SE | df | z ratio | p value |
|---|---|---|---|---|---|
| first - second | 0.0813 | 0.0136 | 200 | 5.966 | <.0001 |
| first - third | 0.1244 | 0.0136 | 200 | 9.129 | <.0001 |
| second - third | 0.0431 | 0.0136 | 200 | 0.0051 | <.0051 |

Note: Degrees-of-freedom method: asymptotic Confidence level used: 0.95

**Experiment 2 Trial Types**

Table 6. Tukey Test Trial Type

| Trial Type | estimate | SE | df | z ratio | p value |
|---|---|---|---|---|---|
| step - gap | 24.494 | 1.70 | Inf | 14.401 | <.0001 |
| step - overlap | --0.124 | 1.69 | Inf | -0.073 | 0.9970 |
| gap - overlap | -24.618 | 1.70 | Inf | -14.462 | <.0001 |

Note: Degrees-of-freedom method: asymptotic Confidence level used: 0.95

**Trial Type by Task**

Table 7. Tukey Test Trial Type by Task

| Trial Type | estimate | SE | df | z ratio | p value |
|---|---|---|---|---|---|
| step anti-saccade - gap anti-saccade | 17.77 | 2.44 | Inf | 7.298 | <.0001* |
| step anti-saccade - overlap anti-saccade | -4.89 | 2.41 | Inf | -2.030 | 0.3253 |
| step anti-saccade - step pro-saccade | 44.87 | 2.40 | Inf | 18.692 | <.0001* |
| step anti-saccade - gap pro-saccade | 76.09 | 2.41 | Inf | 31.518 | <.0001* |
| step anti-saccade - overlap pro-saccade | 49.51 | 2.41 | Inf | 20.537 | <.0001* |
| gap anti-saccade - overlap anti-saccade | -22.66 | 2.43 | Inf | -9.306 | <.0001* |
| gap anti-saccade – step pro-saccade | 27.10 | 2.43 | Inf | 11.156 | <.0001* |
| gap anti-saccade - gap pro-saccade | 58.31 | 2.44 | Inf | 23.875 | <.0001* |
| gap anti-saccade - overlap pro-saccade | 31.74 | 2.44 | Inf | 13.010 | <.0001* |
| overlap anti-saccade - step pro-saccade | 49.76 | 2.40 | Inf | 20.746 | <.0001* |
| overlap anti-saccade - gap pro-saccade | 80.97 | 2.41 | Inf | 33.575 | <.0001* |
| overlap anti-saccade - overlap pro-saccade | 54.40 | 2.41 | Inf | 22.587 | <.0001* |
| step pro-saccade - gap pro-saccade | 31.22 | 2.38 | Inf | 13.142 | <.0001* |
| step pro-saccade - overlap pro-saccade | 4.64 | 2.37 | Inf | 1.959 | 0.3661 |
| gap pro-saccade - overlap pro-saccade | -26.58 | 2.38 | Inf | -11.170 | <.0001* |

Note: Degrees-of-freedom method: asymptotic Confidence level used: 0.95

**Experiment 2 Odds Ratio: Trial Types**

Table 8. Log odds for Errors by Trial Type

| Trial Type | estimate | SE | df | z ratio | p value |
|---|---|---|---|---|---|
| step - gap | 1.011 | 0.234 | Inf | 4.319 | < .0001 |
| step - overlap | 0.206 | 0.264 | Inf | 0.780 | 0.7151 |
| gap - overlap | -0.805 | 0.199 | Inf | -4.048 | 0.0002 |

Note: Results are given on the log odds ratio (not the response) scale.

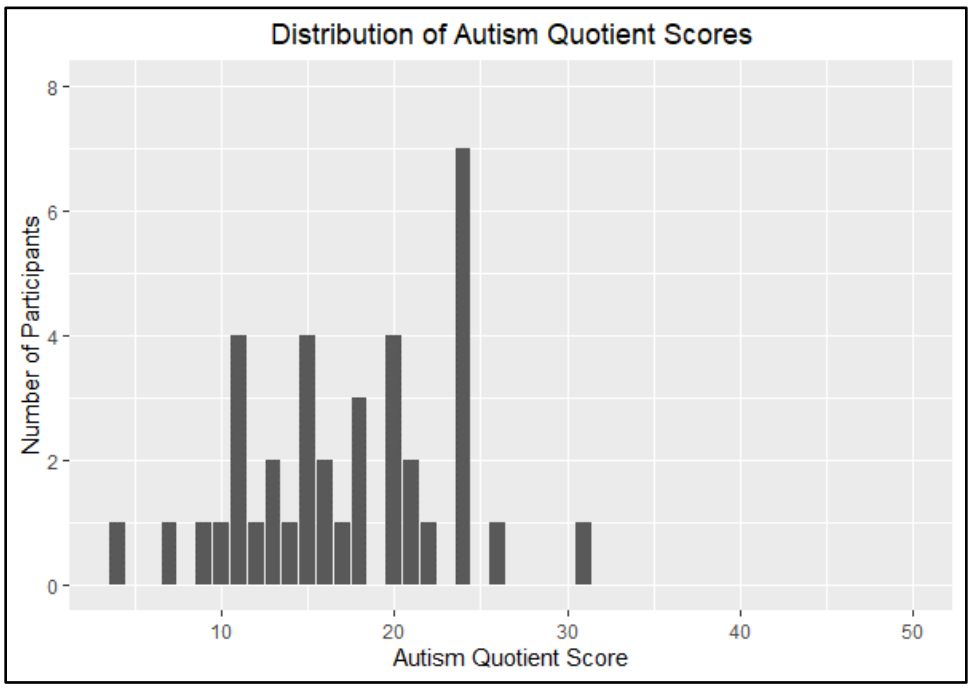


Figure 16. This histogram shows the distribution of Autism Quotient Scores among participants in Experiment 2.

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