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Nicole R. Baker
Stephen F Austin State University

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THE EFFECTS OF TRANSCRANIAL DIRECT CURRENT STIMULATION (tDCS) ON FACIAL EXPRESSION APPROACH/AVOIDANCE IN COLLEGE STUDENTS AND FACULTY WITH BROAD AUTISM PHENOTYPE

By

Nicole Rene Baker, M.S.

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THE EFFECTS OF TRANSCRANIAL DIRECT CURRENT STIMULATION (TDCS) ON FACIAL EXPRESSION APPROACH/AVOIDANCE IN COLLEGE STUDENTS AND FACULTY WITH THE BROAD AUTISM PHENOTYPE

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Nicole Rene Baker, M.S.

APPROVED:

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Luis Aguerrevere, Ph.D., Dissertation Chair

_____

Nina Ellis-Hervey, Ph.D., Committee Member

_____

Scott Drury, Ph.D., Committee Member

_____

Elaine Turner, Ph.D., Committee Member

_____

Sheryll Jerez, Ph.D.
Interim Dean of Research and Graduate Studies

ABSTRACT

Transcranial Direct Current Stimulation (tDCS) has been proposed as an alternative noninvasive therapy for individuals with autism. This study trained brain activity in college students and / or faculty with Broad Autism Phenotype (BAP) while eye tracking data was collected. The purpose of this study was to determine if tDCS training to the frontal lobes could increase approach toward social interactions in adults classified as BAP as demonstrated by eye-tracking measures in response to faces and gaze fixation. The study included 21 total participants recruited from the Science, Technology, Engineering, and Math (STEM) courses / professions at a Regional East Texas University. Participants were classified as BAP+ based on their scores on the Broad Autism Phenotype Questionnaire (BAPQ). Findings revealed statistically significant differences in the participant revisit gaze and a trend in reduction of fixations and in fixation duration increase after tDCS stimulation. Additionally, this study found a moderate correlation between BAPQ scores and revisit revistors and suggested the closer the family member of the BAP+ participant, the higher the BAP score. The results of the current study support the integration of eye tracking to provide early identification and intervention and propagate the importance of clinicians' and researchers' focus on the factors that modulate eye tracking measures to reduce symptomology of ASD and BAP as well as other conditions with overlapping brain regions.

Keywords: Broad Autism Phenotype (BAP), Electroencephalography (EEG), Eye-tracking, Transcranial Direct Current Stimulation (tDCS)

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CHAPTER I: Introduction

In 2013, the Diagnostic Statistical Manual-5th edition (DSM-5) defined Autism Spectrum Disorder (ASD) as a neurodevelopmental disorder that included impairments in social interaction, communication and restricted repetitive, or stereotyped behaviors (American Psychiatric Association, 2013). Social skill impairments in individuals with ASD included difficulty making sense of social situations, not understanding social cues or social conventions and impaired social cognition. Weston (2019), for example, indicated that people classified as ASD appeared to not look through peer or familial faces despite recognition. As a result, it seems that ASD demonstrated deficits that impeded the development of joint attention and other social processes, which could result in inappropriate or misunderstood social behaviors, and in turn, could cause social stress, withdrawal, dysphoric emotions, among other adverse mental health impairments.

A study by Hendricks & Wehman (2009) found that ASD-related deficits in socialization created challenging obstacles in participation in higher education. Many college students classified ASD reported often feeling lonely and isolated due to a lack of involvement and social-skill deficits. According to Wenzel and Rowley (2010) college students with ASD have been experiencing challenges with social interactions because they need to adapt to several new situations. McLeod et al. (2019) also examined experiences of college students on the autism spectrum in comparison to

neurotypical peers and found that students on the spectrum differed from peers in social outcomes, reported lower-quality social relationships, and higher levels of bullying victimization than neurotypical students which suggested social rejection from interactional challenges and stigmatization. Additionally, McLeod et al. (2019) reported that college students on the spectrum were less likely to have a confidant, which also decreased their social interaction and skill-building opportunities.

Bailey et al. (1998) referred to Broad Autism Phenotype (BAP) as individuals who displayed some autistic traits in the general population. A genetic connection between BAP and autism has been established. For instance, recent evidence suggested over 50% of the risk of developing ASD is attributed to genetic variation, and concordance rates reported 60–70% in monozygotic twins and 5–30% in siblings. Yoo (2015) also revealed a recurrence rate of 18% in infant siblings and of 33% in multiplex families. Similarly, 10–20% of siblings of individuals with autism have displayed symptoms of communication and social impairments related to autism (Bolton et al., 1994).

Trevisan and Birmingham (2015) found that college students with BAP scored significantly lower on academic and social adjustment compared to the non-BAP comparison group. Repeated research indicated deficits in emotional facial processing in individuals with ASD/BAP that contributed to decreased ability in social interaction. Qiao et al. (2020), more specifically, noted atypical eye-gaze, deviant emotion recognition, and impaired ability in using contextual information of faces as major

obstacles for individuals with ASD/BAP.

ASD and BAP deficits were correlated with specific brain regions, and research studies continue to evolve in brain findings of individuals with ASD and BAP (Billeci et al., 2019). Alpha activity was determined to be the neural oscillations in the frequency range of 8–12 Hz which occurred when people felt relaxed and when the brain was in an idle state without concentrating on anything. Previous investigations have found a link between individuals with ASD and peak alpha activity in the frontal and temporal lobes as well as the cerebellum and the subcortical regions involving the amygdala and hippocampus (Firth & Hill, 2004, Ha et al., 2015). Neuroimaging continues to advance these studies, providing more detailed specificity in the regions correlated with ASD and BAP. Additionally, brain studies examined areas of the brain associated with visual processing and involving direct and averted gaze, which were determined as critical for social cues and revealed findings which connected social deficits in ASD / BAP and emotional facial processing (Pitskel et al., 2011). Moreover, brain findings that have examined BAP and family members with ASD have revealed overlap of brain regions critical for social functioning, that included the superior temporal gyrus, inferior temporal gyrus, middle frontal gyrus, frontal lobe, and amygdala in individuals with ASD and in fathers with ASD, which suggested intergenerational transmission of these neural substrates and social deficits (Billeci et al., 2019).

Transcranial Direct Current Stimulation (tDCS) is an alternative noninvasive therapy for individuals with ASD and BAP that involves focal modulation of the cortical brain areas. Previous studies have shown success in tDCS stimulation applied over the left or right dorsolateral prefrontal cortex (DLPFC) based on the findings that individuals with ASD often displayed DLPFC hypoactivation. A recent study conducted by Qiao et al. (2020) showed positive results that examined the effects of tDCS that facilitated emotional facial processing in individuals with high autistic traits. The use of tDCS that targeted the right temporal parietal junction (TPJ) facilitated gaze behavior of individuals with high autistic traits (AT) and specifically facilitated effects of anodal stimulation apparent for both happy and fearful faces in the mouth area (Qiao et al., 2020). Thus, tDCS therapy was presented as a promising method to improve emotional facial processing with the potential to improve social interactions for those with ASD or BAP.

The general purpose of this study was to observe the brain activity of subjects with high BAP scores while processing eye contact duration, while participants viewed the Facial Expression of Emotion Stimuli and Tests (FEEST) as measured by the Tobii pro studio eye-tracker. The study compared QEEG activity (brain electrical activity) in the temporal lobe areas before, during, and after tDCS treatment. This study recruited individuals in all majors related to STEM, as studies by Wei et al. (2013) have indicated an elevated prevalence of individuals with BAP in these careers.

Further tDCS research for individuals with ASD or BAP has been indicated as

beneficial for both psychology and education, as previous research has demonstrated improved behavior and cognition which allowed for improved quality of life, to include greater autonomy and improved academic outcomes (Rothärmel et al., 2019). Research has determined early interventions were integral to reduced ASD / BAP symptomology and continued research is indicated for earlier identification and specificity of interventions. Additionally, tDCS research on executive functioning disorders, to include ASD, has revealed critical information regarding the various roles of brain regions in ASD / BAP, how psychopathology diagnoses may be interconnected, and how to guide further individualized and appropriate concurrent treatment strategies for individuals with ASD (Mahmoodifar, 2019). Furthermore, increased autonomy in an educational setting has facilitated the goal of least restrictive environment through greater likelihood of instruction received in an inclusive, general education setting by reduced behavioral symptoms and increased cognitive abilities.

CHAPTER II: Literature Review

Autism

Autism Spectrum Disorder (ASD) is a complex set of behaviorally defined disorders that include impairments in social interaction (American Psychiatric Association, 2013). Kanner (1943) first identified social impairment as the defining characteristic of ASD. Kanner described ASD as difficulties with non-verbal communication, such as correctly interpreting facial expressions and gestures, and lack of acknowledgement of others. However, additional research has helped better define and identify ASD. Diagnostic criteria continue to evolve as does the view of autism in research and society.

Whiteley et al. (2021) argued that the taxonomy of autism warranted further examination as the scope of ASD diagnosis has broadened. Currently, the core issue of alterations in social cognition affecting emotion recognition remain critical components of autism diagnosis. Therefore, social cognition, including areas as diverse as social motivation and emotion recognition, continue to be the focus of ongoing ASD research. Park et al. (2016) presented ASD as not a single disorder as originally indicated by Kanner (1943), but rather currently defined as a broader multi-factorial disorder characterized by deficits in social behaviors and nonverbal interactions such as reduced eye contact, facial expression, and body gesturing resulting in decreased social

cognition. Leung et al. (2016) examined social deficits in those with ASD related to "every day" executive functioning and demonstrated a link between behavioral regulation and executive processes (e.g., inhibition, shifting, and emotional control), and the relation between social symptom and metacognitive executive processes (e.g., initiation, working memory, planning, organization, and monitoring), as distinct in ASD and not characteristic in the wider population. This indicated that the social symptoms of ASD appeared to be more associated with a specific set of executive functions which suggested those on the spectrum may require a more widespread use of executive functions for social abilities (Leung et al., 2016).

The DSM 5 (American Psychiatric Association, 2013) acknowledged individuals with autism fell on a spectrum according to their level of functional independence and show varying degrees of severity regarding the main symptoms: difficulties in social communication, restricted and repetitive behavior, preference for sameness and routines, and sensory abnormalities. Bailey et al. (1998) proposed broadening the spectrum so autistic traits in the clinical population and within the general population were included. According to a study conducted by Aspril John Hopkins, and the Center for Disease Control (2020), the prevalence of ASD around the world in both children and adults as of the time of this study, was 1.85% of the population. This was a 10% increase from the 2018 report. The DSM 5 categorized autism by assigning one of three levels based on severity of symptoms, and an accurate diagnosis should include the specific level of severity to clearly define the diagnoses

and guide treatments and interventions. Gilmore (2019) provided a clear description of each level. Level 3 is defined as the most severe autism diagnosis and was described as requiring very substantial support.

Individuals diagnosed in this level present significant impairments in their verbal and nonverbal communication, avoid interactions with others (but may communicate needs in alternative ways), and may display behaviors that are highly inflexible, and repetitive. Those diagnosed in the level 3 category present significant rigidity and become highly distressed in situations that break away from the routine or require them to change their focus or task. Level 2 was described as requiring substantial support and was further clarified as those individuals that need more support than those with a level 1 diagnosis, while also presenting more severe social deficits that may make holding a conversation very challenging. Those with a level 2 also presented more severe social deficits. Those with a level 2 diagnosis may struggle to communicate coherently, are more likely to respond inappropriately, or may only discuss topics of specific interest.

These individuals may also have difficulty with nonverbal communication, avoid eye contact, demonstrate inflexible behaviors, and may not handle change well. Level 1 was described as the mildest of the 3 levels of ASD, and it was defined as requiring support. People placed in this level have social difficulties and may find it difficult to initiate conversations with others but are often verbal and may engage in conversations of specific interest as well as conversations not of specific interest.

However, they may respond inappropriately or lose interest more quickly than others not on the spectrum. As a result, individuals in this level may find it difficult to establish friendships and may have difficulty with employment (Gilmore, 2019). This level is sometimes referred to as high functioning. Often those in this level display mild symptomology that may not be obvious to many by casual or brief observations. However, level 1 autism (high functioning) is inclusive of the criterion outlined in the DSM 5, unlike those identified under the BAP.

The Broad Autism Phenotype

Broad Autism Phenotype referred to individuals that displayed some autistic traits in the general population (Bailey et al., 1998). Individuals classified as BAP were defined as those who fell outside the autism spectrum, although they presented many similar characteristics. For example, individuals with BAP have been noted to struggle with social interactions, such as reduced eye contact, or difficulty maintaining conversations, particularly for topics not of specific interest to them. Also similar to those in the level 1 category, individuals with BAP did not display obvious symptomology to others, especially if interactions or observations were limited in frequency or duration. Given the similarities of those with a level 1 autism diagnosis and BAP, there has been significant research on BAP that focused on the homogeneity between those with BAP and first-generation family members diagnosed with ASD (Gerdts & Bernier, 2011).

A genetic connection between BAP and autism has been established. For

instance, recent evidence suggested over 50% of the risk of developing ASD is attributed to genetic variation, and concordance rates reported 60–70% in monozygotic twins and 5–30% in siblings. Yoo (2015) also revealed a recurrence rate of 18% in infant siblings and of 33% in multiplex families. Similarly, 10–20% of siblings of individuals with autism have displayed symptoms of communication and social impairments related to autism (Bolton et al., 1994). Tomblin et al. (2003) determined speech language impairment (SLI) as a risk to family members who had a relative with autism and in reciprocity, autism as a risk to family members who had a relative with SLI. Thus, the two appeared to be bi-directional. Therefore, given the connection of genetic vulnerability to autism, there was a possibility of inherited familial characteristics similar to autism in siblings (Bailey et al., 1998).

The concept of a BAP was first suggested by studies that indicated relatives of individuals diagnosed with ASD are more likely to express mild autistic traits, regardless of diagnosis. Relatives of individuals with ASD appeared to show genetic liability for deficits associated with ASD (Bailey et al., 1998). Sasson et al. (2013), for example, found BAP features ranged between 14–23% for parents of a child with autism in contrast to BAP features in 5–9% of a community-based group of comparison parents. Kanner noted, in a foundational paper, that there are often unusual social behaviors in the parents of children with ASD, such as having a preoccupation with “abstractions of a scientific, literacy, or artistic nature, and limited genuine interest in people” (Kanner, 1943, p. 250). Evidence of familial phenotype to autism

began to emerge through studies conducted by Wolff and Morris (1971), which sought to validate information presented in several previous studies that indicated parents of autistic children seemed highly intellectual, cold, compulsive, detached, obsessive, perfectionistic, and unemotional. However, unlike ASD, BAP personality characteristics of these family members are not pervasive across all three domains (social skills, pragmatic language, and restricted interests and behaviors; Pickles et al., 2000). Thus, BAP is currently suggested as the likelihood of family members of those diagnosed with ASD to display mild autistic traits (De Groot & Van Strien, 2017).

Further evidence emerged through studies that included interviews conducted with relatives of individuals with ASD. Wolff et al. (1988) interviewed parents of children with autism and parents of children with intellectual disabilities, who were unaware of this diagnosis, and found the parents of children with autism had more difficulty establishing rapport, an unusual way of communicating, and a lack of emotional responsiveness and empathy. Moreover, the parents of the children with ASD also reported special interest patterns, a preference to being alone, and over-sensitivity to experience when compared to the parents of the children with intellectual disabilities. Hughes et al. (1999) found that parents of individuals with autism were more impaired on executive function tasks when compared to parents of individuals with other disabilities.

Piven et al. (1994) concluded that first-degree relatives of ASD children demonstrated a milder variant cognitive profile of autism. More specifically, in a study

by Landa et al. (1992) significant differences were noted in social language use between parents of children with autism and the control group made up of parents of children with Down syndrome and adults without children with autism. Specifically, 42% of the parents of children with autism had deficits in pragmatic language skills compared to only 2% of the control group. Bolton et al. (1994) found that approximately 20% of siblings of individuals with ASD evidenced symptoms of autism, including social impairments, atypical communication, or restricted behaviors, compared to the control group of siblings of children with Down syndrome (3.1%). Additionally, BAP was more prevalent in male relatives of individuals with ASD. Results of ASD parents paralleled, but to a lesser degree, than those of their non-ASD children. However, ASD parent symptoms remained higher than those exhibited by the control group of parents and siblings of children with Down syndrome.

Additional studies have provided more specific etiology through studies of both multiplex and simplex ASD families. Rubenstein and Chawla (2018) presented in multiple studies involving either parent (mom or dad) of typical developing children, parents of children with Down syndrome, or nonbiological relatives of children with ASD, and found BAP to be more universally common in parents of children with ASD. Furthermore, multiplex families were more likely to have parents with BAP than simplex families. Piven et al. (1997) indicated multiplex ASD families were more likely than simplex ASD families to have children with autism, due to genetic causes. The genetic liability for autism was also more likely to be higher in multiple-incidence

autism probands than single-incidence probands. Using a semi-structured family history interview, Piven and colleagues (1997) compared stereotyped interests and behaviors and deficits in social communication between 25 multiple-incidence autism families and 30 Down syndrome families with the objective of better defining the BAP. Multiple incident autism families had higher rates of stereotyped behaviors and social and communication deficits than down syndrome probands.

BAP in Typically Developing Populations

BAP has been diagnosed in individuals who did not have an identified family member with ASD. Diagnosis of BAP for individuals without family members with ASD were determined by the same measures on the Broad Autism Phenotype Questionnaire (BAPQ) and the Autism Quotient (AQ) as those BAP individuals with family members with ASD. Although research of BAP outside of ASD relatives has been very limited, there was evidence to suggest the existence of BAP in the general population. Wheelwright et al. (2010) identified elevated BAP features in 22% of fathers and 9% of mothers in typically developing children which indicated the presence of BAP in the general population in contrast to previous studies that indicated only those with immediate family members with ASD presented BAP characteristics.

The BAP-STEM Connection

In the National Longitudinal Transitional Study- 2, findings showed that individuals with ASD had the highest STEM participation rates (Wei et al., 2012). Theories derived from previous research indicated individuals with ASD had average or

above average systemizing skills but, in contrast, below average empathy skills. Therefore, they were more apt to systemizing than empathizing (Baron-Cohen, 2009). Systemizing involves analyzing and constructing, which are skills found in STEM related careers. Ruzich et al. (2015) found an increased prevalence of individuals on the autism spectrum in jobs that are in STEM related fields. Furthermore, individuals who worked in STEM related fields consistently scored higher on the (AQ). Ruzich et al. (2015) also concluded that traits commonly associated with autism were strongly linked to traits associated with being male and with STEM occupations, regardless of other factors. These findings reinforced a study conducted by Baron-Cohen et al. (1997) which sampled 919 ASD families and found that 28.4% of the paternal members were engineers compared to only 15% being engineers in neurotypical families in the control group.

BAP and Social Communication

Social functioning has been shown to be a critical component of ASD and BAP. Like many characteristics of ASD, the social functioning of individuals with ASD or BAP have presented with varying degrees of deficits, correlated to the severity of the overall individual symptomology. Wainer et al. (2011) indicated in their findings that individuals with BAP experienced social difficulties related to two independent dimensions, pragmatic language difficulties and aloofness. These same two qualities were what Dovgan and Villanti (2021) attributed the gravitation of BAP individuals toward STEM interests, as these areas typically include more structure, which is

advantageous to individuals who have restricted interests and a need for routine. Similarly, Baron-Cohen et al. (2001) found that STEM students displayed greater BAP characteristics. Therefore, there was a prevalence of individuals with BAP in the STEM community as evidenced in previous studies. This prevalence was largely attributed to the structure and reduced need for social interaction typical of STEM studies and career fields. Furthermore, individuals with ASD often possess restricted or focused areas of interest that allow them to thrive in STEM-related fields that are highly specialized.

Jobe and White (2007) examined the possible relationship between social functioning and a broader autism phenotype. In a sample of undergraduate students from a large university, characteristics associated with autism were measured, as well as self-reported dating and friendship history, feelings of loneliness, and social motivation. Results indicated those with a stronger BAP reported significantly greater loneliness and friendships that were fewer and shorter in duration. For those in romantic relationships, a stronger BAP was moderately and positively correlated with the length of relationship. Jobe and White (2007) found that those with characteristics of autism, BAP, and related conditions, did not necessarily prefer loneliness but rather experienced loneliness due to a lack of social skill and understanding (Jobe & White, 2007). A later study was conducted by Sasson et al. (2012) that examined the relationship between BAP characteristics, real-world social skills, and social-cognitive abilities. Results of this study suggested that better social-cognitive ability is associated with greater real-world social skill. Study results displayed social BAP was negatively associated with both

social skill and social-cognitive performance, while the nonsocial BAP was not significantly correlated with either social skill or social cognition. Social-cognitive performance was positively associated with social skill. Thus, this study indicated subclinical autism-related social traits within the general population were related to reductions in social skill and social-cognitive ability (Sasson et al., 2012).

BAP and College Life

Social adjustment has been shown as a risk factor for college success in students with ASD / BAP (Kurtz et al., 2012). Jackson et al. (2018) conducted a national online survey of students with an autism diagnosis and found that respondents reported satisfaction with their academic and social lives but also high rates of depression (35.7%), social anxiety (33.9%), loneliness (75%), and past-year suicidal ideation (53.6%). These issues faced by college students on the spectrum are believed to be the result of pragmatic language difficulties, aloof personality traits, and rigidity, all which affected study and social skills. Previous research by Losh et al. (2008) found relatives of those with autism displayed rigidity, showed little interest in others or activities, were overly conscientious, displayed increased anxiety, and therefore had greater difficulty adjusting to college and engaging in social interactions. Adding to this difficulty, Losh et al. (2008) also indicated individuals with BAP displayed difficulty on standardized tests of verbal fluency and reading which likely also contributed to social inabilities and difficulty in academics.

Kuang (2016) defined social attention as one special form of attention that

involved the allocation of limited processing resources in a social context. Previous studies on social attention often regarded how attention was directed toward socially relevant stimuli such as faces and gaze directions of other individuals. Social attention also contributed to the college experience of individuals with ASD / BAP. Hanley et al. (2015) compared attention profiles between university students with ASD and neurotypical peers using eye-tracking and acknowledged that (a) the social difficulties of ASD in youth are often translated into social interactions experienced as adults, and (b) decreased social attention also contributed to inability to process facial expressions thus reducing understanding of social cues and communication. Trevisan and Birmingham (2015) examined whether specific ASD characteristics were associated with reductions in specific aspects of college adjustment, by comparing individuals identified as having BAP with those who scored below the cutoff score. Their findings asserted individuals with BAP performed lower academically and scored lower on social adjustment to college, compared to non-BAP college students. Trevisan and Birmingham (2015) also discovered that one or more facets of the BAP significantly explained variance in scores in college adjustment, most notably the difficulties with pragmatic language and social deficits.

The Broad Autism Phenotype Questionnaire (BAPQ)

The BAPQ is a freely available, 36-item measure that is now the most used self-report questionnaire used with adults to measure three subscales of ASD characteristics present in the BAP. Exploratory factor analysis and internal consistency parameters

confirmed a robust three-factor structure of the BAPQ, that corresponded to the proposed Aloof, Pragmatic Language and Rigidity subscales (Sasson et al., 2013). Kanner (1943) initially suggested a correlation between the number of parents with autistic children who presented with rigidity and lacked interest in abstract ideas. More recently, Hurley et al. (2007) noted the BAP as a phenomenon in which family members of individuals with ASD displayed characteristics similar to those with ASD but in milder form, which reinforced Kanner's observations and prompted additional research into the BAP.

The BAPQ was designed to reliably measure personality and language traits that were previously identified as defining features of BAP, that included social personality, rigid personality, and pragmatic language (Piven et al., 1997). A study that included 626 undergraduate college students compared the BAPQ, AQ, and Social Responsiveness Scale (SRS), regarding their internal consistency, factor structure, distribution of scores, and criterion-related validity (Ingersoll et al., 2011). Results showed a continuous distribution and criterion validity in all three measures. Ingersoll et al. (2011) also revealed that the factor structure that corresponded to the BAPQ was better at assessing BAP traits in the general population than the AQ or the SRS, and that the BAPQ and SRS have better internal consistency than the AQ (Ingersoll et al., 2011). The BAPQ differed from the AQ and SRS in that it did not measure the triad of characteristics associated with ASD but was rather designed to assess BAP traits in unaffected individuals (Sasson et al., 2013).

In a study conducted by Wheelwright et al. (2010), parents of children with ASD scored significantly higher on the AQ than control parents, both on total AQ score and on four of five of the subcategories, which replicated findings in a previous study conducted by Bishop et al. (2004). Wheelwright et al. (2010) found that 33% of fathers of children with ASD, and 23% of mothers scored at or above the BAP cut-off point (BAP is defined as AQ scores of one to two SDs above the mean AQ scores 23–28). High heritability of autism has been indicated in multiple studies. Sasson et al. (2013) confirmed the high heritability of autism in their study of likelihood of both parents having BAP, in groups of parental pairs of children with autism compared to parental pairs of typically developing children. Findings revealed that only a small percentage of both members of both groups of parental pairs had positive BAP composites, with significantly more parental pairs with positive BAP composites in the parental pairs of children with autism (4.3%), compared to the parental pairs of typically developing children (1.6%). Significantly more pairs of parents of children with autism both had at least one BAP feature (15.1%), compared to only 5.3 % of each member of the typically developed children's parental pairs (Sasson et al., 2013). Similar findings of higher rates of BAP among parents of children with autism compared to parents of typically developed children were also found in a study conducted by Maxwell et al. (2013). Maxwell and colleagues (2013) administered the BAPQ to 129 typically developed (TD; 93 males) children and 245 children with ASD (210 males) aged 6 to 18 years old and their parents. Parents completed the BAPQ, and more scored above BAPQ cutoffs

in the ASD group than the typically developed control (TDC) group. Specifically, 21% of fathers and 10% of mothers met criteria in the ASD group, whereas 7% of fathers and 1% of mothers met criteria in the TDC group (Maxwell, et al. 2013). These findings reinforced previous studies that also indicated hereditability and findings of higher rates of BAPQ in fathers (Bishop et al., 2004; Seidman et al., 2012; Wheelwright et al., 2010).

In aggregate, the subscales of the BAPQ have internal consistency and have high sensitivity and specificity for the direct, clinical assessment ratings of the BAP. The various measures of the BAP have helped provide an efficient, reliable, easy to administer, consistent measure of the characteristics associated with the primary diagnostic domains of autism: 1) social abnormalities, 2) pragmatic language difficulties and 3) rigid personality and a desire for sameness observed in the general population and in relatives of individuals with ASD (Sasson et al., 2013). These milder measurable traits of the BAP were thought to represent genetic liability for ASD (Piven et al., 1997). Research supported the heritability of these traits (Constantino 2003; Sasson et al., 2013) and the value of studying these traits in the general population (Sasson et al., 2013). The BAPQ was developed in a sample of parents of children with ASD and was designed to correspond to a conceptualization of the BAP as a set of personality traits. As such, it has demonstrated convergent validity with direct clinical assessment of the BAP that used interview, clinical assessment, informant report, and consensus ratings by trained raters (Ingersoll et al., 2011), which made it the current best measure of BAP

and provided further support for genetic liability in ASD.

Facial Processing in ASD and BAP

In typically developed individuals, a core and extended system that work together to determine meaning from faces has been indicated. The core system included a region in the lateral middle fusiform gyrus (commonly referred to as the fusiform face area [FFA]), the occipital face area (OFA) in the lateral inferior occipital gyrus, and the posterior superior temporal sulcus (pSTS). The extended system included the amygdala, insula, and other limbic regions, which were most active when tasks required the analysis of emotion. More specifically, when participants tried to determine intentions, activation of the region of the temporal-parietal junction was required, and when attitudes were being determined, such as if someone were trying to be deceitful or trustworthy, activation of the anterior cingulate cortex was necessary (Haist & Anzures, 2017).

The focus of much ASD emotional and social processing research has focused on the role of the amygdala. Monk et al. (2009) expanded on previous studies and examined amygdala activation in response to face stimuli in participants with ASD and controls while (a) measuring attention bias; (b) examining functional connectivity between the amygdala and the ventromedial prefrontal cortex; and (c) evaluating functional connectivity in areas involved in processing facial expressions, between the amygdala and structures around the superior temporal sulcus. These structures were thought to influence one another in social tasks so the goal was to determine how these

interactions might be altered in ASD. In response to emotional faces, those with ASD showed abnormalities in brain function even when attention bias was equivalent to that in the control group, and the ASD group showed greater right amygdala activation to happy and sad faces. Furthermore, the ASD group showed greater positive functional connectivity between the right amygdala and ventromedial prefrontal cortex to happy faces and showed less positive functional connectivity between the right amygdala superior/medial temporal gyri to happy, sad, and angry faces (Monk et al., 2009).

A later study by Miu et al. (2012) examined emotional facial processing in neurotypicals with autistic traits (BAP) with two objectives: to investigate (1) observational fear conditioning (FC) performance and (2) attention to emotion biases in neurotypical selected for Autistic Traits (AT). Researchers chose FC that involved emotional faces, observed in a learning model, as an unconditional stimulus (US), and a task that investigated the effects of fearful and neutral gaze in direct attention, and also in the Reading the Mind in the Eyes test (RMET). During the RMET, participants were asked to identify mental states based on facial expressions. Miu et al. (2012) hypothesized that high AT participants would show abnormal responses in the FC task and in comparison, to neutral faces, fearful faces would not bias attention in high AT participants. Findings indicated that observational FC is influenced by AT and that neurotypicals with AT differed in the perception and interpretation of the learning model's mental state during the observed painful experience, or the representation of empathic pain in observational FC, and also differed in autonomic or brain reactivity

during observational FC (Miu et al., 2012).

Safar et al. (2020) examined whole-brain functional connectivity in adults with ASD (N = 104) during implicit perception of happy and angry faces. They hypothesized that adults with ASD would show reduced functional connectivity during processing of angry faces compared to controls. Results presented a network of reduced gamma band phase synchrony 80–308 millisecond (ms) which followed angry face onset in adults with ASD compared to controls. This network involved frontal regions and connections to the right temporal areas known to be involved in facial and emotional processing. No significant increase in gamma phase synchrony was found following the presentation of angry faces relative to baseline, which suggested these regions were atypically recruited in ASD, and therefore, impaired processing of angry faces, which reinforced previous findings of emotional facial processing impairing social communication in individuals with ASD (Safar et al., 2020).

Similarly, Hanley et al. (2015) furthered social studies in cognitively able students with ASD through the use of eye-tracking that explored social difficulties in individuals with ASD. Hanley et al. (2015) recruited college-age participants, as previous studies indicated those with ASD or BAP often experienced significant difficulty in college, due to social deficits that resulted from ASD / BAP. The study included 11 participants recruited through a UK university Office of Disability Services, all with a diagnosis of ASD. Students with ASD were matched to students with no known developmental or learning difficulties recruited through the same university. The

study aimed to capture spontaneous gaze that focused on how real-life social attention was related to social functioning in adults with ASD. Results showed the percentage of fixations to areas of interest across groups (ASD, TD) and regions (face, body, wall) revealed a main effect of region, but no significant main effect of group nor an interaction. However, both ASD and TD participants prioritized facial information during the interaction but revealed subtle group differences. Overall, the eyes were viewed longer by the TD group than the ASD group, and the ASD group viewed the mouth longer than the TD group. When these specific differences were analyzed, it was determined that longer time spent looking at the eyes was associated with better social awareness, and longer time spent looking at the mouth was associated with poorer social awareness. As a result, ASD individuals did not follow the flow of an interaction or detect subtle, non-verbal facial cues that were critical to the overall outcome of the social interaction (Hanley et al., 2015).

The Frontal Lobe and Facial Expression Recognition

Current research and exploration of ASD diagnoses and symptomology has implicated core and extended networks of the brain. Variations in these networks that exist in ASD individuals in comparison to TD peers are critical in early identification, to include possible future genetic testing identification, and in intervention treatments. Multiple studies demonstrated consistency in impaired areas of the brain in both ASD and BAP individuals, just with varying extents of symptomology. The amygdala, cerebellum, corpus callosum, orbitofrontal cortex, temporal parietal lobe, and insula, all

influenced facial recognition (Adolphs et al., 1994; Dekhil et al., 2020; Dziobek et al., 2010). However, the frontal lobe appeared to affect voluntary movement, expressive language, and executive tasks, which in turn affected abilities of individuals with ASD and BAP to gauge reaction and expression from others and to react and/or express themselves appropriately to others.

As previously stated above, the frontal lobe of the brain is responsible for voluntary movement, expressive language, and executive tasks involving a collection of cognitive skills such as planning, organization, initiation, and self-monitoring and control of responses. Williams et al. (2001) discussed the role of mirror neurons in theory of mind (ToM) and the dysfunction of the mirror neuron (MN) that resulted in a deficit in imitation. ToM as a result, produced several symptoms that characterize ASD. ToM was first coined by Premack and Woodruff (1978), and according to Baron-Cohen (1985), accounted for the emergence of pretend play. Baron-Cohen et al. (1993) elaborated on ToM in later research and indicated that a deficit in ToM also played a role in emotion recognition impairment in individuals with ASD. Children with autism were repeatedly observed as impaired in the recognition of surprise but reacted comparably to TD children with happiness and sadness (Jelili et al., 2021; Sato et al., 2017). This was also attributed to the fact that surprise was indicated as a belief-based emotion whereas happiness and sadness were indicated as reality-based expressions of emotion. This ToM element of surprise task became a core component in ASD assessment, such as that used in the Autism Diagnostic Observation Schedule (ADOS). As Williams et al. (2005)

pointed out, differential patterns of activity during imitation and action observation in ASD and TD were most evident in the right temporal-parietal junction, also associated with ToM. Additionally, Williams et al. (2005) conducted a focused study on the role of MN in ToM and determined ToM and imitation were affected by dysfunction of the MN. Moreover, Williams et al. (2005) noted a striking difference in the ASD group in their failure to show activation of TPJ during imitation, but instead showed activation of this area during observation, with the reverse occurring for the TD control group. These findings reinforced the role of the TPJ in imitation for ASD and in social cognitive development.

Research has also indicated differences in the orbitofrontal cortex (OFC) in individuals with ASD. The OFC is related to and helps control social behavior, because it contains the olfactory cortical areas and receives information from the temporal lobe and neurons that learn and reverse visual stimuli, creating a reinforcement stimulus. Additionally, Bachevalier and Loveland (2006) noted the connections between the amygdala and the OFC in the modulation of emotional behavior in situations that involved the rapid change necessary for social interaction and bonding, and as a reinforcement agent in the context of expectancies for reinforcers in goal-directed behaviors. Thus, individuals with ASD who presented deficits in the OFC not only had difficulty initiating and sustaining social interactions, but also lacked the motivation, as they did not process the reinforcement nature of a social situation. Lastly, this exchange included information about faces, which impaired facial expression identification, also a

common trait in individuals with ASD.

Quantitative EEG and ASD / BAP

The term quantitative EEG (QEEG) refers to quantitative signal analysis of the digitized electroencephalogram. Electroencephalogram (EEG) is a non-invasive procedure used to measure the electrical activity of firing neurons in the brain through metal electrodes filled with a conductive substance placed on the head to record and amplify the sound of synaptic excitation of neurons in the outer section of the cortex. A quantitative electroencephalogram (QEEG) as defined by the American Academy of Neurology is "the mathematical processing of digitally recorded EEG in order to highlight specific waveform components, transform the EEG into a format or domain that elucidates relevant information, or associate numerical results" (Nuwer, 1997, p. 278), thus, it applies computerized mathematical algorithms to transform raw EEG data into a number of frequency bands of interest (Billeci et al., 2013).

Machado et al. (2013) conducted QEEG spectral and coherence analysis of children with ASD from the Institute of Neurology and Neurosurgery in Havana, Cuba, that included two groups: 14 TD control group and 11 participants diagnosed with autism, under three conditions (eye fixation on a green dot as a control group, video and audio, video without audio). EEG was recorded from 19 locations over the scalp using the International 10/20 system. Significant reductions were found for the absolute power spectral density (PSD) in the central region for delta and theta in the posterior region for sigma and beta bands, lateralized to the right hemisphere. More specifically, the ASD

group showed statistically significant higher absolute and normalized values for the Beta and Gamma bands than the control group, and in general coherence values showed a tendency to reduced values during the experimental conditions video and audio and video with audio, compared to the control condition. Additionally, the examiners detected no facial or other emotional behavioral signs among the children with autism, contrary to the control participants, which further reinforced findings that indicated a clear differentiation between children with autism from control subjects in QEEG spectral analysis. These coherence differences in individuals with ASD reflected the presence of rigid neuron networks, explained the repetitive behavior expressions, impairments in social interactions, communication, and imagination characterized by autism (Machado et al., 2013).

An additional study by Dickinson et al. (2017) investigated peak alpha frequency (PAF) as a neural marker of network-level brain activity, and demonstrated that peak alpha frequency was lower in individuals with ASD than typically developed individuals. Using 38 seconds of cleaned data that were selected for spectral power analysis for six areas of interest (F3, F4, C3, C4, O1 and O2), results demonstrated significant effects of age on PAF, and specifically found that children with ASD did not show the typical increase in PAF with age. These findings supported atypical network-level brain activity likely due to disruptions in white matter in development (PAF are associated with increased white matter in typical developing individuals). Therefore, EEG of individuals with ASD allowed functional tracking of structural processes

underlying large-scale network development and allowed for earlier identification and intervention for individuals with ASD.

QEEG has been used in several studies for the assessment of ASD, in hopes of finding out quantitative indices characterizing brain functions. Billeci et al. (2013) found that those with ASD displayed differences in coherence and symmetry. ASD individuals showed greater percentage of delta, less alpha activity, higher degree of coherence between and within hemispheres, and less amplitude asymmetry. Much of the previous research over asymmetry in ASD has solely focused on language regions. However, Cardinale et al. (2013) investigated asymmetry in those with ASD in nonverbal regions of the brain and indicated hemispheric asymmetries detected in components thought to be implicated in auditory, visual, sensorimotor, executive, attentional, and visuospatial processing. The atypical rightward shift of asymmetry for sensorimotor components and motor processing in ASD and lower participation in the left hemisphere was determined as a pervasive feature of brain organization in ASD that contributed to a large number of ASD characteristics (Cardinale et al., 2013).

Much of what individuals learn in life is acquired through imitation, and imitation is also a key element to developing social skills. The discovery and research into the role of the Mirror Neuron System (MNS) and the deficits in MNS function in individuals with autism has led to greater understanding of how MNS and social / emotional processing in individuals with ASD are related. MNS display activity in relation to an individual's actions and to matching actions of others. In a study

conducted by Ramachandran and Oberman (2006) using EEG measurements, it was determined that mu suppression occurred in children with ASD only when a voluntary movement was made by the child but not when the child watched someone else perform the action, thus indicating the child's motor system was intact, but the child's mirror neuron system was deficient. Of further importance was consideration is the anatomical location of the MNS. Researchers Iacoboni and Dapretto (2006) emphasized the proximity of the MNS to the frontoparietal system and also indicated the MNS is linked with sensorimotor integration and social cognition. Imitative behavior was indicated as necessary for development of social skills and given the role of mirror neurons in imitation and action recognition, the MNS deficit in ASD individuals contributed to their inability to possess empathy and therefore also contributed to difficulty with processing emotional faces. As a result, individuals with ASD had difficulty understanding others which led to increased social deficits (Dapretto et al., 2005).

QEEG and BAP

QEEG findings have also allowed researchers to identify phenotypes in family members of individuals with autism. In a study conducted by Losh et al. (2008), findings demonstrated a consistent linear trend across measures of personality traits, associated BAP, friendship preferences, and pragmatic language between simplex and multiplex ASD parents. Moreover, multiplex family ASD parents displayed greater BAP traits and showed it is more common for both parents in multiplex families to show BAP traits. Gerdts and Bernier (2011) expanded on the research of Losh et al. (2008) and examined

neural studies using EEG to provide further support for biological differences between ASD parents and siblings compared to controls. Specifically, Gerdts and Bernier (2011) revealed a difference in task processing in ASD parents and siblings compared to controls and also indicated a difference in facial processing in ASD parents and siblings. Gerdts and Bernier (2011) presented consistent findings with earlier studies and indicated BAP traits are more common in male relatives than female relatives of those with ASD and consistently found core deficits in those with ASD, but to a lesser extent, in relatives of those with ASD such as differences in social and communication impairments. Additional familial differences observed in ASD family members, compared to controls, included variable cognitive abilities, differences in ToM and executive functioning skills, increased head circumference, and differences in neural functioning and structure.

Impaired areas of the brain in both ASD and BAP individuals in multiple studies have demonstrated the effects on social functioning of individuals with ASD or BAP. The frontal lobe has been repeatedly implicated in autism and is well supported in previous histopathological research, animal and human lesion studies, and replicated evidence of atypical activation of the temporal lobe in theory of mind tasks, which play a key role in cognitive development (Penn, 2006). Moreover, the OFC contributed to stimuli reinforcement and the deficits in the OFC in individuals with ASD impaired the learning and reversal of stimulus reinforcement associations; therefore, the behavioral responses were no longer appropriate, because the reinforcement contingencies were changed (Rolls, 2006). More specifically, within the OFC, the insula was credited with a

critical role contributing to ASD / BAP symptomology.

Anterior Brain Asymmetry in ASD

Brain asymmetry refers to a structural or functional difference in the two brain hemispheres which affect behavioral competencies and task performance. Anterior regions of the brain are more involved in language. Within the anterior brain lies the anterior temporal lobe, right superior temporal gyrus, and the right inferior frontal gyrus, which affect inferencing and processing skills (Virtue et al., 2008).

Individuals with autism have been significantly associated with cortical thickness asymmetry in the frontal, orbital surface area, cingulate and inferior temporal areas. These cortical regions are involved in social cognitive processes, including perceptual processing, cognitive and emotional control, and reward evaluation, all of which affect social behavior (Postema et al., 2019).

Postema et al. (2019) gathered magnetic resonance imaging (MRI) data from 54 sets collected from the Enhancing Neuro-Imaging Genetics through Meta-Analysis (ENIGMA) consortium to perform the first highly powered study of structural brain asymmetry in ASD, and used a protocol for image analysis with asymmetry indexes (AI) = (Left−Right)/(Left + Right) for 1778 individuals with ASD and 1829 TD controls. Results indicated significant effect of diagnosis including frontal regions (superior frontal, rostral middle frontal, medial orbitofrontal), temporal regions (fusiform, inferior temporal), and cingulate regions (rostral anterior, isthmus cingulate). Two cortical regional surface area asymmetry indexes (AI), the medial and lateral orbitofrontal cortex,

were also significantly associated with diagnosis (medial: $\beta = 0.006$, $t = 3.2$, $P = 0.0015$; lateral: $\beta = -0.005$, $t = -3.3$, $P = 0.0010$). More specifically, Postema et al. (2019) had 80% statistical power to detect Cohen's *d* effect sizes in the range of 0.12–0.13. Findings showed significantly altered asymmetries of seven regional cortical thickness asymmetries in ASD compared with controls, and the magnitude of all regional thickness asymmetries were decreased in ASD compared with controls. Rightward asymmetry of the medial orbitofrontal surface area was also decreased in individuals with ASD, as was leftward asymmetry of the lateral orbitofrontal surface area. Individuals with ASD also showed an increase in leftward asymmetry of putamen volume, compared with controls. These findings of cortical thickness asymmetry supported laterality as important organizing features of the healthy human brain for multiple aspects of complex cognition and implicated their susceptibility to disruption in disorders. Thus, the findings of Postema et al. (2019) suggested altered neurodevelopment affected brain structures in ASD. The large-scale analysis of brain asymmetry in ASD encouraged additional research on the default mode network (DMN) organization, which is evidenced in differences in ASD, that included alterations in functional laterality (Postema et al., 2019).

Previous research has presented the role of asymmetrical cortical activity in social cognitive processes, but some researchers have examined more specific functions affected by brain asymmetry. Kelley et al. (2017) reviewed literature that applied physical manipulations of frontal asymmetry to determine the role of asymmetrical

frontal activity in approach versus avoidance and the necessity of approach / avoidance motivation as a necessary part of survival. Previous research by Davidson et al. (1990) demonstrated increased right frontal cortical activity was associated with avoidance motivation and increased left cortical activity was correlated with trait approach motivation. Therefore, researchers sought to examine the effects of manipulations of asymmetrical frontal activity. In their analysis of the literature, Kelley et al. (2017) reviewed the effects of manipulation of cortical activity using tDCS, on anger and aggression, jealousy, risky decision making, food craving and caloric ingestion, and fear memory. Following a 15-minute session of tDCS where participants were randomly assigned to an increase in relative left frontal cortical excitability (anodal over F3/cathode over the F4), an increase in relative right frontal cortical excitability (cathode over F3/anode over F4), or sham stimulation, participants who received tDCS to increase left cortical act displayed greater aggression that reinforced similar findings in previous studies by Hortensius et al. (2011) and Dambacher et al. (2015). Taken together, results demonstrated an increase in left cortical activity and increased anger-driven aggression, whereas an increase in right frontal cortical activity decreased aggression. Jealousy is an additional approach / avoidance motivated emotion. Using the same protocol (15-minute anodal F3, cathodal F4, random assignment) researchers found increase to the left frontal cortical activity increased jealousy, reinforcing previous findings that tDCS over the DLPFC modulated emotional responses associated with frontal asymmetry. In their review of tDCS effects on risky decision making, Kelley et al. (2017) indicated that tDCS

increased right frontal cortical activity, using cathode F3 / anodal F4, and demonstrated decreased risk-taking and selection of safer, less risky choices, which suggested that a manipulated increase in right frontal activity resulted in less temptation by larger, less-likely rewards. Additionally, findings also demonstrated cathodal F3 / anodal F4, increased right prefrontal activity stimulation, demonstrated decreased food cravings, and increased fear memory consolidation. In summary, these findings suggested increase in left frontal cortical activity increased approach-motivated responses and increased right frontal cortical activity decreased approach-motivated responses and increased avoidance motivated responding (Kelley et al., 2017).

A further study of approach-motivation related to anterior brain asymmetry was conducted by Lautttia et al. (2019) that examined direct and averted gaze in children with ASD. Given impairments in social skills is one of the earmarks in the early identification of ASD, Lauttia et al. (2019) sought to expand on ASD individuals' avoidance of other people's faces and eyes in comparison to TD children. Specifically, they examined frontal EEG asymmetry responses to direct and averted gaze in three- to six-year-old children with severe ASD and intellectually disabled (ID). TD children and children with ID without ASD served as control groups. Lauttia et al. (2019) investigated whether a similar pattern was observed in children with severe ASD and ID, or whether these children instead showed smaller approach-related activity in response to direct gaze (indicated by less relative left-sided frontal EEG activity in response to direct rather than to downcast gaze in the children with ASD). Participants included 20 children with ASD,

17 children with intellectual disability (ID) without ASD, and 19 TD children, ages three to six years, who had no history of neurodevelopmental or neurological disorders. Results demonstrated that within the TD group, direct gaze elicited greater approach-related frontal activity than downcast gaze, opposite to the activity in children with ASD, who showed greater approach-related activity in response to downcast gaze than to direct gaze. Control participants with ID but without ASD, demonstrated no differences in frontal EEG activity patterns in response to direct versus downcast gaze. These findings supported previous findings that indicated children with ASD did not show enhanced heart-rate orienting response to direct gaze, but TD children and children with ID without ASD did. Lauttia et al. (2019) therefore asserted children with ASD showed greater approach-related frontal EEG activity in response to the dynamic conditions than to the static conditions, and their findings indicated group-specific abnormalities in response to social cues in children with ASD. Findings explained how these differences were associated with difficulties in social behavior (Lauttia et al., 2019).

Autism symptomology is diverse and therefore complicates research on the matter. However, the Modifier Model of Autism presented by Mundy et al. (2007) implicated variations in autism result from not only syndrome specific causal processes but also from variability in specific modifier processes that affect social and emotional development. Burnette et al. (2010) expanded on a previous study they conducted as well as others, that presented two specific goals: (1) to replicate the observation that left frontal EEG asymmetry is associated with attenuated social symptom intensity within a

larger sample of higher functioning children with autism, and (2) to determine if domains of behavior other than social symptoms were meaningfully related to anterior EEG asymmetry differences in autism. Additionally, Burnette et al. (2010) addressed a hypothesis that examined the prediction that retrospective parent report of age of onset of symptoms on the Autism Diagnostic Inventory (ADI) would be associated with anterior EEG asymmetry in higher functioning children and adolescents with autism. Participants included 35 children (32 boys) with a prior diagnosis of ASD without intellectual disability or higher functioning autism (HFA, IQs above 70), and a comparison group of 28 children (25 boys) without ASD or intellectual disability. Results of this study combined with previous findings by Sutton et al. (2005), demonstrated frontally mediated individual differences in brain processes associated with behavioral approach and avoidance tendencies that contributed to significant variability in symptom presentation and patterns of behavior and ideation related to anger and anxiety. Additionally, patterns of right resting frontal EEG asymmetry were thought to reflect relatively greater activation of a neural network that included the frontal cortex, amygdala, septohippocampal system, and brainstem, that regulate responses to signals of punishment, non-reward, and novelty; therefore, those with greater right anterior brain activity exhibited inhibition of movement towards goals and withdrawal from novel situations and social interactions. In contrast, those with greater left-brain activity exhibited more activation of goal-directed, reward seeking behavior, and anticipated positive affective states when exposed to cues of potential reward, as well as anger or

frustration when approach-related goals were blocked. The findings of this study indicated (a) symptom ratings were more pronounced in HFA children with IQs in the borderline range, and less prominent among children in the higher ranges of IQ, and (b) that IQ itself was not a modifier of the expression of autism. Furthermore, relations between anterior EEG asymmetry and emotional functioning and developmental history observed in the current study were not moderated by IQ, and anterior EEG asymmetry measurement of a generic dimension of human individual differences allowed for more precise assessments of diagnostic subgroups among children with autism, as EEG asymmetry provided a useful measure of approach and avoidance tendencies (Burnette et al., 2010).

In summary, repeated research studies have demonstrated the role of brain asymmetry in ASD and in specific, the contribution of asymmetry to approach / avoidance. Furthermore, identification of specific regions affected by brain asymmetry provided greater understanding, and therefore, earlier identification and intervention for ASD and BAP symptomology, and promoted and facilitated further research into brain asymmetry and interventions.

Transcranial Direct Current Stimulation (tDCS)

Transcranial Direct Current Stimulation (tDCS) is a brain stimulation used to modulate cortical excitability, producing facilitatory or inhibitory effects upon a variety of behaviors. Although many interventions have proven useful for individuals with ASD or BAP, greater intervention is needed. One form of intervention showing promise in

improving attention and social skills in individuals with ASD / BAP is tDCS therapy. tDCS provides a weak current from one to two mA to the scalp through two electrodes, an anode and a cathode. It can modulate the spontaneous neuronal activity by inducing either positive (anodal) or negative (cathode) intracranial current flow in specific brain regions. Anodal stimulation increases cortical excitability, whereas cathode stimulation inhibits the same (Nitsche & Paulus, 2000; Terney et al., 2008).

In a study that applied tDCS to 13 children identified with ASD, Kang et al. (2018) asserted that anodal tDCS intervention over the DLPFC increased cortical excitability for children with ASD and balanced the excitation and inhibition of neurons. This expanded on a previous study by Amatachaya et al. (2015) where researchers demonstrated that even one stimulation of anodal tDCS over the left DLPFC resulted in a significantly higher peak alpha frequency, measured from the F3 electrode, which resulted in increased processing ability for individuals with ASD. The DLPFC is the cortical area involved in planning, organization, regulation, and inhibition, all areas of deficit in individuals with ASD / BAP. Additionally, the DLPFC is connected to the orbitofrontal cortex, the basal ganglia, thalamus, hippocampus, and posterior temporal, parietal, and occipital areas, linking the DLPFC to restricted and repetitive behaviors and hyper- and hypo- sensitivities to stimuli. Thus, the DLPFC is a targeted area of tDCS for treatment in individuals with ASD / BAP. In a recent study by Qiu et al. (2021) researchers applied tDCS over the left DLPFC. The modulation effect of a three-week anodal tDCS treatment with ASD was investigated. Researchers found that after tDCS

treatment, Childhood Autism Rating Scales (CARS) and Aberrant Behavior Checklist (ABC) scores were significantly reduced. Additionally, Qiu et al. (2021) found significant correlation between baseline CARS and ABC scores and CARS and ABC score changes pre versus post treatment, which indicated those with more severe ASD symptoms tend to have greater response to tDCS treatment.

In a double-blind, randomized, sham-controlled study conducted by Han et al. (2022), researchers conducted a multisession prefrontal tDCS on ASD participants ages 14–21-years, with a 1.5 mA five days per week for two weeks. Participants showed a highly significant reduction in SRS scores, which indicated improved social skills. Given the hypoconnectivity within the medial PFC and the significance of this area in processing information, these findings also implied tDCS with the left DLPFC cathode placement and right supraorbital region anode placement promoted improved processing of social information, relative to oneself within the right medial PFC, which resulted in clinically observable social functioning improvements (Han et al., 2021).

Qiu et al. (2021) expanded on previous tDCS studies to improve memory function in ASD by conducting a pilot prospective, single-blinded, randomized, parallel clinical study to test the efficacy of three-week tDCS at the left DLPFC in individuals with ASD. The researchers hypothesized that three weeks of tDCS treatment could be well-tolerated and may significantly reduce the symptoms associated with ASD. The anodal electrode was placed over the left frontal lobe (F3) of a10-20 EEG electrode placement, and the cathodal electrode was placed on the right shoulder contralateral to the anode. tDCS

treatment was applied at 1mA for minutes. For sham tDCS after the setup electrodes, the staff turned on the device for 15 seconds, then turned it off to simulate the somatosensory effect of the real tDCS. Results showed after real tDCS treatment, but not after sham tDCS treatment, CARS scores were reduced significantly and significant correlation between baseline score changes (pre- minus post-treatment) after real tDCS, indicated those with more severe symptoms tended to have a greater response to tDCS treatment (Qiu et al., 2021).

Previous brain imaging studies found that the volume of the right brain structures related to social function were greater in the right hemisphere relative to the left and also relative to TD subjects, and hypoactivation of the left hemisphere relative to the right has been found in individuals with ASD. Amatachaya et al. (2015) researched the possibility of tDCS increase in alpha frequency in anodal area which reflected as an increase in synaptic recovery and was associated with improved symptomology in those who received tDCS. Specifically, the researchers hypothesized (1) a greater increase in peak alpha frequency (PAF) pre- to post-tDCS stimulation among a group of children with ASD who receive anodal tDCS over the F3 cortex, relative to a group who receive sham tDCS; (2) a negative association between change in PAF and change in autism symptoms; (3) increases in alpha frequency and associations between changes in alpha frequency and autism symptoms would be specific to the stimulation site (F3) and would not be found at other electrode sites. Findings indicated a single stimulation of anodal tDCS over the left DLPFC (F3 in the international 10/20 system) resulted in significantly

greater increases in PAF measured from the F3 electrode that is maintained for 24 hours among participants in the active tDCS condition. Additionally, a significant association between improvements in the Autism Treatment Evaluation Checklist (ATEC) Sociability and Health/Physical/Behavioral subscales and an increase in PAF in those who received active tDCS treatment, indicated increased cortical activity in the left frontal regions associated with improvements in some ASD areas of concern (Amatachaya et al., 2015).

Expanding on previous research and narrowing the focus of tDCS to examine approach-avoidance conflict (AAC), Chrysikou et al. (2016) conducted a study that demonstrated increased right DLPFC activity led to decreased AAC. Researchers predicted that excitatory stimulation over the right DLPFC would show decreased approach behavior. Participants in the study included 63 college students who were randomly assigned to one of three conditions: (a) anodal stimulation over the right DLPFC (n = 21; 65% males), or (b) anodal stimulation over the left DLPFC (n = 21; 62% males), or (c) sham stimulation (n = 21; 29% males), which were blind to the participant. Then, tDCS was administered with an anode placed over the F3 or F4 on the 10/20 system for stimulation. Results indicated participants with high anxiety sensitivity showed significantly limited approach behavior under excitatory right tDCS over DLPFC. Excitation over the left DLPFC enhanced performance on the control forward digit span (FDS). Chrysikou et al. (2016) also noted that the functional impact of right DLPFC depended on the baseline anxiety level of the individual and suggested future

research employ concurrent tDCS and neuroimaging to possibly determine the precise effects of neurostimulation for the function of cortical and subcortical networks. Overall, the results demonstrated that over-excitation of the right DLPFC with high sensitivity to anxiety led to decreases in approach behavior during affective decision making (Chrysikou et al., 2016).

Following suggested correlations of frontal lobe asymmetry and approach versus withdrawal motivation from previous research, Ohmann et al. (2018) conducted a study and examined the effect of anodal tDCS applied over the left DLPFC on approach motivation. Using the Effort-Expenditure for Reward Task (EEfRT) to measure effort allocation, researchers Ohmann et al. (2018) hypothesized left frontal anodal tDCS would increase participants' willingness to allocate more effort during EEfRT. Specifically, researchers expected an increase in overall hard task choices (HTC) for tDCS stimulation of the left DLPFC compared to sham stimulation. The study included 60 right-handed participants aged 18-35 years. Participants received monetary compensation and were told they could receive additional money based on their collected rewards from the EEfRT. Results showed no main effect of stimulation condition, but the interactions of stimulation and both reward attributes revealed that anodal tDCS increased effort expenditure for both trials with low probability of reward and high reward magnitude. This reinforced previous findings that suggested effort expenditure in low-probability trials correlated with higher trait approach motivation and increased left frontal brain activity. Furthermore, given the absence on main effect of stimulation condition and

presence of interactions between stimulation condition and both reward attributes, these results demonstrated support that tDCS stimulation may interact with task-induced brain activity as well as the idea of asymmetric activity of frontal brain sites and motivation (Ohmann et al., 2018).

Rationale

Previous studies suggested similarities in symptomology and brain structure and function in individuals with ASD and BAP (Billeci et al., 2016; Gerdts & Bernier, 2011). Both conditions presented social deficits that inhibit one's ability to interact in daily exchanges in academic, professional, and personal environments. Moreover, previous studies noted difficulties for individuals with ASD and BAP to interact socially in the college setting which resulted in social and academic repercussions. Studies have also suggested commonalities in brain function that indicated frontal lobe asymmetry in individuals with ASD and BAP was a key contributor to this social deficit demonstrated (Jobe & White, 2007; McLeod et al., 2019; Trevisan & Birmingham, 2015). tDCS is a neuromodulatory technique that has demonstrated positive influence on approach/avoidance to objects and situations by training the frontal lobe (Hadoush et al., 2020; Han et al., 2021; Ohmann et al., 2018). The purpose of this study was to determine if tDCS training to the frontal lobes could increase approach toward social interactions in adults classified as BAP as demonstrated by eye-tracking measures in response to faces and gaze fixation.

Hypotheses

The following were the specific hypotheses tested in this study:

I. BAP participants would show greater fixation on facial features after completing tDCS training.

II. BAP participants trained with tDCS would show less frontal lobe alpha asymmetry than when trained with sham.

III. BAP participants trained with tDCS would spend more time looking at faces on a social interaction video relative to sham.

IV. There would be a relationship between BAPQ scores and familial connections.

Chapter III: Method

Participants

The study included 21 total participants, male and female. Power analysis using an effect size of 1.2 (large effect) indicated that 19 participants were needed to obtain statistically significant results. Participants were recruited from college STEM classes, at a regional university in East Texas. Participants were recruited via emails sent through university course instructors and via fliers posted in the STEM buildings. Inclusionary requirements included active participation in college in a STEM course and high Broad Autism Phenotype Questionnaire (BAPQ; cutoff score at 3.17 for females and 3.55 for males; Sasson et al., 2013). Participants were excluded if they had a history of psychopathology, traumatic brain injury, or metal implants of any kind. This protocol was approved by the Institutional Review Board (IRB) at the regional university in East Texas. Incentives were provided for participant participation in the amount of a $20.00 gift card provided for each participant following completion of their participation in the study.

EEG collection and tDCS training

Gel-soaked EEG and tDCS electrodes were placed on the brain frontal lobes (F3 and F4). The anodal electrode was placed over DLPFC, and the cathode electrode was placed over the right supraorbital. EEG signals were monitored and tDCS training was

accomplished by using a dual amplifier and battery-driven constant-current stimulator (STARSTIM Neuroelectrics). Each client underwent both tDCS and sham stimulation, separated by at least 24 hours. tDCS stimulation was delivered by 2mA for approximately 20 minutes, whereas sham stimulation was delivered at the same current level for a one-minute ramp up of 2 mA and then turned off without the participant's knowledge. EEG was collected for 5 minutes immediately after the stimulation or sham session.

Materials

A demographics and brief medical history questionnaire was used to assess possible extraneous variables (i.e., history of chronic pain, substance abuse, medication use) and the exclusion criteria (i.e., history of traumatic brain injury, psychopathology, or metal implants), as well as to gather demographic information on the participant. Additionally, the BAPQ was used to measure three subscales of ASD characteristics present in the BAP.

The Broad Autism Phenotype Questionnaire (BAPQ)

The BAPQ is a self-report questionnaire used with adults to measure three subscales of ASD characteristics presented in the BAP: Aloof, Pragmatic Language, and Rigidity (Hurley et al., 2007). The BAPQ contains 36 items on a six-point scale, with responses that ranged from *very rarely*, to *very often*. The BAPQ provided a total score and scores for the three subscales. The BAPQ demonstrated strong internal consistency with Cronbach's scores which ranged from 0.80 to 0.95 (Sasson et al., 2013). The BAPQ performed better than the SRS (Constantino, 2003) and the AQ (Baron-Cohen et al.,

2001) in measuring internal consistency, criterion validity, and incremental validity of the BAP in non-clinical adults (Ingersoll et al., 2011). Although Hurley and colleagues (2007) originally set the BAP cutoff at 3.15, a recent empirical study suggested that higher cutoffs of 3.17 for females and 3.55 for males lead to fewer false positives (Sasson et al, 2013).

Social Interaction Anxiety Scale (SIAS)

The Social Interaction Anxiety Scale (SIAS) is a 20-item self-report that was originally developed in conjunction with the Social Phobia Scale to determine individuals' levels of social anxiety (Mattick & Clarke, 1998). The SIAS was developed more specifically to assess fears and anxiety related to social interactions such as meeting with others or initiating and maintaining conversations. The SIAS discriminates between clinical and non-clinical populations (Brown et al., 1997; Le Blanc et al., 2014; Mattick & Clarke, 1998) and has also been found to differentiate between those with social anxiety and those with general anxiety (Osman et al., 1996), making it a useful clinical screening tool. Originally developed in Australia, it has been tested and found to work well in diverse cultures worldwide and has strong psychometric properties in clinical and non-clinical samples (de Beurs et al., 2014).

Facial Expression of Emotion Stimuli and Tests (FEEST)

To measure perception of facial expressions (happiness, fear, surprise, sadness, disgust, and anger) a set of computer-transformed pictures that showed faces from FEEST were used. Each face showed two emotions with different degrees of intensity

(for example: 90% happiness/10% surprise; 70% happiness/30% surprise, 50% happiness/50% surprise, 30% happiness 70% surprise, and 10% happiness/90%surprise).

The FEEST stimuli consisted of more than 1,000 images of faces derived from photographs in the Ekman and Friesen (1976) series. The stimuli set included prototype (unmodified) facial expressions and computer-manipulated versions. In the computer-manipulated images, morphing and caricaturing techniques were used to systematically change the images in ways that allowed the creation of novel tests and experiments suited to a wide range of purposes. Morphing was used to create images that fell along regularly graded transitions from one prototype expression to another, whereas caricaturing was used to increase or decrease the intensity of a particular expression (Facial expressions of emotion – stimuli and tests, 2002).

The FEEST stimuli can be used to create supplementary tests for specific purposes. For example, it is possible to explore emotion recognition deficits in detail by seeing whether a person who does not recognize certain emotional expressions can match different pictures as representations of the same underlying emotion, perceive changes in the intensity of an unrecognized expression. Since numerous previous studies indicated individuals with ASD / BAP suffer from social deficits due to inability to process emotional facial recognition, the FEEST served as a valuable tool to assess pre and post effects of tDCS. Studies have shown early in development, infants and particularly studies of at-risk populations such as family members of ASD / BAP

individuals, have helped to clarify differences in development of gaze and facial information processes in autism (Elsabbagh et al., 2012; Volkmar, 2011).

Social Interaction Video

Participants viewed video segments obtained from YouTube, approximately 30 seconds in length, that demonstrated social interactions, after each tDCS or sham session. Participants viewed one video on day one and one video on day two of a victimized individual. Videos were randomly assigned, and eye-tracking measures and EEG data were taken during the video and analyzed to determine participant time spent looking at faces.

Eye-Fixation Measure

Eye tracking was measured using the Tobii Pro Studio eye-tracker. The Tobii Pro TX300 (developed by Tobii Technology AB, Danderyd, Sweden) with a 300Hz sampling rate (binocular) and a maximum total system latency of 10 ms (Tobii Pro, 2010). The eye-tracker server was integrated into the base of the monitor, which was a 23-inch thin film transistor LCD with a screen resolution of 1920, 1080 pixels and screen response time of 5 ms as required according to the Tobii Pro TX300 brochure. The eye tracker server was connected to an eye tracker computer running Tobii Pro Studio (bundled software for the Tobii eye tracker and used for presenting stimuli and recording gaze data). Eye tracking was used to specifically measure the number of eye fixation counts and total fixation durations in target areas (faces). Fixation count, total fixation duration and gaze were the eye-tracking variables of interest. Fixation count was defined as the

number of times the participant fixated outside of the target. Visit duration was defined as the sum of the time duration on the target. Gaze was defined as the location the participant was looking at on the stimuli image.

Procedure

Individuals involved in STEM courses were recruited through completion of the BAPQ in one of their STEM courses. Participants came into the laboratory and were given an informed consent form stating the general details of the study, limits of confidentiality, and explaining voluntary participation. Participants were asked to read and sign the form if they agreed to continue. After the informed consent was signed, the researcher gave the brief medical history questionnaire as an interview, which the participants answered privately. The researcher then had each participant sit down in the assessment room and began the cap process. First, the researcher measured to determine what size cap was needed. Second, the researcher applied Neuro-prep gel on the two spots on the participants' head that were measured and the ear lobes (reference and earth). The Neuro- prep was intended to clean the scalp to obtain clean brain-wave pattern readings and increase conductivity. Note that participants were randomly assigned to the two treatment orders (i.e., sham-active or active-sham). The two treatment sessions for each participant were conducted on similar times and days for each individual participant with 24 hours of wash out in between each session.

Then, the cap was placed on the participant's head and electro-gel was applied to the scalp. The cap was plugged into the amplifier, and the participants were instructed to

relax and be as still as possible, as movement could interfere with the scan. The participants' heads were cleaned, and the EEG cap placed on the participant's head. Participants received sham or stimulation for 20 minutes. Next, EEG data was collected for 5 minutes following tDCS. Then, participants' eye tracking measures were collected while completing the FEEST and interactive social video. Once the tasks were completed, the participants were debriefed.

Design

This study used a quantitative mixed methods design, with a randomized single-blind controlled placebo (sham tDCS) crossover trial performed over two weeks consisting of: (1) a single session of single-subject 2mA anodal or sham tDCS (depending on order of assignment) for 20 minutes, eye tracking measures taken with 60 images displayed for 100 ms per facial expression, followed by eye tracking while viewing a social interaction video to measures fixations and gaze approach / avoidance, and (2) a single session of single-subject 1mA anodal or sham tDCS (depending on order of assignment) for 20 minutes, eye tracking measures taken with 60 images displayed for 100 ms per facial expression, followed by eye tracking while viewing a social interaction video to measure fixations and gaze approach / avoidance.

Data Analysis

For descriptive purposes, the researcher determined the means and standard deviations of the demographic and outcome variables, then tested the assumptions of normality and determined outliers. If EEG variables were found to violate any of the

above summations, corrections were applied.

A dependent samples *t* test was used to determine if BAP+ when trained with tDCS displayed greater fixation time on facial expressions than those who were not trained with tDCS. A repeated measures mixed ANOVA was used to compare Time Spent on faces (while looking at images and the social interaction video) before and after tDCS or sham training. Lastly, correlations were conducted to determine the relationship between Alpha Asymmetry. For all analyses, p values of <0.05 were considered statistically significant. Analysis was completed using IBM SPSS software.

Chapter IV: Results

Final Sample

A total of 21 participants (BAP+ $n = 21$) were included in the study. The current sample ranged in age from 18 to 52 years old, with 10 male participants (47.6%) and 11 female participants (52.4%). BAP + cutoff used was a total score on the BAPQ of 3.17 (Sasson et. al, 2013). Data analysis was completed using SPSS for frequencies, descriptive, correlations, preliminary analysis, and *t*-tests. The Sex of the participants was divided almost equally, and BAP scores ranged from 3.17 to 4.44. Although age ranged from 18 to 52 years, of the 21 participants, two-thirds of them were under the age of 23 years. In terms of familial relations with an ASD diagnosis, this was also split nearly evenly across the three categories, sibling, other family, or none known. Please refer to Table 1 for demographics.

Table 1

Participant demographics

		%	Frequency (n = 21)
Sex	Female	52.4	11
	Male	47.6	10
Age	18 – 22	66.7	14
	23 and above	33.6	7
Familial Relation	Sibling	28.6	6
	Other Family Member	33.3	7
	None Known	38.1	8
BAPQ Scores	3.17	4.8	1
	3.25	14.3	3
	3.39	4.8	1
	3.50	9.5	2
	3.53	9.5	2
	3.56	9.5	2
	3.58	4.8	1
	3.67	14.3	3
	3.69	4.8	1
	4.14	9.5	2
	4.17	4.8	1
	4.25	4.8	1
	4.44	4.8	1

Preliminary Analysis

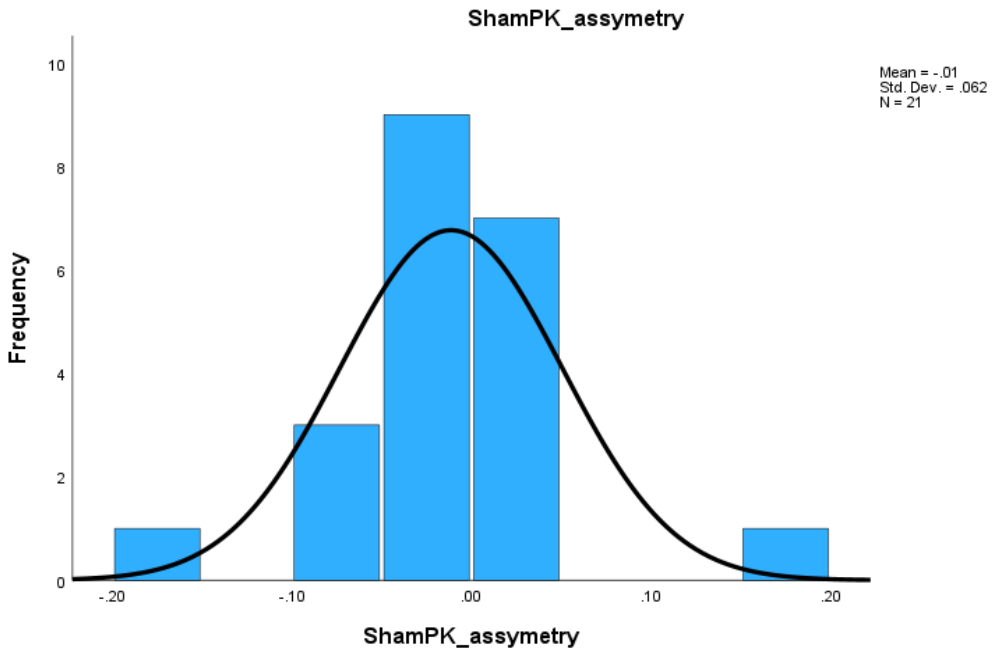
Test of Normality

QEEG Data. A test of normality was conducted to determine whether the EEG data (i.e., sham Peak Alpha asymmetry) was normally distributed. The sham condition was tested as it was assumed that participants did not receive any stimulation, and thus, showed the distribution of the EEG data under a "normal" condition. Hair et al. (2010) and Byrne (2010) state that the normality assumption is not fulfilled when the skewness

coefficient is outside the range of ±2 and the kurtosis coefficient is outside the range of ±7. For Peak Alpha Asymmetry the skewness (-.140) and kurtosis (4.502) demonstrated a partly peaked distribution. Please refer to Figure 1.

Figure 1

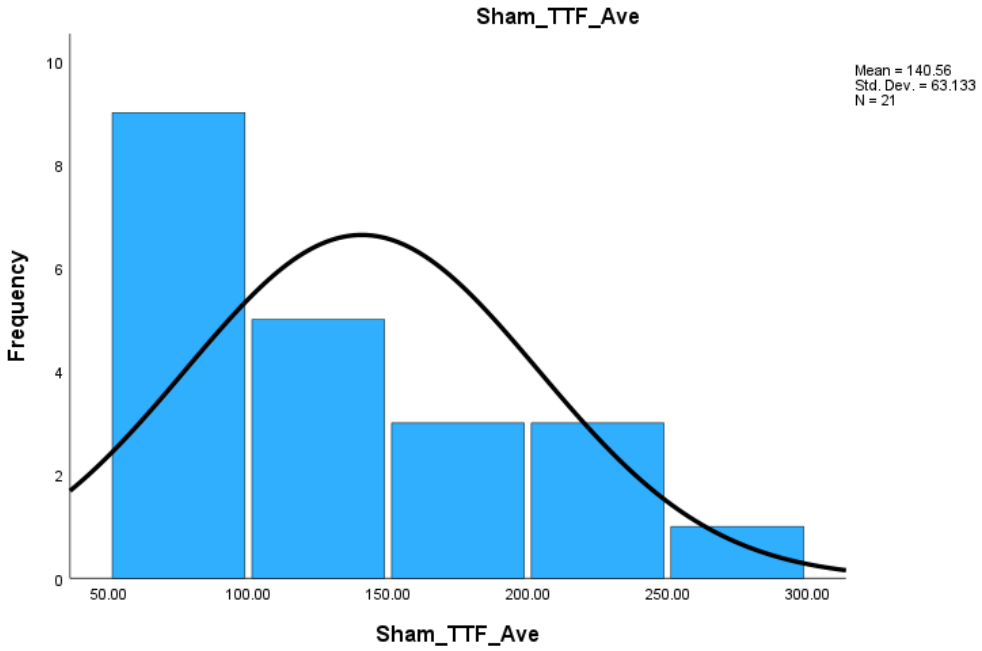
Distribution of Sham PK Asymmetry



Distribution of Time to First Fixation. A test of normality was also conducted to determine whether the eye tracking data were normally distributed. Results for sham time to first fixation revealed no concerns with skewness (.891) and kurtosis (.237, SE=.501), indicating the data was normally distributed. Please refer to Figure 2.

Figure 2

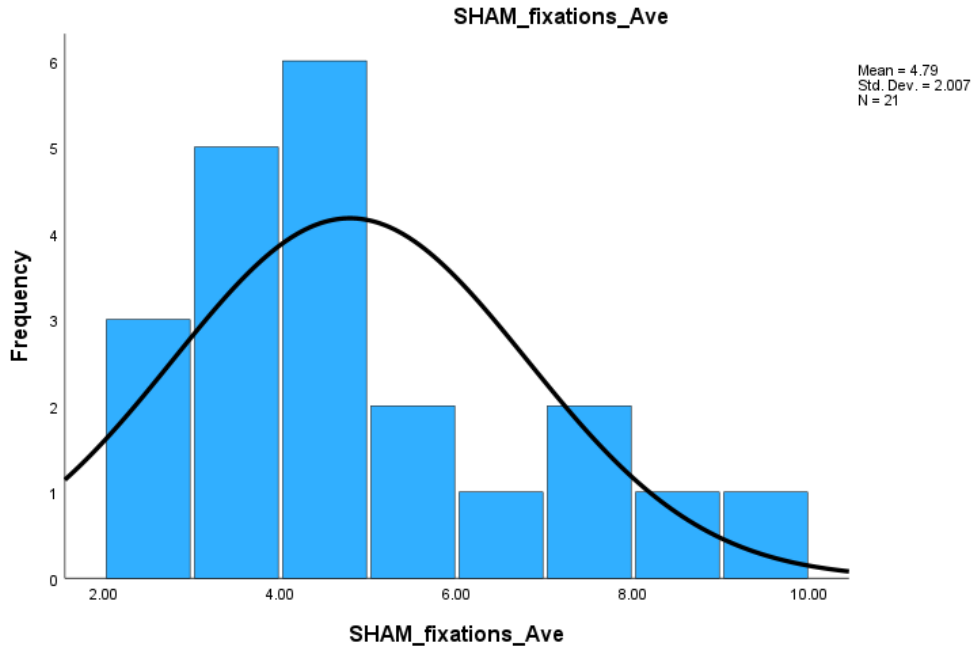
Distribution of Time to First Fixation



Distribution of Sham Fixation Average. Results for sham fixations average revealed skewness (1.120) and kurtosis (.728, SE=.501), indicating the data was normally distributed. Please refer to Figure 3.

Figure 3

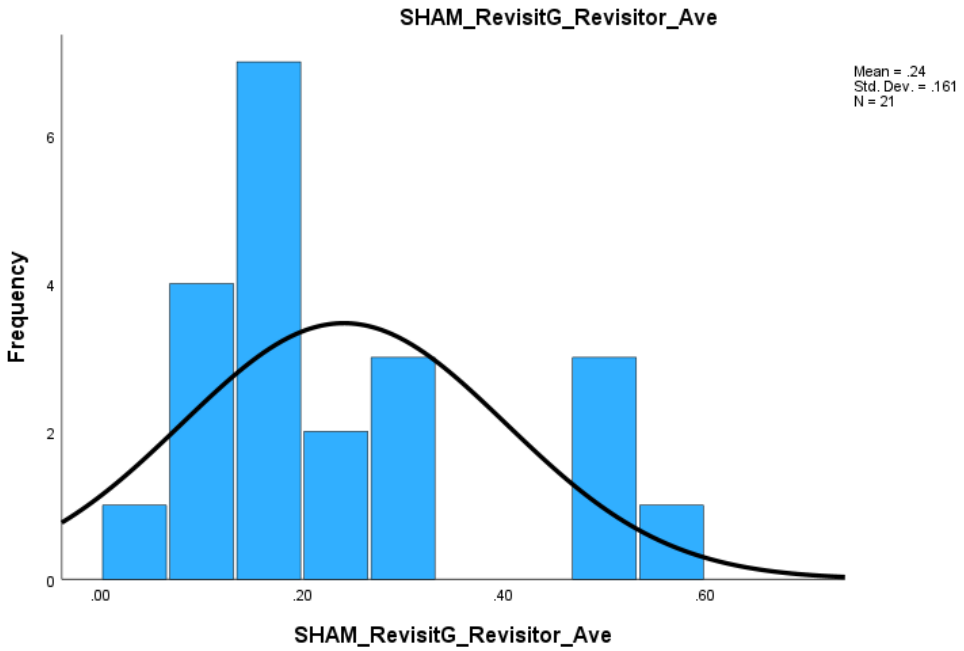
Distribution of Sham Fixation Average



Distribution of Sham Revisits Gaze. Results for sham revisits gaze revealed skewness (1.055) and kurtosis (.215, SE=.501), indicating the data was normally distributed. Please refer to Figure 4.

Figure 4

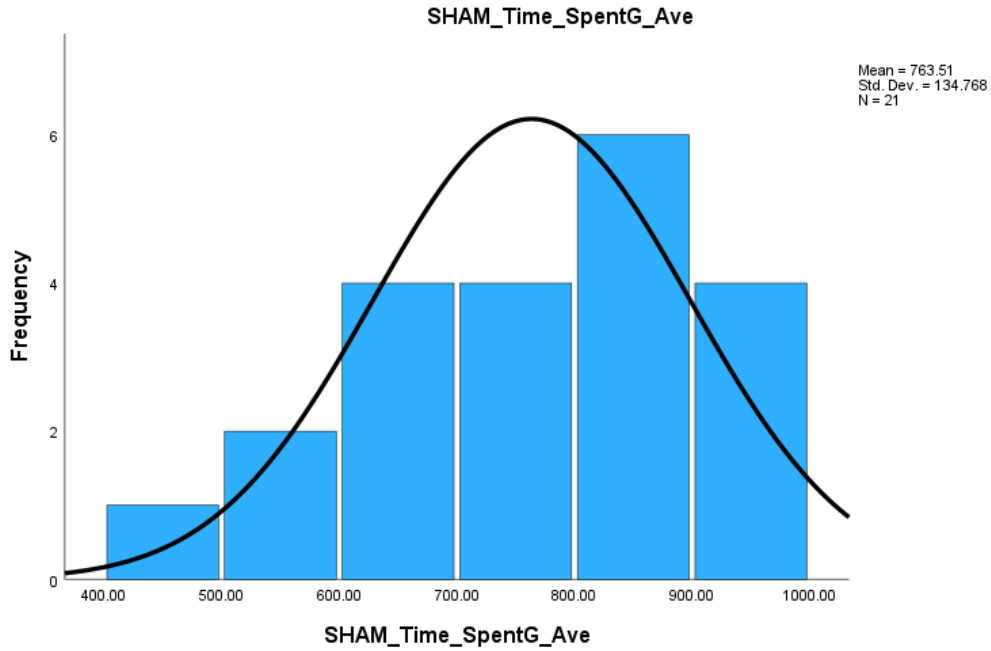
Distribution of Sham Revisits Gaze



Distribution of Sham Time Spent. Results for sham time spent revealed skewness (-.709) and kurtosis (-.093, SE=.501), indicating the data was normally distributed. Please refer to Figure 5.

Figure 5

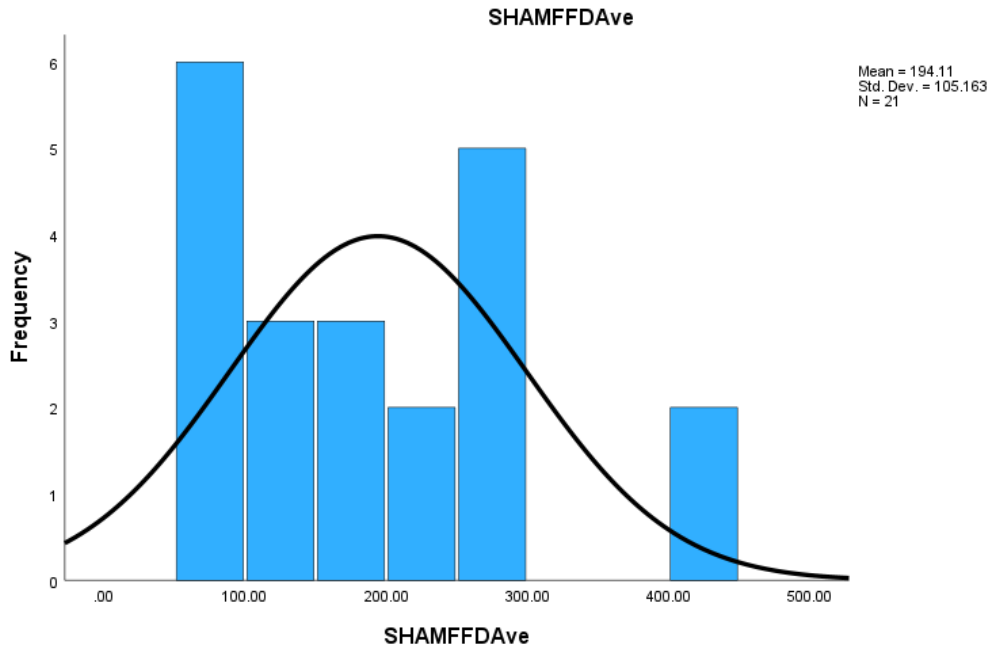
Distribution of Sham Time Spent



Distribution of Sham First Fixation Duration Average. Results for sham first fixation duration average revealed skewness (.863) and kurtosis (.200, SE=.501), indicating the data was normally distributed. Please refer to Figure 6.

Figure 6

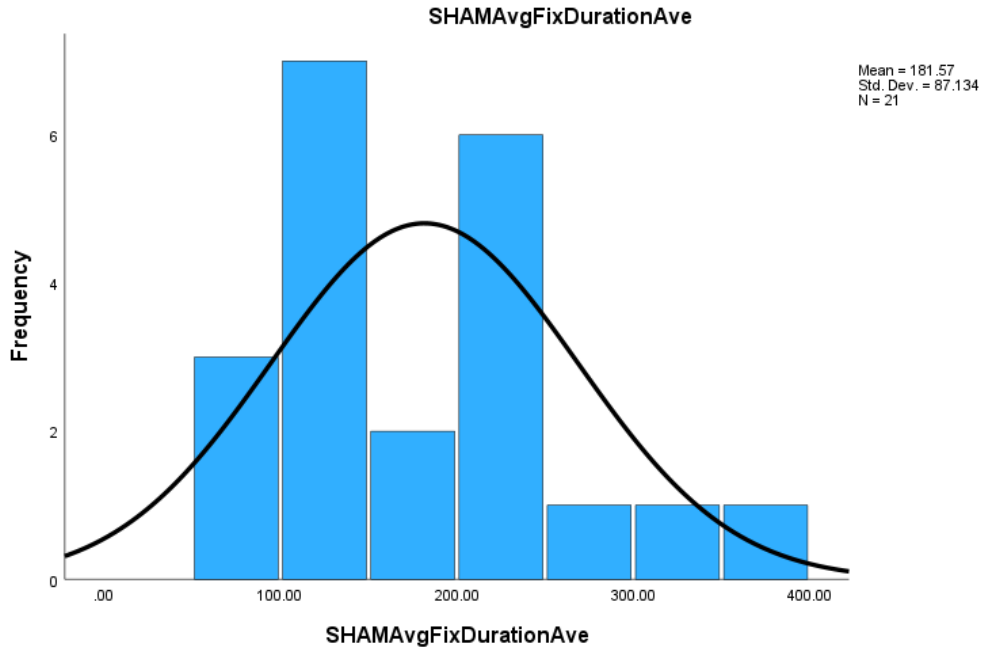
Distribution of Sham First Fixation Duration Average



Distribution of Sham Average Fixation Duration Average. Results for sham average fixation duration average revealed skewness (.557) and kurtosis (-.487, SE=.501), indicating the data was normally distributed. Please refer to Figure 7.

Figure 7

Distribution of Sham Average Fixation Duration Average



Outlier Determination

The 3rd and 1st quartile (+ or – 1.5 interquartile range) was used for the determination of outliers. No outliers were identified. Please refer to Figure 8 and 9.

Figure 8

Outliers For PK Asymmetry Sham

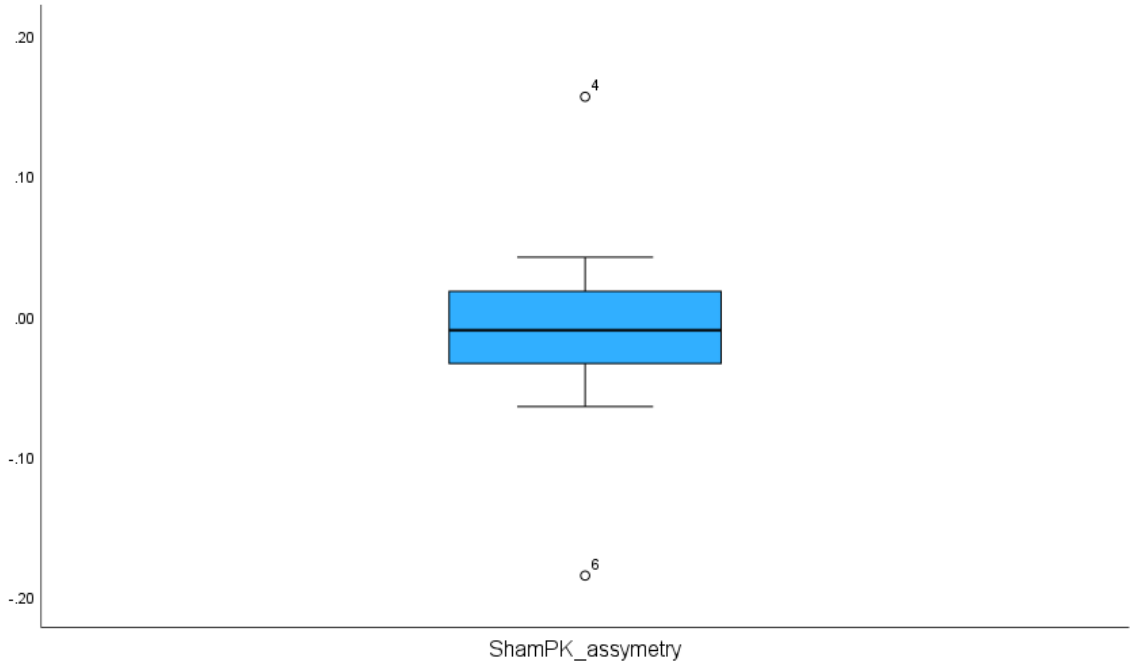
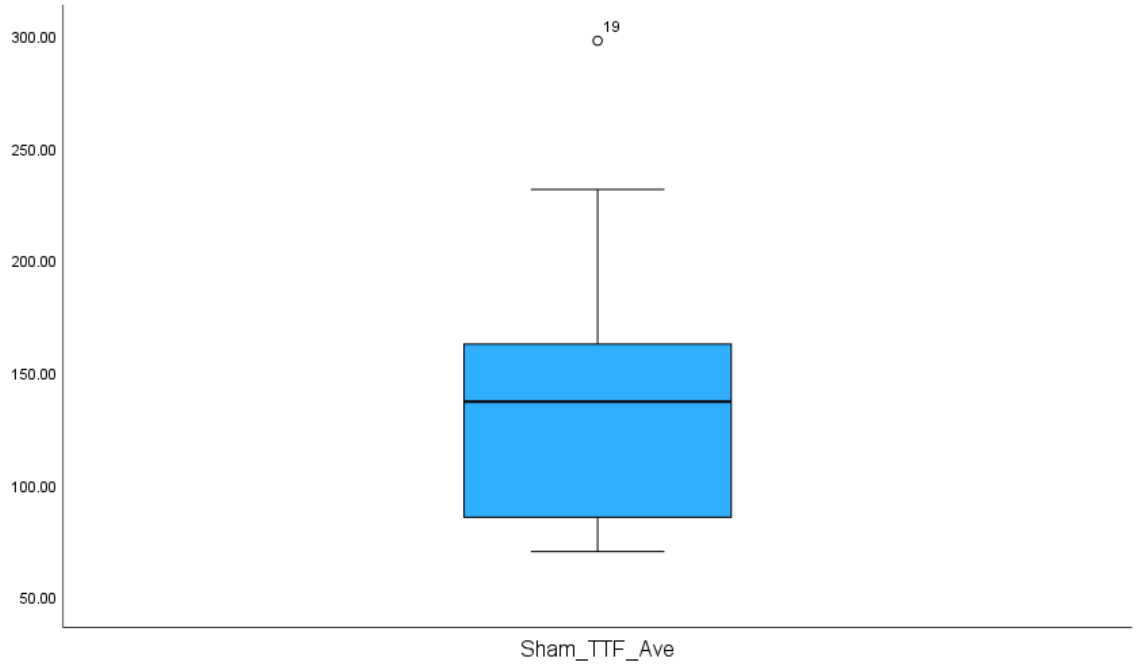


Figure 9

Outliers for Time to First Fixation Sham



Relationship between Variables

Several Pearson's *r* correlations were computed to assess the relationships between demographic, BAP, EEG and eye-tracking variables. Results indicated that family and time to first fixation were positively correlated. Thus, the closer the family relationship, the less time taken for first fixation to be made. Results also indicated that family relationship and time spent were negatively correlated, suggesting that the closer the family relationship, the more time taken spent looking at an image. Age correlated positively with time to first fixation and negatively with time spent. This suggested that as age increased, the time to first fixation was greater. In contrast, as age increased, time spent decreased. Therefore, the older the participant, the less time spent on the image

overall. Fixation and time spent were positively correlated, which suggested that as fixations increased, the time spent on an AOI also increased. Fixations and first fixation duration were negatively correlated, which suggested that as fixations decreased, first fixation duration and time spent on the first fixation increased. Fixations and average fixation duration were also negatively correlated. Likewise, the relationship between revisits gaze and time spent revealed revisits gaze and time spent were also negatively correlated, meaning as the number of times a participant revisited an AOI increased, the time spent on the AOI decreased. Finally, first fixation duration and average fixation duration were positively correlated which indicated the duration of the participant's gaze on the first fixation, the greater the average of duration of fixations inside the AOI. Please refer to Table 2 and 3.

Table 2

Sham EEG and Demographic Correlations

	BAP Score	Family	Age	Sex	Sham Asymmetry Power	Sham Peak Alpha Asymmetry
BAP Score	_	-0.062	0.202	-0.383	-0.168	0.247
Family	-0.062	_	0.318	-0.123	0.008	-0.244
Age	0.202	0.318	_	-0.295	0.162	0.134
Sex	-0.383	-0.123	0.295	_	-0.193	-0.110
Sham Asymmetry Power	0.095	0.459	0.522	-0.161	_	-0.214
Sham Peak Alpha Asymmetry	-0.066	-0.025	0.077	-0.354	-0.214	_

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Table 3

Eye tracking and Demographic Correlations under Sham

	BAP Score	**Family**	**Age**	**Sex**	**Sham Time to First Fixation**	**Sham Fixations**	**Sham Revisits Gaze**	**Sham FFD Avg.**	**Sham Avg. Fix. Duration Avg.**	**Sham Time Spent**
BAP Score	_	-.062	.202	-.383	.095	-.066	-.216	-.021	-.032	-.036
Family	-.062	_	.318	-.123	.459*	.914	.342	-.356	-.373	-.500
Age	.202	.318	_	-.295	.522*	.741	.118	-.344	-.413	-.433
Sex	-.383	-.123	-.295	_	.486	-.354	.048	.347	.424	.110
Sham TTFF	.095	.459*	.522*	-.161	_	-.296	.407	-.410	-.414	-.921**
Sham Fixations	-.066	-.025	.077	-.354	-.296	_	.-055	-.626**	-.682**	.277
Sham Revisits Gaze	-.216	.342	.118	.048	.407	-.055	_	-.307	-.338	-.673**
Sham FFD Avg.	-.021	-.356	-.344	.347	-.410	-.626**	-.307	_	.973**	.062
Sham Avg. Fix. Duration Avg.	-.032	-.373	-.413	.424	-.414	-.682**	-.338	.973**	_	.433

Table 3 continued

Sham Time Spent	-.036	-.500*	-.433*	.110	-.921**	.277	-.673**	.415	.433	_

Notes:
*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Additional Pearson's *r* correlations were computed to assess the relationships between demographic variables and eye tracking. Age and Sex did not correlate with stim, but BAP Score and revisits were trending, indicating BAP score tended to positively correlate with revisits after stim, resulting in reduction of revisits. Please refer to Table 4 below.

Table 4

Stim EEG and Demographic Correlations

	Age	BAP Score	Stim Fixations Avg.	Stim Revisit Revisitors Avg.	Stim Avg. Fixation Avg.
Age	-	.202	-.176	.277	.122
BAP score	.202	-	-.020	.396	-.037
Stim Fixations Avg.	-.176	-.176	-	.185	-.462*
Stim Revisit Revisitors Avg.	.277	.396	.185	-	-.226
Stim Avg. Fixation Avg.	.122	-.037	-.462*	-.226	-

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Effects of tDCS on Peak Alpha Asymmetry

A *t*-test was conducted to determine the effects of the tDCS training on Peak Alpha Asymmetry. There were no statistical or observed differences between the sham (M = -0.01; SD = 0.07) and stim (M = -0.00; SD = 0.03), t (20) = -0.06, p = 0.541.

Effects of TDCS on Eye Tracking

A number of dependent samples *t*-tests were conducted to determine the effects of tDCS on the EEG and eye-tracking variables. Results indicated statistically significant results for revisit gaze. Specifically, participants when in the active tDCS, revisited the AOI (eyes of the person) less, when compared to the sham condition. Although they were not statistically significant, the results indicated an observed difference in the number of fixations on the AOI by condition, meaning that the tDCS condition had more fixations than the sham condition. Additionally, the results indicated statistically significant results for revisit revisits when viewing the video segments. Specifically, in the active tDCS condition, the number of times the participant revisited the AOI was reduced when compared to the sham condition. No other comparisons were statistically significant or trending to be statistically significant. Please refer to Table 5.

Table 5

Results of Eye Tracking T-tests

Condition	Sham		Stim		*t*	*p*
	M	*SD*	*M*	*SD*		
Time to first fixation	140.56	63.13	171.82	201.4	-0.71	0.487
Fixations	4.79	2.01	4.09	2.02	1.66	0.113
Time Spent	763.51	134.77	753.39	212.49	.21	0.837
Time Spent Percent Avg.	76.34	13.47	75.35	21.24	.21	0.839
Revisit Gaze Revisitors	0.24	0.16	0.16	0.12	2.60	0.017*
Revisit Gaze Visits	0.99	0.02	0.94	0.22	1.21	0.241
First Fixation Duration Avg.	194.11	1.16	237.55	155.57	-1.16	0.259
Average Fixation Duration Avg.	181.57	87.13	222.62	153.54	-1.20	0.244
Video Time Spent Percentage	35.95	15.00	32.43	15.42	.95	.354
Video Revisit Revisits	4.05	1.75	3.19	1.36	2.34	.030*

* $p < .05$

Exploratory Analyses

Given the effects of tDCS on the eye-tracking variables fixations and revisitors, multiple analyses were conducted to clarify relationships between these variables and important autism and anxiety variables.

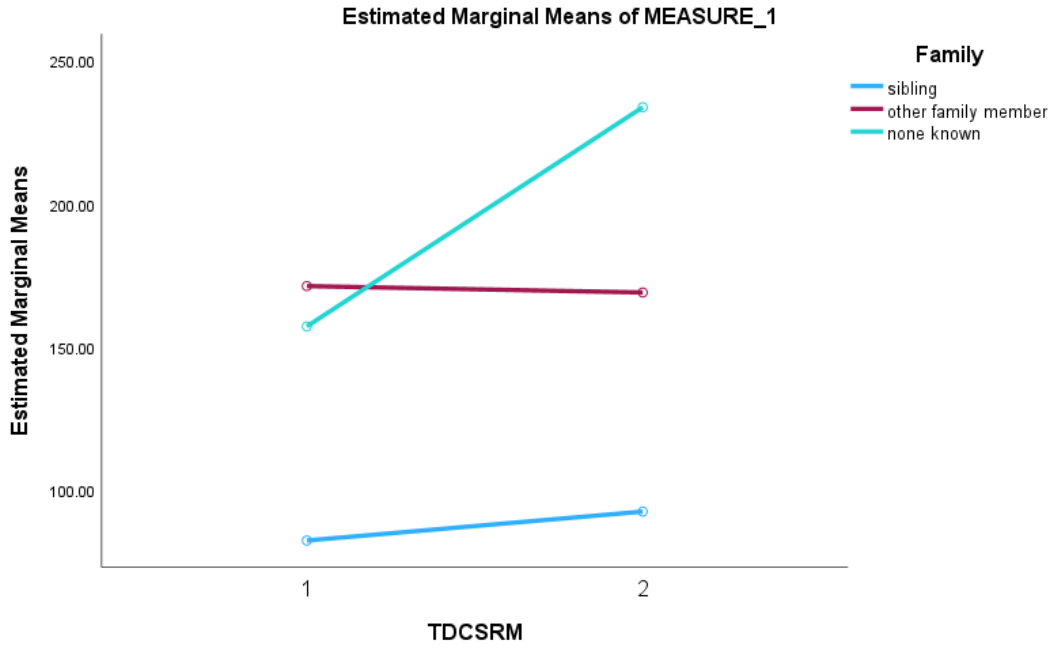
Effects of TDCS by Eye tracking by Autism Family Relation

Time to First Fixation by Family Relation

A 2-way ANOVA was conducted to determine the effects of TDCS on BAP by family relations. Results suggested that the interaction was not statistically significant in sham time to first fixation (TTFF) and stim TFF, $F(2, 1) = .306$, $p = .740$, $\eta_p^2 = .033$. The graph, Figure 10 represents TTFF mean values by family member during sham and tDCS. The graph indicates those that have siblings with ASD do not demonstrate effects of tDCS while those with no known family member have an increase in time to first fixation. Please see Figure 10.

Figure 10

Time to First Fixation by Family

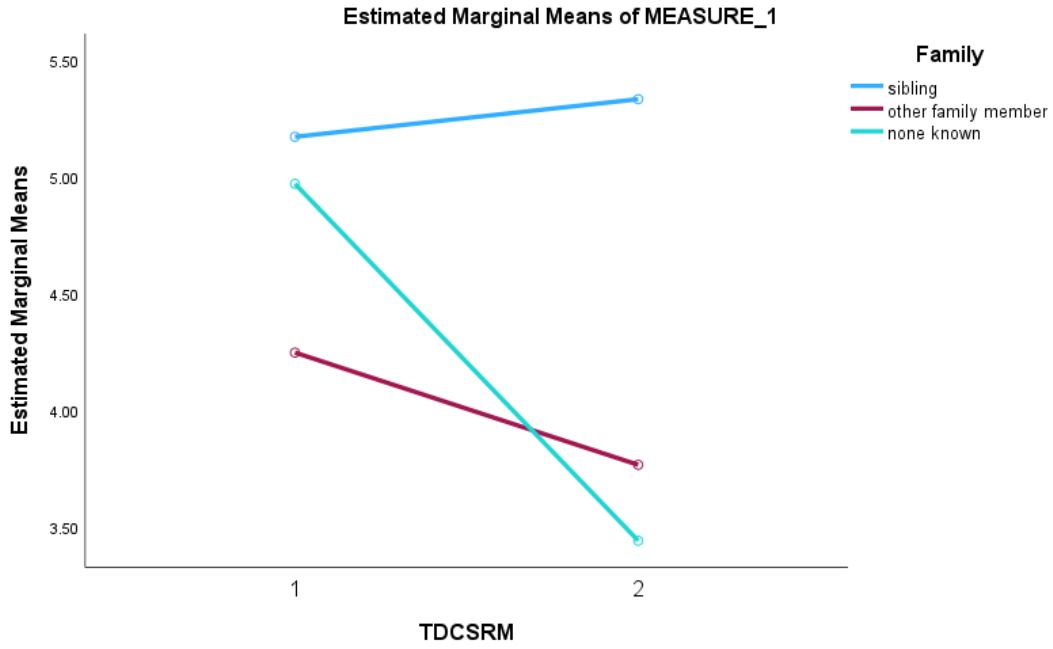


Fixation Average by Family Relation

Results suggested that familial interaction was not statistically significant in sham fixation average and stim fixation average, $F(2, 1) = 1.45$, $p = .262$, $\eta_p^2 = .138$. The graph, Figure 11 represents fixation average mean values by family member during sham and tDCS. The graph indicates those that have siblings with ASD did not demonstrate effects of tDCS while those with no known family member demonstrate a trend in decreased fixation average with tDCS. Please refer to Figure 11.

Figure 11

Fixation Average by Family

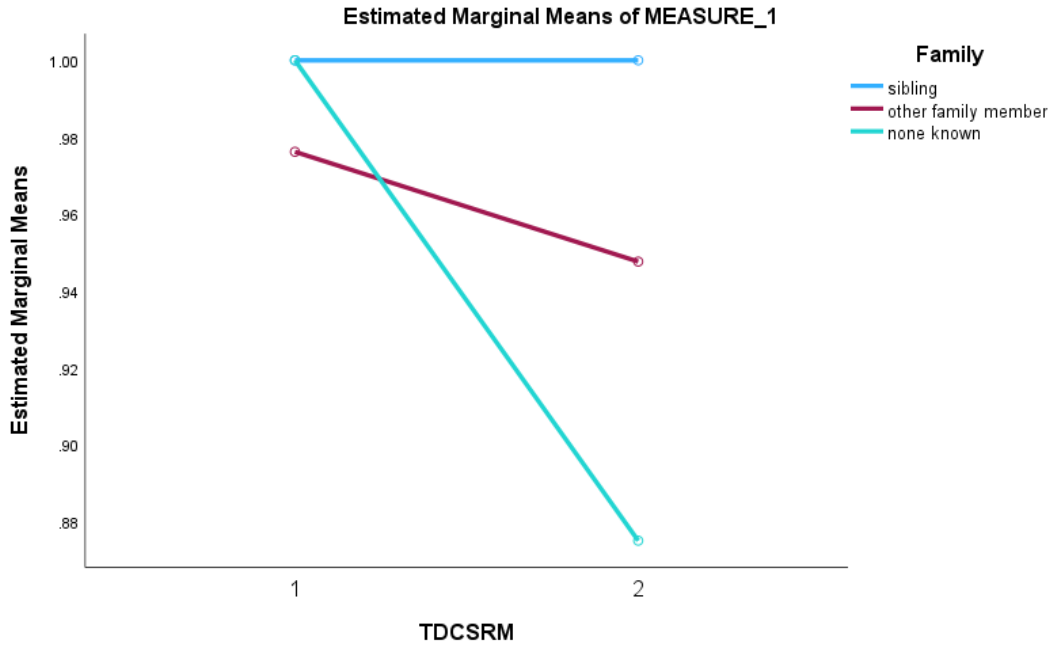


Revisit Visitors by Family Relation

Furthermore, results suggested that familial interaction was not statistically significant in sham revisit visitors and stim revisit visitors, $F(2, 1) = .637$, $p = .540$, $\eta_p^2 = .066$. Figure 12 represents revisit visitors mean values by family member during sham and tDCS. The graph indicates those that have siblings with ASD did not demonstrate effects of tDCS while those with no known family member demonstrated a trend in decreased number of visits to the AOI with tDCS. Please refer to Figure 12.

Figure 12

Revisit Visitors by Family

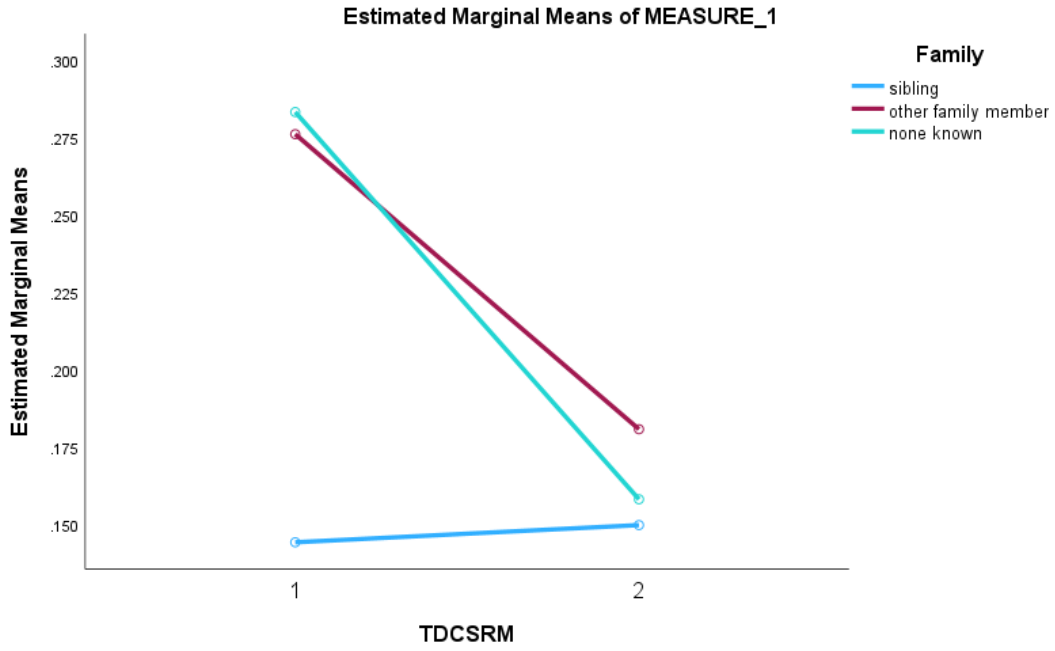


Revisit Revisitors by Family Relation

Further familial interactions represented in the two by two analysis suggested that familial interaction was not statistically significant in sham revisit revisitors average and stim revisit revisitors average, $F(2, 1) = 1.76$, $p = .200$, $\eta_p^2 = .164$. Figure 13 represents revisit revisitors average mean values by family member during sham and tDCS. The graph indicates those that have siblings with ASD did not demonstrate effects of tDCS, while those with a family member that is not a sibling with ASD or no known family member demonstrated a trend in decreased average number of returns to the AOI with tDCS. Please refer to Figure 13.

Figure 13

Revisit Revisitors Average by Family



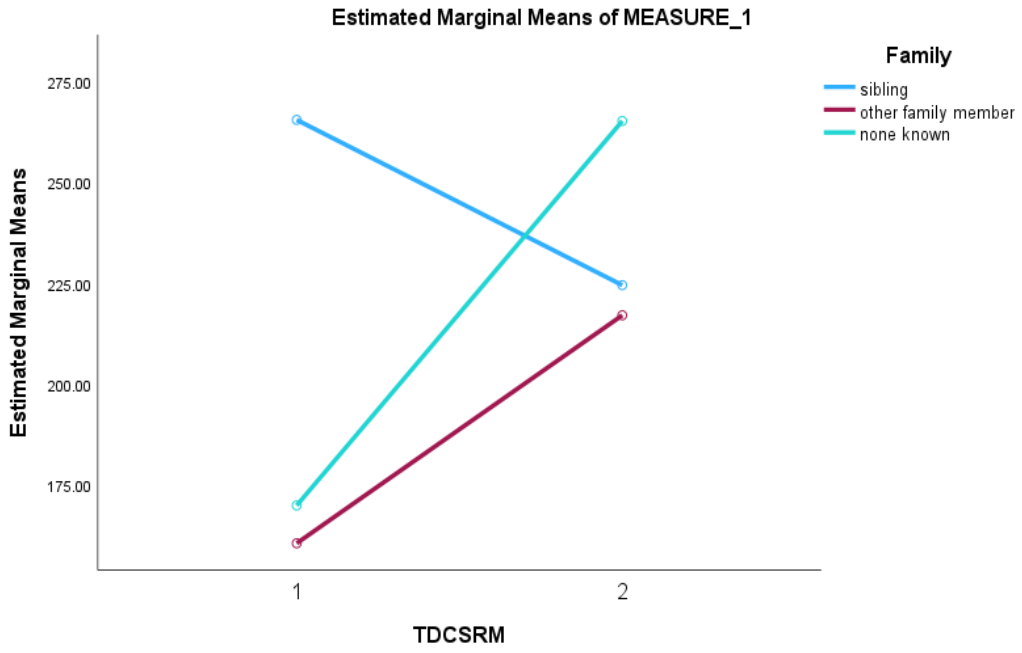
Fixation Duration Average by Family Relation

The last two by two result suggested that familial interaction was not statistically significant in sham average fixation duration average and stim average fixation duration average, $F(2, 1) = 1.31$, $p = .295$, $\eta_p^2 = .127$. Figure 14 represents average fixation duration average mean values by family member during sham and tDCS. The graph indicates those that have siblings with ASD demonstrated a trend in decreased average fixation duration average with tDCS while those with a family member with ASD that is

not a sibling or no known family member demonstrated a trend in increased average fixation duration average number to the AOI with tDCS. Please refer to Figure 14.

Figure 14

Average Fixation Duration Average by Family



Effects of TDCS by Eye Tracking by BAP Sex

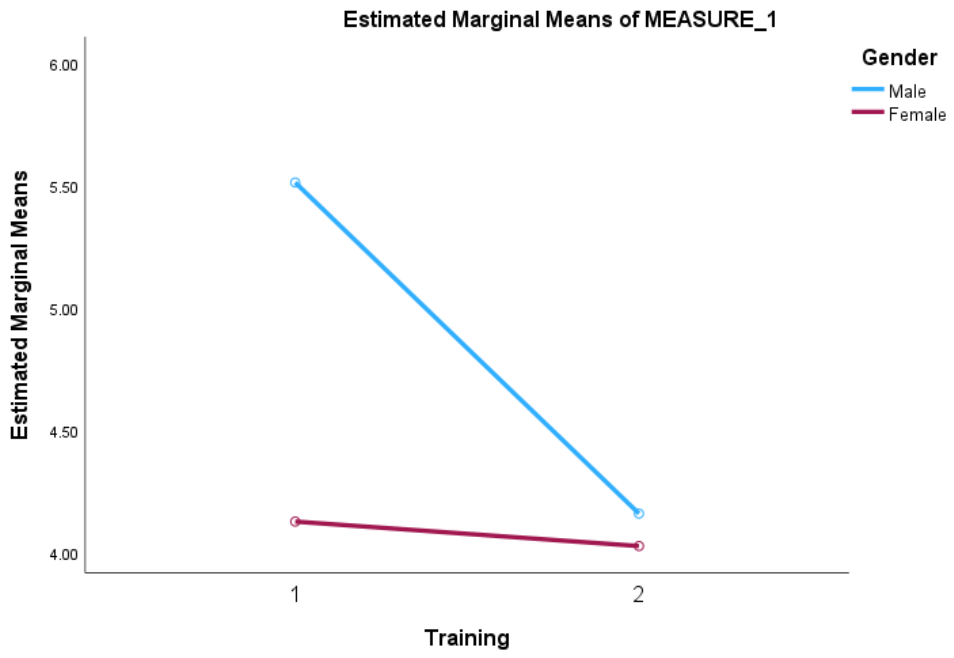
Fixation Average by Sex

A 2-way ANOVA was conducted to determine effects of TDCS on Broad Autism Phenotype by Sex. There were several observed differences in males and females. Results suggested that Sex was not statistically significant in sham fixation average and stim fixation average, $F(2, 1) = 2.36$, $p = .141$, $\eta_p^2 = .111$. Figure 15 represents fixation

average mean values by Sex during sham and tDCS stim, and the graph indicates the number of fixations for males were high with sham and low for females with sham. However, males had high fixations to begin with and demonstrated significant reduction in fixations in comparison to females. It is worth consideration that females started with a low number of fixations in sham, thus they remained low possibly due to the low number of fixations in sham allowing little room for change following tDCS stim. It is possible this may also have a connection with demonstrated differences in characteristics of males and females with ASD. Please refer to Figure 15.

Figure 15

Fixation Average by Sex

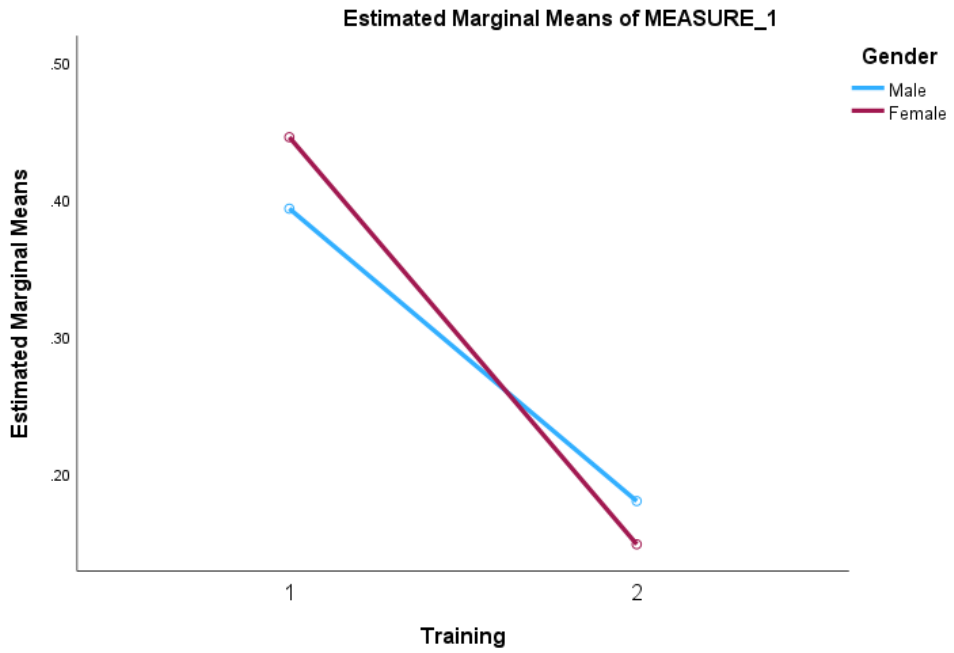


Revisit Revisitors by Sex

Results for revisit revisitors average by Sex indicated Sex was not statistically significant in sham revisit revisitors average and stim revisit revisitors average, $F(2, 1) = .594$, $p = .450$, $\eta_p^2 = .030$. Figure 16 represents revisit revisitors average mean values by Sex during sham and tDCS stim. The graph demonstrates a trend in both males and females who demonstrated high revisits with sham, and both demonstrated a large reduction in revisits following stim. A greater reduction of revisits is observed in females following tDCS than males, with females demonstrating a higher number of revisits than males following sham and a lower number of revisits following stim. Please refer to Figure 16.

Figure 16

Revisit Revisitors by Sex



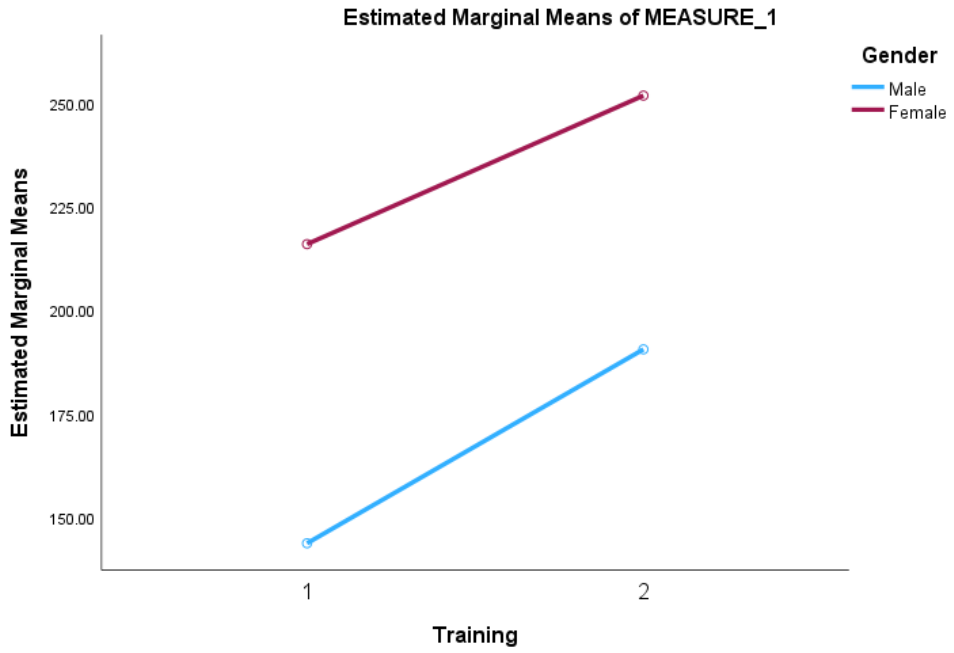
Average Fixation Duration Average by Sex

Results for average fixation duration average by Sex indicated Sex was not statistically significant in sham average fixation duration average and stim average fixation duration average, $F(2, 1) = .024$, $p = .878$, $\eta_p^2 = .001$. Figure 17 represents average fixation duration average mean values by Sex during sham and tDCS stim. Observed differences in the graph demonstrate a trend in both males and females. Females demonstrated a higher number of fixations with sham than males; however, both

males and females demonstrated an increase in average fixation duration average with stim. Please refer to Figure 17.

Figure 17

Average Fixation Duration Average by Sex



Effects of TDCS by Eye Tracking by Family Controlling for Anxiety

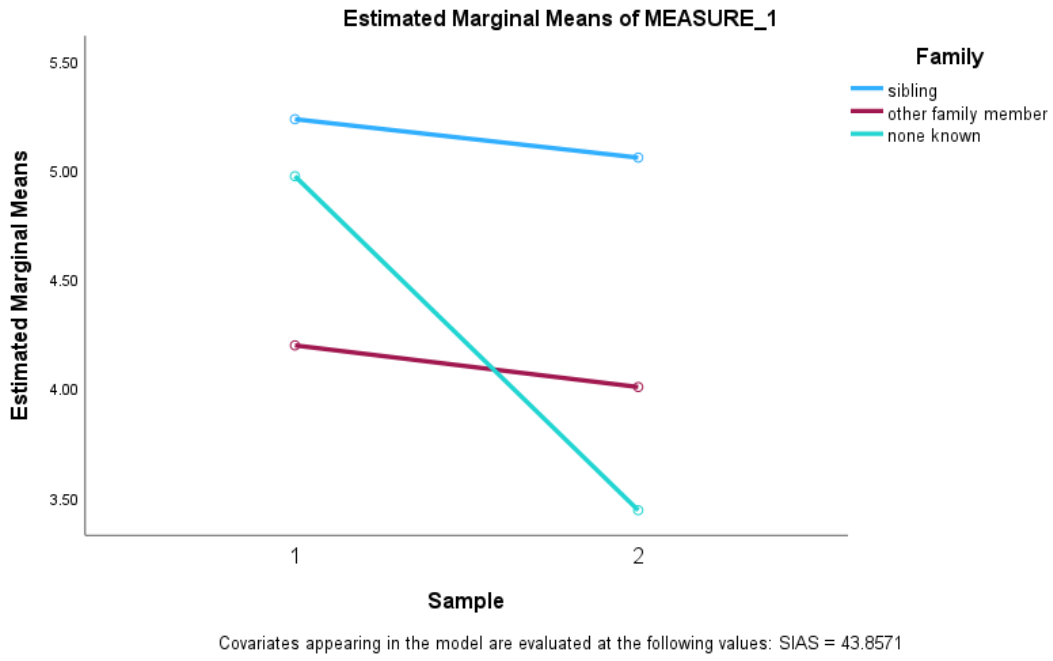
Fixation Average by Family when Controlling for Anxiety

We explored the possibility that anxiety may be a covariate in the effects of tDCS on eye tracking variables. Results suggested that family was not statistically significant in sham fixation average and stim fixation average, $F(2, 1) = .597$, $p = .562$, $\eta_p^2 = .066$. Figure 18 represents fixation average mean values by family when controlling for anxiety

during sham and tDCS. We found that when controlling for anxiety, tDCS seems to have a greater effect in reducing the number of fixations most observably in those participants with no genetic link. Please refer to figure 18.

Figure 18

Fixation Average by Family when Controlling for Anxiety



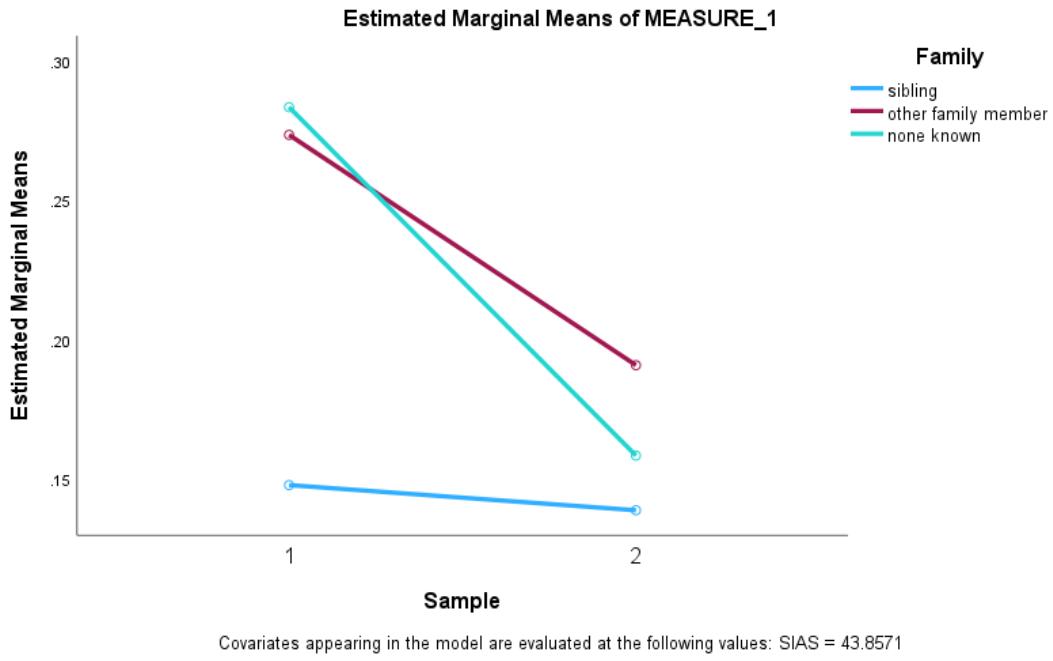
Revisit Gaze by Family when Controlling for Anxiety

Results for revisits gaze suggested that family was not statistically significant in sham revisit gaze and stim revisit gaze, $F(2, 1) = 1.31$, $p = .296$, $\eta_p^2 = .134$. Figure 19 represents revisit gaze mean values by family when controlling for anxiety during sham and tDCS. There was an observable decrease in the number of revisits to the eyes, the AOI, for those with BAP and no known family member with autism or with an extended

family member with Autism. In contrast, those with BAP and an immediate family member with Autism indicated no effects of tDCS on revisit gaze. Please refer to Figure 19.

Figure 19

Revisit Gaze by Family when Controlling for Anxiety



CHAPTER V: Discussion

People with Broad Autism Phenotype (BAP) are considered neurotypicals who demonstrate autistic traits (Gerdts & Bernier, 2011; Losh et al., 2009). BAP+ often have difficulty making sense of social situations due to an inability to understand social conventions and impaired social cognition (Bailey et al., 1998). These deficits result in difficulty with emotional facial processing and compromise development of joint attention as well. Qiao et al. (2020) specifically identified atypical eye-gaze and the impaired ability to use the contextual information of faces as obstacles for individuals with ASD and BAP. More specifically, social deficits correlated with specific brain regions. Specifically, individuals with ASD showed distinguishable activity in the frontal and temporal lobes as well as the cerebellum, amygdala, and hippocampus (Frith & Hill, 2004; Ha et al., 2015). Qiao et. al. (2020), for example, showed that the effects of tDCS to facilitate emotional facial processing; specifically targeting the right temporal parietal junction (TPJ), facilitated gaze behavior of individuals with high autistic traits (AT), and specifically facilitated effect of anodal stimulation, apparent for both happy and fearful faces in the mouth area. Thus, tDCS improved facial processing related to social interactions for those with ASD or BAP. The purpose of this study was (a) to observe the brain activity of subjects with high BAP scores while processing eye contact duration and to (b) determine if tDCS training to the frontal lobes increased

approach toward social interactions in adults classified as BAP+, as demonstrated by eye-tracking measures in response to faces and gaze fixation while viewing the Facial Expression of Emotion Stimuli and Tests (FEEST) as measured by the Tobii Pro studio eye-tracker.

The first hypothesis was that BAP+ participants would show greater fixation on facial features after completing tDCS training. This hypothesis was partially supported, given that results indicated a trend in reduction of fixations and a trend in fixation duration increase after tDCS stimulation. Additionally, in support of this hypothesis, the study found statistically significant differences in the participant revisit gaze. Specifically, participants had a greater number of revisits during sham compared to stim conditions, indicating tDCS training helped reduce the number of times a person reanalysed the eyes of the stimuli faces and made more direct contact with the eyes. Importantly, this study found a moderate correlation (r=.40) between BAPQ scores and revisits revisitors. This suggests that tDCS training may have reduced an eye tracking behavior that positively relates to autism phenotype. Senju (2013) reported individuals with ASD did not show bias to attend to others' eyes, especially when they observed social and communicative actions, attributing this weaker attention to the eyes as an explanation of atypical facial processing and attentional engagement. Therefore, the current research shows favorable results for the application of tDCS for increasing social cognition in individuals with BAP.

The second hypothesis presented indicated that BAP+ participants would show less frontal lobe asymmetry following tDCS stimulation than demonstrated following sham tDCS. Results indicated minimal change in participant asymmetry with tDCS, contrasting with the hypothesis that participants would show less frontal lobe alpha asymmetry following tDCS. This may be the result of only one stim session or the prior lack of asymmetry in some participants. Furthermore, this may also be due to the protocol used. This study used a typical ADHD protocol which may not have provided anodal and cathodal stimulation to the left and right DLPFC to produce best asymmetry outcomes. Smits et al. (2021) used a protocol with anodal over the right inferior frontal gyrus (IFG) and cathodal over the left orbital area, a protocol more common to reducing anxiety, and Faber et al. (2012) found that right anodal induced a decrease in anxiety scores. Similarly, Yadollahpour et al. (2019) found that reversing the anodal and cathodal resulted in decreased prefrontal asymmetry index (AI), so that the asymmetry was reversed towards right side and demonstrated improvement of executive network induced by tDCS. However, in this researcher's study, although no significant changes in the brain were observed, we were able to see changes in some of the variables.

Third, the researcher hypothesized that BAP+ individuals would spend more time looking at faces on a social interaction video after tDCS relative to sham. Results indicated minimal change which contrasted this study's hypothesis that BAP+ individuals would spend less time looking at faces on a social interaction following tDCS. However, in partial support of this hypothesis, the study found statistically significant differences in

the participant revisit revisits. These results suggest that participants had a reduced number of revisits under the active tDCS condition compared to sham condition, indicating that tDCS training helped reduce the number of times a person reanalysed the eyes of the stimuli faces in the video segment, and participant made more direct contact with the photos eyes following the active tDCS training.

A final hypothesis presented there would be a relationship between BAP scores and familial relations. Piven et al. (1997) found that social and communication deficits and stereotyped behaviours examined in individuals with ASD and BAP, may be expressions of genetic liability. Sasson et al. (2013) further supported findings of genetic liability in ASD and BAP, and identified intergenerational transmission of BAP features, and also indicated increased severity of autism behaviours in children with parents that demonstrated the presence of BAP traits. Results of this study also suggest that the closer the family member (sibling, other family member, or no family member known) of the BAP+ participant, the higher the BAP score, reinforcing findings of previous studies conducted by Sandin et al. (2014), that included the largest population-based longitudinal study evaluating familial risk. Sandin and colleagues (2014) found that risk of ASD was elevated with increased genetic relatedness, also in concordance with the results found in this study supporting genetic liability in ASD and BAP.

Overall, the current study results suggested that tDCS was able to reduce the number of revisits in the participants with other family members and the no known relation, but it did not influence the participants with a direct genetic link to autism. It is

possible that stimulation of the DLPFC using tDCS has effects in social attentional aspects of focusing the eyes of individuals, only on persons with BAP, with no direct relationship with autism. Researchers Heeren et al. (2017) found tDCS over the left DLPFC, focusing on the same brain region as the current study, reduced attentional bias in individuals with social anxiety disorder. Furthermore, it was indicated that since DLPFC initiates control over emotions by inhibition of the amygdala, the effects of tDCS on individuals with deficits in emotional control from ASD, BAP, or anxiety, may benefit from tDCS regardless of familial relation. The BAPQ focuses on characteristics of individuals with ASD, just to a lesser extent, and therefore it is possible some participants with a high BAPQ that indicated classification as BAP+, may present similar characteristics to those with ASD, but may in fact meet criteria for other conditions, or none at all specifically, but still present social deficits. Therefore, the results of the current study draw attention for tDCS therapy to more specifically focus on attentional bias versus overall emotional processing for individuals who are BAP+.

Additional further exploration of tDCS effects was conducted by dividing participants into Sex groups, male and female. A study conducted by Supekar et al. (2022) with Stanford Medicine found Sex differences in functional brain organization in males and females with ASD, specifically in the temporal cortex area associated with language processing and in the intraparietal sulcus which plays a crucial role in visuospatial attention. Further exploring Sex differences, the results of this study indicated males displayed greater fixations with sham, while females displayed

observably less fixations with sham. Males had observable decrease in fixations possibly due to the high fixation numbers initially. This may possibly support some differences in presenting characteristics in males and females with BAP. Results also indicate decreased trends in revisits (the number of times a participant looked at faces), by both males and females after tDCS, while fixations duration (the time participants looked at a particular area of the face) increased in both male and females after tDCS.

One possible effect of tDCS is a reduction in anxiety towards looking at someone's eyes. Studies by Stein et al. (2020) showed that DLPFC stimulation reduced anxiety in individuals with anodal stimulation over the left DLPFC and cathodal stimulation over the right DLPFC. An additional study by Vicario et al. (2020) found decreased anxiety following stimulation to the DLPFC resulting from reduction in amygdala activation, which reinforced findings by Heeren et al. (2015) in a study on anxiety reduction through tDCS involving attentional bias. This study's exploration of anxiety found that when controlling for anxiety, tDCS seemed to have a greater effect in reducing fixation number and reducing revisits to the eyes. Ni et al. (2023) found that social anxiety and autistic traits affected attention to the eyes and had an interactive impact on first fixations, and social anxiety was related to longer first fixation duration on the eyes in people with high and medium levels of autistic traits, but not in people with low levels of autistic traits. Therefore, a protocol more specific to reducing social anxiety may show improved results of tDCS in individuals with BAP.

Implications

The current study found effects of tDCS on facial engagement. Additional studies have found decreased symptomology using a similar protocol with 2mA anodal F3 and cathodal over the right supraorbital. However, varying from the current study, these studies included 5 to 20 sessions of tDCS and showed greater reduction in symptomology (Li et al., 2022; Smits et al., 2021; Vicario et al., 2020). Therefore, expanding the protocol from one stim session to multiple stim sessions is indicated. Furthermore, as tDCS becomes more widely researched and accessible, further studies using tDCS may be useful for individuals with anxiety, depression, or ADHD in reducing social aversions. For instance, Vicario et al. (2020) conducted a study examining the results in multiple disorders not limited to but including, generalized anxiety disorder, social anxiety disorder, and panic disorder and found tDCS therapy to be successful on all three conditions. Likewise, Cheng et al. (2022) found significant effects of tDCS on Depression and Anxiety. Lastly, Soff et al. (2016) found that application of tDCS over the left DLPFC for a number of consecutive days resulted in long term improvement in both neuropsychological function and improvement in inattention, supporting implications for additional research and application to modulate brain activity to improve symptoms of ADHD and also supporting the current study indication for multiple sessions of tDCS stimulation for best results.

Further advantages of tDCS include ease of use, noninvasive and inexpensive application, and thus far, no reported serious side effects. Moreover, there is also an at

home option for applying tDCS therapy, making it even more accessible and cost-effective. At home devices equipped with security systems to prevent overuse alleviate associated costs for patients such as travel to and from facilities for multiple sessions, time away from home, and disruptions to daily responsibilities (Carvalho et al., 2018).

The current study indicates that eye-tracking technology is useful in determining social attention. Eye-tracking studies the range of eye-movements while engaged in various activities in a non-invasive way with precision. It can be used to explore processing variations in different disorders and can also serve as a measure of treatment progress. Ni et al. (2023) explored the overlap between individuals with autistic traits and social anxiety and found these two traits had an interactive impact on the first fixations on the eyes suggesting similarities in traits of individuals with ASD and social anxiety. Canigueral & Hamilton (2019) explored the role of eye-gaze in social interactions and found that individuals with autistic traits such as those with BAP, have difficulty with social dynamics of gaze resulting in reduced coordination between eye gaze, and other social behavior impacting successful progression of interaction. The current study supported these findings in modulating gaze revisits as a means to improve social interaction for those with BAP. These results of the current study, combined with additional supporting research, propagate the importance of clinicians' and researchers' focus on the factors that modulate eye tracking measures to reduce symptomology of a variety of conditions to include but not limited to ASD, BAP, ADHD, depression, PTSD, and social anxiety.

Individuals with ADHD, depression, PTSD, and social anxiety also experience social deficits similar to those with ASD and BAP. However, whereas individuals with ASD and BAP struggle with direct gaze and fixation duration, Armstrong and Olatunji (2012) found those with PTSD, anxiety, and depression have difficulty shifting fixations and demonstrate attentional bias to increased negative stimuli. Likewise, Pishyareh et al. (2015), found that individuals with ADHD also suffer from attentional bias that interferes with social interaction. Specifically, in a study with ADHD children, Pishyareh and colleagues (2015) found that ADHD children tended to have longer sustained attention to unpleasant stimuli or neutral stimuli, and indicated these deficiencies resulted in abnormal attention to negative emotional pictures and therefore difficulty in processing emotional faces similar to those with ASD or BAP. Thus, the findings of the current study on modulating eye tracking to improve gaze and fixation for BAP+ individuals, could also prove effective in improving facial processing for those with ADHD, depression, PTSD, and social anxiety.

As eye tracking technology continues to advance and become more accessible, there are vast implications for its use in educational settings. Recent studies, for instance, have demonstrated eye-tracking training improved memory and reading abilities. In a study conducted by Chan et al. (2022) findings supported application of eye-tracking techniques to improve cognitive function for children with learning difficulties. More specifically, findings have indicated improved reading accuracy and delayed recall. Further supporting recall improvement through eye-tracking, researchers examined

efficacy of learning through eye-tracking in a different perspective that also offered support of integration of eye tracking into the general educational setting. When reviewing efficacy of multimedia as an instructional tool, Molina et al. (2018) found texts and images in close proximity will result in more efficient retention of content.

Integrating eye-tracking into schools could provide valuable information in identifying and developing interventions for students with certain disabilities. The Burkhart Center for Autism Education and Research (2017), has used eye tracking to diagnose and evaluate efficacy of interventions in children as young as 12 months. Through the use of an eye tracker incorporated into a large monitor, children were shown video clips, and eye tracking variables collected allowed researchers to identify fixations, gaze and shifts in gaze. Findings indicated children with autism likely focused on the background or unimportant details rather than characters' faces. These same strategies have been applied pre and post intervention to improve communication and social interaction (Young, 2017). Additional diagnostic eye tracking has also been found effective for individuals with ADHD. Deng et al. (2022) developed neural sequence using eye tracking to diagnose ADHD which demonstrated eye gaze of individuals with ADHD interacts differently with the visual stimulus in comparison to typically developing controls. As ASD and AU referrals are on the rise in schools, eye tracking can provide empirical data to reinforce current measures used for diagnoses and measure progress and efficacy of interventions.

The use of eye tracking in schools could also provide useful information on internal cognition and allow for reflective learning as well. Eye tracking research conducted in college programs to improve learning outcomes has shown great promise. Ashraf et al. (2018) found that eye-tracking has contributed significantly to the training, assessment, and feedback practices, specifically in medical education, and quantitative data gained is facilitating improved feedback of student performance and student performance reflection. More recent integration of eye tracking in education was conducted in a research partnership including Vanderbilt University, North Carolina State University, Indiana University, University of North Carolina Chapel Hill, and the Educational nonprofit Digital Promise, with first year nursing students, U.S. Army soldiers, and middle school science students as study participants. Through multimodal data collection, the research team is collecting data on eye gaze position and speech that then applies artificial intelligence and machine learning algorithms to analyze learning and provide student feedback and training development. This study incorporated eye tracking as part of a much larger analysis of learning that is capturing what students are looking at, where they move and stand, how they move, how they interacted with others and learning devices such as lab equipment, surgical tools, media devices used for instruction, and much more. Instructors were then able to observe all this data later and evaluate instruction and learning, and this instructional benefit is in addition to feedback and self-reflection this information is providing for the students (Anthony, 2023). The

implications for this level of integration of eye tracking are vast and have the potential to completely restructure education.

Limitations

This study has several important limitations. Firstly, we used a common tDCS protocol commonly used to treat individuals with ADHD. This protocol may not have provided anodal and cathodal stimulation to the left and right DLPFC to produce best asymmetry outcomes. Findings from previous studies have indicated right anodal stimulation has resulted in improved hemispheric asymmetry and indicated improvement in attention and tactile demands and therefore may have better supported the asymmetry hypothesis of this study (Kelley et al., 2017; Li et al., 2022; Sanchez et al., 2016; Zandvliet et. al., 2017). Secondly, the sample was comprised of a convenience sample of college students and instructors from STEM courses and not reflective of the general population. Third, the sample was from an East Texas college, and thus it would likely not be reflective of diversity with more participants between the ages of 18–22 (66.7%) comparative to other age groups. A more diverse sample that included a broader range of age, additional career specialties, more diverse cultural backgrounds and varied socioeconomic status, that better reflected the general population and provided a larger participant pool in general, may have resulted in additional significant findings. Fourth, although a power analysis was completed indicating ample participants at 21, when participant numbers were broken into subgroups, numbers were not sufficient to get significance in many areas where trends were present. Fifth, since the study was a single

blind randomized trial of sham and stim, residual from stim for those who received it in the first session may have affected findings. Providing a longer wash out period between sessions could have provided greater accuracy in the effectiveness of the tDCS stim sessions. Furthermore, including multiple weekly sessions over a longer period of time resulting in a greater total duration of treatment, may have also increased efficacy of the tDCS therapy, as has been evidenced in previous studies by (Li et al., 2022; Soff et al., 2016; Qiu et al., 2022).

It is also important to note that the study used a self-report questionnaire to obtain data regarding personality traits, adjustment, and functions of friendships. Participants sometimes provide socially desirable responses on questionnaires which might threaten the validity of some of the data. Items on the personality questionnaires might have been interpreted as reflecting neuroticism and viewed as maladaptive and undesirable to endorse (Chan, 2022). The study did not use ASD screening measures to rule-out the existence of participants with ASD, although none of the participants reported a history of developmental disorders or ASD. Also, the study relied solely on self-reported neurological and psychological history. Lastly, no control was included.

Future Studies

The findings of this study provide valuable evidence for the use of tDCS to reduce fixations and fixation duration given observable trends and with significance found in revisits. Future studies should include a larger number of participants as observed trends in fixations and fixation durations lacked significance due to low numbers. Future studies

should also consider adjusting the protocol. The current study protocol used a 2mA for 20 minutes single sham and single stim session anodal F3 and cathodal F4. Gómez et al. (2017) used a protocol of 20 daily sessions of tDCS applied to the left DPLFC (1 mA, 20 min) and observed a significant reduction in the total score on the Autism Behavior Checklist and Autism Treatment Evaluation Checklist. Their performance on three clinical scales was evaluated before and at the one-, three-, and six-month markers, after completing the sessions, and also reported a significant decrease in the total score of the clinical scales, improvement in autistic behavior one month after the stimulation, and improvements were maintained until the sixth month after. Additionally, Electroencephalogram (EEG) functional connectivity analysis showed that brain stimulation also resulted in an increase in brain functional connectivity. Future studies should also broaden the participants to include a broader range of ages. This is recommended as college students and instructors lack generalizability.

Future research should also include more demographic information regarding culture as certain cultural practices may affect results, for example, cultures that value eye contact versus a culture that discourages it. Additionally, cultural social practices that vary may also result in differences in results, therefore including demographic information regarding ethnicity may be valuable.

Additionally, future research should include additional objective measures to replicate the findings of the current study and also include a group of individuals with social anxiety, BAP+, BAP-, and individuals diagnosed with ASD. Including multiple

groups could provide further evidence of brain differences along the spectrum, as well as in those with social anxiety not on the spectrum who struggle with similar social deficits. Billeci et al. (2016) found brain differences in the fusiform gyrus, temporal gyrus, the amygdala and reduced anterior-posterior asymmetry in BAP and ASD when compared to controls but found no differences in BAP compared to ASD. Likewise, a study by Martin et al. (2009) also indicated brain differences in the amygdala and temporal gyrus but did not cite differences in anterior-posterior asymmetry in individuals with anxiety. Therefore, including multiple groups with similar social deficits may provide further evidence of variation between and within groups.

Conclusion

Nonverbal language plays a critical role in social skills as social interactions involve a variety of complex exchanges such as gaze, facial expressions, and gestures. Facial processing and gaze are two of the earliest indicators of abnormal brain development in individuals with ASD and BAP (Canigueral & Hamilton 2019; Dawson et al., 2002; Risko et al., 2016; Thurm et al., 2006). tDCS as a therapy for social skill improvement is lacking throughout the literature for ASD and BAP, as research has mostly focused on short-term effects. Numerous neuroimaging studies of individuals with ASD have demonstrated abnormal patterns of brain activity indicating slower processing of faces (McPartland et al., 2004; Nomi & Uddin, 2015; Sato et al., 2012). Given individuals with BAP present three of the same defining features of individuals with ASD, (pragmatic language difficulties, aloof personality, and rigid personality), the

current study demonstrates differences in brain activity and eye-tracking measures while processing faces in those with BAP. Although EEG results indicated minimal change in participant asymmetry with tDCS, eye-tracking results showed observed decrease in fixations and statistically significant reduced revisits, indicating the tDCS training helped reduce the number of times a person will re-analyse the eyes of the stimuli faces and thus improved facial processing. Additional trends observed in the current study also show promise for identifying Sex differences in individuals with BAP and for tDCS therapy as a possibility in reducing anxiety.

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Appendix A

IRB Approval

Principal Investigator: Luis Aguerrevere
Human Services
2906
Aguerrevle@sfasu.edu

Co-investigators: Nicole Baker

RE: The Effects of Transcranial Direct Current Stimulation on Approach Avoidance in College Students with the Broad Autism Phenotype.
Case Number: **AY 2022-2234**

TYPE OF RESEARCH: Pilot Study (Doctoral Dissertation)

FROM: Emmerentie Oliphant, Chair, IRB-H

DATE: April 14, 2022

Thank you for submitting your IRB application entitled "The Effects of Transcranial Direct Current Stimulation on Approach Avoidance in College Students with the Broad Autism Phenotype." to the IRB fo review. It has been reviewed and **approved** based on the following criteria:

Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Your project has approval through **April 14, 2023.** Should you need additional time to complete the study you will need to apply for an extension prior to that date. The IRB should be notified of any planned changes in the procedures during the approval period, as additional review will be required by the IRB, prior to implementing any changes, except when changes arenecessary to eliminate immediate hazards to the research participants. The researcher is also responsible for promptly notifying the IRB of any unanticipated or adverse events involving riskor harm to participants or others as a result of the research.

All future correspondence regarding this project should include the case number **AY 2022-2234.**

Appendix B

Medical Background Questionnaire - Baker

Q1 Participant ID

_____

Q2 Age

_____

Q3 Birth Date

_____

Q4 Sex

- ○ Male (1)
- ○ Female (2)

Q5 Ethnicity Origin (or Race)

- ○ White or Caucasian (1)
- ○ Hispanic or Latino (2)
- ○ Black or African American (3)
- ○ Asian/Pacific Islander (4)
- ○ Native American or American Indian (5)
- ○ Other (6) _____

Q6 Level of Education

▼ No High School (1) ... Doctorate or Professional Degree (12)

Q7 Which hand do you write with?

- ○ Right Hand (1)
- ○ Left Hand (2)

Q8 Are you currently losing time from work because of an injury?

- ○ No (1)
- ○ Yes (2)

Q9 Are you currently involved in a legal claim against someone for an injury or accident?

- ○ No (1)
- ○ Yes (2)

Q10 Do you drive a car?

- ○ Yes (1)
- ○ No (2)

Q11 Can you manage your money and balance your checkbook?

- ○ Yes (1)
- ○ No (2)

Q12 What limitations, if any, do you have with regard to activities of daily living (e.g., dressing, grooming, hygiene, toileting)?

_____

_____

_____

_____

_____

Q13 What limitations, if any, do you have with household chores (e.g., laundry, yard work, cooking, home repairs, cleaning)?

_____

_____

_____

_____

_____

Q14 Please describe an average or typical day for you. Include when you awaken, what you do during the day, when you sleep and eat, etc.

_____

_____

_____

_____

_____

Q15 Do you have any current problem areas/areas of disability? Please Explain.

_____

_____

_____

Q16 In the last year, have you .....

	No (1)	Yes, no doctor (2)	Yes, saw doctor (3)
hit your head resulting in bump, bruise, or scratch? (1)	○	○	○
hit your head resulting in dazing? (2)	○	○	○
hit your head resulting in loss of consciousness? (3)	○	○	○
had a concussion? (4)	○	○	○
injured your neck or back? (5)	○	○	○
broken bone other than head, neck or back? (6)	○	○	○
suffered other painful injury? (7)	○	○	○
suffered from chronic fatigue? (8)	○	○	○
suffered from arthritis? (9)	○	○	○
suffered from carpel tunnel syndrome? (10)	○	○	○
suffered from cancer? (11)	○	○	○
suffered from complex regional pain syndrome? (12)	○	○	○
suffered from migraines or other severe headaches? (13)	○	○	○

suffered from fibromyalgia? (14)	○	○	○
taken opiate drugs (Tylenol III, vicodan, percodan, morphine, oxycontin, or similar)? (15)	○	○	○

Q17 As a child, did you have any of the following conditions ...? (Check all that Apply)

- ☐ Attention Problems (1)
- ☐ Head Injury (2)
- ☐ Muscle Tightness or Weakness (3)
- ☐ Clumsiness (4)
- ☐ Hearing Problems (5)
- ☐ Speech Problems (6)
- ☐ Frequent Ear Infections (7)
- ☐ Learning Disability (8)
- ☐ Other Difficulties (9)

_____

Q18 Were you ever tested for developmental disabilities (e.g., cerebral palsy, specific learning disabilities, autism, etc.)?

- ○ No (1)
- ○ Yes, please explain: (2) _____

Q19 Check any and all the conditions that you have been diagnosed during your life. Add any helpful details (e.g. age at diagnosis, treatment provided) if the condition was serious.

- ☐ AIDS, ARC, or HIV + (1) _____
- ☐ Allergies (2) _____
- ☐ Arterioscleroses (Artery Disease) (3) _____
- ☐ Arthritis (4) _____
- ☐ Asthma (5) _____
- ☐ Blood Disorder (6) _____
- ☐ Brain Infection or Disease (7) _____

- [ ] Cancer/ Chemotherapy (8)
- [ ] Cerebral Palsy (9)
- [ ] Chicken Pox (10)
- [ ] Colds (excessive) (11)
- [ ] Diabetes (12)
- [ ] Encephalitis (13)
- [ ] Epilepsy (14)
- [ ] Fevers (104 F or higher) (15)
- [ ] Liver Disease (16)
- [ ] Hazardous Substance Exposure (17)
- [ ] Heart Disease/ Problems (18)

- [ ] Huntington's Disease (19)
- [ ] Hypertension (20)
- [ ] Kidney Problems/ Disease (21)
- [ ] Lung (Respiratory) Disease (22)
- [ ] Malnutrition (23)
- [ ] Measles (24)
- [ ] Meningitis (25)
- [ ] Multiple Sclerosis (26)
- [ ] Oxygen Deprivation (27)
- [ ] Parkinson's Disease (28)
- [ ] Pneumonia (29)

- [ ] Poisoning (30)
- [ ] Polio (31)
- [ ] Psychiatric Problems (32)
- [ ] Pulmonary Problems (33)
- [ ] Radiation Exposure/Therapy (34)
- [ ] Rheumatic Fever (35)
- [ ] Scarlet Fever (36)
- [ ] Senility (Dementia) (37)
- [ ] Stroke or TIA (38)
- [ ] Thyroid Disease (39)
- [ ] Tuberculosis (40)

☐ Venereal Disease (41)

☐ Whooping Cough (42)

☐ Other Disease/ Disability: (43)

Q20 Please describe any surgeries you have had in the past:

Q21 History of Illness Requiring Hospitalization:

Q22 History of Illness Requiring Medical Intervention but Not Hospitalization:

_____

_____

_____

_____

_____

Q23 Have you ever suffered a serious injury to your head?

- ○ No (1)
- ○ Yes, please describe: (2)

_____

Q24 Please check any diagnostic tests that you have had and describe any abnormal findings:

- [ ] Bone Density (1)
- [ ] ECG (2)
- [ ] EEG (3)
- [ ] MRI/ CT (4)
- [ ] PET (5)
- [ ] Scan Neurological Office Exam (6)
- [ ] X-Rays (7)
- [ ] Other Testing (describe) Type of Test: Date: Findings: (8)

Q25 Do you have epilepsy or a seizure disorder?

- ○ No (1)
- ○ Yes (2)

Q26 If Yes, check the one you have been diagnosed with:

- ☐ Absence (Petit mal) (1)
- ☐ Complex partial (Psychomotor) (2)
- ☐ Partial evolving into generalized (3)
- ☐ Simple partial (Jacksonian) (4)
- ☐ Tonic-clonic (Grand mal) (5)
- ☐ Unclassified Type (6)
- ☐ I do not know which type (7)
- ☐ Please describe it: (8) _____

Q27 Please note all medications taken at present, their dosage, and frequency given.
Name Dosage/ Amount Frequency Given.
Example: Depakote 100 mg. 2 tablets/ AM, 1.5 tablets/ afternoon, 4 tablets/ evening.

_____

_____

_____

_____

_____

Q28 Have you ever been under the care of a psychiatrist, psychologist, or counselor?

- No (1)
- Yes (2)

Q29 If Yes, please answer the following..

- What were you seen for? (1)

_____

- How long did you receive care? (2)

_____

- Is your therapy current or ongoing? (3)

_____

- Did you feel treatment was helpful? (4)

_____

- If no, why not? (5)

_____

Q30 I drink alcohol:

▼ Rarely or never (1) ... Usually (4)

Q31 The usual number of drinks I have at a time is:

_____

Q32 My last drink was:

▼ Less than 24 hrs ago (1) ... Over 48 hrs ago (3)

Q38 Check all that apply:

- ☐ I can drink more than most people my age and size before I get drunk.
- ☐ I sometimes get into trouble (e.g., fights, legal difficulty, problems at work, conflicts with my family, accidents) after drinking. (2)
- ☐ I sometimes blackout after drinking. (3)
- ☐ I have gone through alcohol withdrawal. (4)

Q33 Is there a family history of alcohol abuse?

- ○ No (1)
- ○ Yes, please list relationship(s) to you: (2)

_____

Q34 Please check all the drugs you are now using or have used in the past:

	Currently (1)	In the Past (2)
Amphetamines (including diet pills) (1)	☐	☐
Barbiturates (downers) (2)	☐	☐
Cocaine or crack (3)	☐	☐
Hallucinogens/ LSD (4)	☐	☐
Inhalants (glue, spray cans, etc.) (5)	☐	☐
Marijuana (6)	☐	☐
Opiate narcotics (7)	☐	☐
PCP (angel dust) (8)	☐	☐
Other drugs: (9)	☐	☐

Q35 Do you consider yourself dependent on any of the above drugs?

- ○ No (1)
- ○ Yes, please list the name(s): (2) _____

Q36 Do you consider yourself dependent on any prescription drug(s)?

- ○ No (1)
- ○ Yes, please list the name(s): (2)

_____

Q37 Check all that apply:

- ☐ I have gone through drug withdrawal. (1)
- ☐ I have used I.V. drugs. (2)
- ☐ I have been in drug treatment. (3)

Q38 Have you ever had a lawsuit filed against you?

- ○ No (1)
- ○ Yes, please explain: (2)

_____

Q39 Have you ever filed a lawsuit against someone else?

- ○ No (1)
- ○ Yes, Please explain: (2) _____

Q40 Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, check the box that best describes how you have felt and conducted yourself over the past 6 months.

	Never (1)	Rarely (2)	Sometimes (3)	Often (4)	Very Often (5)
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done? (1)	○	○	○	○	○
How often do you have difficulty getting things in order when you have to do a task that requires organization? (2)	○	○	○	○	○
How often you have problems remembering appointments or obligations? (3)	○	○	○	○	○
When you have a task that requires a lot of thought, how often do you avoid or delay getting started? (4)	○	○	○	○	○

How often do you fidget or squirm with your hands or feet when you have to sit down for a long time? (5)	○	○	○	○	○
How often do you feel overly active and compelled to do things, like you were driven by a motor? (6)	○	○	○	○	○
How often do you make careless mistakes when you have to work on a boring or difficult project? (7)	○	○	○	○	○
How often do you have difficulty keeping your attention when you are doing boring or repetitive work? (8)	○	○	○	○	○
How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly? (9)	○	○	○	○	○

How often do you misplace or have difficulty finding things at home or at work? (10)	○	○	○	○	○
How often are you distracted by activity or noise around you? (11)	○	○	○	○	○
How often do you leave your seat in meetings or other situations in which you are expected to remain seated? (12)	○	○	○	○	○
How often do you feel restless or fidgety? (13)	○	○	○	○	○
How often do you have difficulty unwinding and relaxing when you have time to yourself? (14)	○	○	○	○	○
How often do you find yourself talking too much when you are in social situations? (15)	○	○	○	○	○

How often do you have difficulty waiting your turn in situations when turn taking is required? (16)	○	○	○	○	○
How often do you interrupt others when they are busy? (17)	○	○	○	○	○

Q41 The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all the questions.

Q42 During the past month,

○ When have you usually gone to bed? (1)
_____

○ How long (in minutes) has it taken you to fall asleep each night? (2)
_____

○ What time have you usually gotten up in the morning? (3)
_____

○ How many hours of actual sleep did you get at night? (4)
_____

○ How many hours were you in bed? (5)
_____

Q43 During the past month, how often have you had trouble sleeping because you..

	Not during the past month (0) (1)	Less than once a week (1) (2)	Once or twice a week (2) (3)	Three or more times a week (3) (4)
Cannot get to sleep within 30 minutes (1)	○	○	○	○
Wake up in the middle of the night or early morning (2)	○	○	○	○
Have to get up to use the bathroom (3)	○	○	○	○
Cannot breathe comfortably (4)	○	○	○	○
Cough or snore loudly (5)	○	○	○	○
Feel too cold (6)	○	○	○	○
Feel too hot (7)	○	○	○	○
Have bad dreams (8)	○	○	○	○
Have pain (9)	○	○	○	○
Other reasons (s) please described including how often you have had trouble sleep because of this reason (s): (10)	○	○	○	○

Q44 During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?

- ○ Not during the past month (0) (1)
- ○ Less than once a week (1) (2)
- ○ Once or twice a week (2) (3)
- ○ Three or more times a week (3) (4)

Q45 During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

- ○ Not during the past month (0) (1)
- ○ Less than once a week (1) (2)
- ○ Once or twice a week (2) (3)
- ○ Three or more times a week (3) (4)

Q46 During the past month, how much of a problem has it been for you to keep up enthusiasm to get things done?

- ○ Not during the past month (0) (1)
- ○ Less than once a week (1) (2)
- ○ Once or twice a week (2) (3)
- ○ Three or more times a week (3) (4)

Q47 During the past month, how would you rate your sleep quality overall?

- ○ Very good (0) (1)
- ○ Fairly good (1) (2)
- ○ Fairly bad (2) (3)
- ○ Very bad (3) (4)

VITA

After completing high school in Lakewood, California, Nicole Baker attended Irvine Valley College and received an Associate of Science in 1997. She then moved to Texas and attended the University of North Texas from where she received the Degree of Bachelor of Science in December 2001in Interdisciplinary Studies. She attended Stephen F. Austin University from January 2005 until August 2006 and received a Master of Science in 2006 in Educational Leadership. In 2019, she entered the doctoral program in school psychology at Stephen F. Austin State University and anticipates receiving her degree of Doctor of Philosophy in August of 2023.

Nicole Baker is married with four children, 3 sons-in-law, a daughter-in-law, and four grandchildren. For requirements of her dissertation, she designed and concluded an independent study, *The Effects of Transcranial Direct Current Stimulation (tDCS) on Facial Expression Approach/Avoidance in College Students and Faculty With Broad Autism Phenotype.* In addition, she completed her internship at an APA accredited site and at the University's School Psychology Assessment Center and Neuropsychology Center.

SFASU Address: 1936 North Street
Nacogdoches, TX 75962

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This Dissertation was typed by Nicole R. Baker