The Impact of Autistic Traits on Emotional Prosody and Gesture Perception: The Behavioural and fMRI studies

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Abstract

This thesis combines behavioral and fMRI methods to investigate the neural and behavioral mechanisms of emotional processing in individuals with high-autistic traits (HAQ) compared with those with low-autistic traits (LAQ). The research focuses on the perception and processing of emotional information from prosody, gestures, and audiovisual displays of speech and gesture. It emphasized the study of specific brain regions and compensatory mechanisms that mediate the social communication difficulties commonly observed in those with high-autistic traits. The research involved several experimental studies, each aimed at a different aspect of emotional processing. Participants were divided into two groups based on their scores from the Autism Spectrum Quotient (AQ), which classified them as having high or low autistic traits. This grouping provided a structured approach toward understanding how trait severity impinges upon emotional processing.

In the prosody experiment, the participants were required to recognize emotions solely by the tone of voice. The results showed that the HAQ group showed reduced accuracy and slower response times, particularly in angry and happy emotional cues. The results of fMRI experiment also pointed out that HAQ participants showed less neural activation-indicative of a greater recruitment of cognitive control areas, such as the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC), suggesting more effortful processing to perform one or another type of processing related to emotional content compared with LAQ participants.

The experiment involving with the gesture showed participants with HAQ had an impaired recognition of emotions from body language, especially under congruence or incongruence conditions. Neuroimaging data revealed a greater reliance on brain regions involved in processing information of self-reference, namely the medial prefrontal cortex (mPFC) and insular cortex, implying compensatory strategies that do not fit the efficiency observed in LAQ group. This divergence in the neural pathways underlying the processing indicates the nature of the extra effort and special challenges taken by individuals with high autistic traits to interpret non-verbal social cues.

The audiovisual congruence study investigated how HAQ and LAQ groups integrate multisensory emotional signals. Behavioural results showed participants with HAQ to be significantly less accurate and slower to recognize emotions on trials presenting incongruent signals, such as mismatched body movements and vocal tones. Neuroimaging showed that HAQ individuals activated a wider number of neural structures when processing these emotionally complex situations, including prefrontal regions supporting cognitive control and conflict resolution. In contrast, results from LAQ participants indicated automated neural processing in typically responsible for perceptual integration sites such as the superior temporal gyrus (STG) and fusiform gyrus (FG), consistent with faster and more accurate emotional identification.

Specifically, the multisensory integration fMRI experiment investigated how visual and auditory emotional cues are integrated in individuals with HAQ. Results showed increased activation for the HAQ participants in areas of the brain that are involved in multisensory integration, including the posterior superior temporal gyrus (pSTG) and the ventrolateral prefrontal cortex (vlPFC.). These regions were more strongly activated in HAQ participants than in LAQ participants, in whom congruent emotional stimuli elicited more automatic processing. Further, the results suggest that HAQ individuals engage higher cognitive resources to attain the perception of emotion, emphasizing a basic dissimilarity in the manner of processing emotional information across modalities.

Overall, this thesis provides evidence that individuals with high-autistic traits rely on compensatory neural mechanisms due to difficulties in automatic sensory integration. The findings underpin the relevance of targeted interventions prioritizing enhancement in efficiency regarding emotional processing and reduction of cognitive load during the performance of social communication tasks. Limitations of research include a modest sample size and possible variation in the severity of autistic traits, which could affect generalizability. Larger and more diverse samples would be important to replicate these findings and investigate further the role of individual differences within the HAQ group.

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Author's Declaration

I declare that this thesis, submitted to the University of Glasgow for the degree of Doctor of Philosophy, is the result of my own research, except where otherwise acknowledged, and that this thesis has not been submitted for a higher degree to any other university or institution.

Signed: … ….

(Lee seul Shim)

Date: ………………………………….

List of Definitions/abbreviations

ACC	Anterior Cingulate Cortex
ACG	Anterior Cingulate Gyrus
AC-PC	Anterior Commissure-Posterior Commissure
ADHD	Attention-Deficit/Hyperactivity Disorder
ANOVA	Analysis of Variance
AQ	Autism Spectrum Quotient
COC	Central Operculum Cortex
DLPFC	Dorsolateral Prefrontal Cortex
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, 5th Edition
fMRI	Functional Magnetic Resonance Imaging
FP	Frontal Pole
FDR	False Discovery Rate
FG	Fusiform Gyrus
FSIQ	Full-Scale Intelligence Quotient
FWHM	Full Width at Half Maximum
GLM	General Linear Model
HAQ	High-Autistic Traits
HG	Heschl’s Gyrus
IFG	Inferior Frontal Gyrus
IPL	Inferior Parietal Lobule
IQ	Intelligence Quotient
ITG	Inferior Temporal Gyrus
IQR	Interquartile Range
LAQ	Low-Autistic Traits
LG	Lingual Gyrus
LOC	Lateral Occipital Cortex
mPFC	Medial Prefrontal Cortex
MeFC	Medial Frontal Cortex
MFG	Middle Frontal Gyrus
MNS	Mirror Neuron System
MOG	Middle Occipital Gyrus
MP-RAGE	Magnetization-Prepared Rapid Gradient Echo
MTG	Middle Temporal Gyrus

OFC	Orbitofrontal Cortex
OFA	Occipital Face Area
OP	Occipital Pole
PCG	Posterior Cingulate Gyrus
PFC	Prefrontal Cortex
PHG	Parahippocampal Gyrus
PIQ	Performance IQ
PreCG	Precentral Gyrus
pSTG	Posterior Superior Temporal Gyrus
PT	Planum Temporale
RFX	Random Effects
SD	Standard Deviation
SE	Standard Error
SFG	Superior Frontal Gyrus
SMC	Supplementary Motor Cortex
SMG	Supramarginal Gyrus
SOG	Superior Occipital Gyrus
SPL	Superior Parietal Lobule
STG	Superior Temporal Gyrus
TE	Echo Time
ToM	Theory of Mind
TP	Temporal Pole
TR	Repetition Time
vlPFC	Ventrolateral Prefrontal Cortex
VTC	Volume Time-Course
VIQ	Verbal IQ
WASI	Wechsler Abbreviated Scale of Intelligence
WCC	Weak Central Coherence

1. Introduction

The current chapter reviews major characteristics of social communication and emotional recognition in Autism Spectrum Disorder (ASD). It starts with a general overview of ASD, underlining core features and pointing to crucial difficulties about social communication and emotion recognition. Major research issues of ASD then come into view by outlining the impaired social communication and differences in emotion processing. It introduces the AQ-the Autism Spectrum Quotient-a highly used tool in assessing autistic traits and discusses its role and significance in ASD research. Major theories concerning social communication and emotion recognition in ASD are then discussed: Theory of Mind, Weak Central Coherence, Mirror Neuron System dysfunction, and Double Empathy Theory. It will finally outline the experimental chapters that will follow on prosody, gesture, and multisensory processing deficits in ASD.

1.1. Autism Spectrum Disorder (ASD)

1.1.1. Overview of Autism Spectrum Disorder (ASD)

According to the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; DSM-5; American Psychiatric Association, 2013), Autism Spectrum Disorder (ASD) is a neurodevelopmental condition defined by two core domains: (1) persistent deficits in social communication and social interaction across multiple contexts, and (2) restricted, repetitive patterns of behavior, interests, or activities (RRBs). A detailed summary is presented in Table 1.1 below.

Table 1. 1 DSM-5 Diagnostic Criteria for Autism Spectrum Disorder(ASD)

Domain	Core Features
A. Social Communication and Interaction	Must show persistent deficits in all three areas: 1. Deficits in social-emotional reciprocity 2. Deficits in nonverbal communicative behaviors 3. Deficits in developing, maintaining, and understanding relationships
B. Restricted, Repetitive Behaviors (RRBs)	At least two of the following: 1. Stereotyped or repetitive motor movements, use of objects, or speech 2. Insistence on sameness, inflexible adherence to routines 3. Highly restricted, fixated interests 4. Hyper- or hyporeactivity to sensory input
C. Onset	Symptoms must be present in the early developmental period (but may not fully manifest until later when social demands exceed capacities)
D. Impact	Symptoms must cause clinically significant impairment in social, occupational, or other important areas of functioning
E. Rule Out	Symptoms must not be better explained by intellectual disability or global developmental delay

These symptoms must be present from early developmental periods, though they may not fully manifest until social demands exceed the individual's capacities. For a diagnosis to be made, symptoms must cause clinically significant impairment in social, occupational, or other important areas of functioning and cannot be better explained by intellectual disability or global developmental delay.

Deficits in social communication include difficulties with social-emotional reciprocity (e.g., abnormal social approach, reduced sharing of emotions or interests), nonverbal communicative behaviors (e.g., abnormal eye contact, facial expressions, and gestures), and challenges in developing, maintaining, and understanding relationships. RRBs are expressed heterogeneously and may include stereotyped motor movements or speech, insistence on sameness, inflexible adherence to routines, ritualized behavior, and highly restricted, fixated interests. Sensory sensitivities, such as hyper- or hyporeactivity to sensory input, are also included as part of the diagnostic criteria.

ASD prevalence has been increasing globally, attributed to broader diagnostic criteria, increased awareness, and improved tools (Maenner et al., 2021). This increase in prevalence has indeed been witnessed not only in the United States but also worldwide, with similar trends reported in both Europe and Asia, among other parts of the world, further indicating that this is indeed a global public health issue. While genetic factors are significant, environmental contributions such as prenatal exposures and pollutants are also under investigation (Lyall et al., 2017). Early diagnosis and intervention can greatly improve outcomes (Zwaigenbaum et al., 2015).

Due to changes in the diagnostic criteria that encompass symptoms and severity to a wider range, increased public awareness, and access to better diagnostic tools, the prevalence of ASD has continued to rise worldwide. Commonly, early diagnosis can be made by age 18 to 24 months, allowing timely intervention to take place, thus greatly improving long-term outcomes in communication and social skills. Whereas genetic factors are major contributors, there is an increasing focus on environmental factors, particularly pre-natal exposures, pollutants, and lifestyle variables, although no specific environmental cause has been confirmed.

The observed increased trend in the prevalence of ASD creates the need for more future research in causes, better diagnostics, and individually tailored interventions. More public health efforts, educational support, and lifelong resources are needed to meet the burgeoning demands among ASD cases to maximize their quality of life. Collaboration between healthcare, education, and community resources becomes indispensable in providing appropriate care for persons affected to live a full and meaningful life.

1.1.2.Theories of ASD relevant to social communication

Various theories have been advanced, each postulating mechanisms that underpin core features of ASD with respect to social communication and emotional recognition. It is very important that these theories be understood for the purpose of developing targeted interventions and improving clinical outcomes. The most salient among them are the

Theory of Mind, Weak Central Coherence Theory, Executive Functioning Deficits, Temporal Binding Deficit, Mirror-Neuron System Dysfunction, Enhanced Perceptual Functioning Theory, and Doble Empathy Theory. Each of these theories offers a different paradigm from which specific cognitive and neural mechanisms have been disrupted in ASD and how this results in the heterogeneous presentation of the disorder. These theories are summarised below.

The Theory of Mind (ToM): Where Theory of Mind attributes the state of thinking, believing and desiring and feeling to oneself and others, understanding that others may differ. ToM is used in social interactions; it allows an individual to predict or interpret the behaviours from the mental states of others. Baron-Cohen et al. (1985) concludes that impairment in ToM in individuals with ASD makes them fail to understand other people's perspectives, sarcasm, complex emotions. Neuroimaging in individuals with ASD shows both reduced connectivity and abnormal activation of key ToM-related brain regions, including the medial prefrontal cortex (mPFC) and tempoparietal junction (TPJ), indicating disrupted neural circuitry underlying ToM in ASD (Saxe et al., 2004).

Weak Central Coherence Theory (WCC): Weak Central Coherence (WCC)would mean that individuals with ASD have a detail-dominated cognitive style that, in social or emotional conditions, frequently lacks the perspective of the whole (Frith, 1989). This information processing bias explains why individuals with ASD should show superior performances in tasks requiring detailed-oriented attention and fail in performances in tasks that require integration of several social cues, for example, facial and bodily expressions. This WCC theory underlines the global emphasis in processing for the implementation of interventions that would help individuals with ASD in social communications.

Executive Functioning Deficits: However, indeed, planning, cognitive flexibility, and inhibition are executive functions impaired in ASD, associated with rigid thinking, deficits of social communication development reviewed by Hill (2004). Thus, these deficits appear in failed modulation following changes in topic or perspective, influencing the process of social interaction. Neuroimaging studies present reduced prefrontal cortex activation in conditions challenging cognitive control; thus, there is evidence of a neural basis for executive dysfunctions evident in ASD. Targeted interventions might improve executive functioning to enhance adaptive behaviors.

Temporal binding deficit: Temporal binding integrates the sensory inputs within a narrow temporal window. Such an integration is essential for taking in coherent social perception. Certainly, in ASD, deficits in temporal binding disturb multisensory integration and result in fragmented perception and misinterpretation of social cues, including incongruent facial expression and tone of voice (Stevenson et al., 2014). Neuroimaging studies in ASD also point to atypical activation in superior temporal gyrus (STG), posterior parietal cortex, and insula, which are brain areas related to multisensory integration, highlighting the increased use of interventions in enhancing temporal synchrony.

Mirror-Neuron System (MNS) Dysfunction: The Mirror-Neuron System (MNS) includes regions like the inferior frontal gyrus (IFG) and inferior parietal lobule (IPL), which are equally activated both in Observation and imitation. This system is very important for social learning and empathy. According to Rizzolatti & Craighero, 2004, people with ASD usually have less activation in MNS, which provides them minimal comprehension about the actions of others and their emotions. This dysfunction underlines difficulties in reading non-verbal signals and empathizing; thus, it is indicative of a potential for imitation-based therapies in enhancing social skills.

Enhanced Perceptual Functioning Theory: The theory of Enhanced Perceptual Functioning by Mottron (2006) postulates that individuals with ASD are inherently capable of enhanced perceptual processing in narrow tasks that involve discrimination based on either visual or auditory stimuli. However, internally, this high-contrast perception overrides the integration of social-emotional information and a wide view of social comprehension. Elucidation of this perceptual bias would, therefore, help in framing interventions that match detail-focused strengths with the need for social information processing.

Double Empathy Theory: Proposed by Damian Milton (2012), this theory challenges the traditional deficit-based view of autism. It argues that communication breakdowns between autistic and non-autistic individuals stem from mutual misunderstandings, driven by differences in perspective and communicative style. The theory emphasizes reciprocal understanding and the legitimacy of neurodivergent communication, reframing social difficulties as a two-way phenomenon rather than a one-sided impairment.

Recent developments in autism research, particularly in the UK, have emphasized the importance of reframing autism beyond deficit-based perspectives and toward more neurodiversity-affirming approaches (Bottema-Beutel et al., 2021). This shift highlights the importance of respecting autistic perspectives and communicative styles rather than pathologizing them. In light of this, the present thesis incorporates this theoretical stance to critically reflect on how mutual misattunement, rather than individual deficits, may account for communication difficulties observed in the empirical findings of this study. This approach is further supported by recent findings demonstrating the effectiveness of autistic peer-to-peer communication, which suggests that shared neurotype enhances mutual understanding (Crompton et al., 2020).

1.2. Literature review of social communication in ASD

Difficulties in social communication are one of the most specific, salient features in defining Autism Spectrum Disorder (ASD), having a great complicating factor on an individual interacting with others in socially viable ways. Social communication struggles manifest in both verbal and non-verbal modalities, bringing serious difficulties in understanding and responding to social cues, maintaining conversations, and developing meaningful relationships (Tager-Flusberg, 1999; Bolis et al., 2018). Recent meta-analyses confirm that these pragmatic and nonverbal reciprocity difficulties persist into adulthood, affecting pragmatic language comprehension and the ability to respond nonverbally in social interactions (Dimitrova & Özçalışkan, 2022; Schaeffer et al., 2023). This section will discuss the neural basis of social communication, the challenges persons with ASD face, and their consequences for daily functioning and possible interventions.

1.2.1. Neural systems underlying social communication

Social communication is dependent on the interaction of several regions of the brain, together referred to as the "social brain," which has been said to involve the superior temporal sulcus, amygdala, fusiform gyrus, and prefrontal cortex. These mutually associated regions interactively contribute to the processing of social information, interpreting dynamic social cues, and controlling social behaviors. Consequently, comprehension of their functioning and interaction represents a requisite step toward understanding the basic nature of social communication deficits found in ASD.

The superior temporal gyrus (STG) is seen to play a critical role in the interpretation of dynamic social cues-for example, facial expressions, eye gaze, and vocal intonations-and the integration of auditory-visual information important for understanding others' emotions and intentions (Allison, Puce, & McCarthy, 2000; Pelphrey et al., 2005). In ASD, the superior temporal gyrus (STG) typically shows under-activation during social tasks, leading to difficulties recognizing subtle social signals such as emotional tone or gestures (Pelphrey et al., 2005; Zilbovicius et al., 2006). More recent fMRI and EEG studies support this under-activation and altered connectivity impacting audio-visual integration (Just et al., 2012; Matyjek et al., 2024)

The amygdala is involved in the processing of emotional and social stimuli, including the identification of emotions such as fear from facial expressions (Adolphs, 2001; Davis & Whalen, 2001). It assesses the emotional significance of social information and guides suitable responses accordingly. Due to abnormal activation and connectivity of the amygdala in ASD, emotional expressions are inadequately interpreted, which may lead to social avoidance or inappropriate responses that complicate social interactions (Baron-Cohen et al., 2000; Swartz et al., 2013).

It is also involved in facial recognition and nonverbal emotional expression processing, specifically the fusiform gyrus (FG) and the fusiform face area (FFA) (Kanwisher, McDermott, & Chun, 1997; Haxby et al., 2000). In ASD, this structure commonly demonstrates hypoactivation during face-processing tasks, leading to difficulties in face recognition and problems in decoding emotional information capable of impairing social recognition and engagement (Schultz, 2005; Pierce et al., 2001)

Prefrontal cortex controls social norms and modifies behavior according to feedback provided. Prefrontal cortex deficiency is associated with ASD impairment characterized by theory of mind, perspective-taking, and executive control, which cannot vary behaviors based on social signals and even present the challenge of social matters displaying complexities (Miller & Cohen, 2001; Wood & Grafman, 2003). The atypically functioning prefrontal cortex in ASD is associated with impairments in theory of mind, perspective-taking, and executive control, engendering besetting problems in adjusting behavior based on social signals and negotiating complex situations of a social nature (Hill, 2004; Solomon et al., 2009)

1.2.2. Social communication difficulties in ASD

Social communication impairments in ASD include sophistication at both the verbal and the non-verbal level, often because of atypical neural processing, influencing the capability to perceive, interpret, and respond to social cues. Verbal communication problems often relate to problems of pragmatics or the use of language in social contexts. Individuals with ASD often have problems initiating or maintaining a conversation, in turn-taking, and understanding nonliteral language such as idioms, jokes, and sarcasm (Tager-Flusberg 1999). Abnormal prosody — including altered rhythm, pitch, and intonation — adds complexity to impaired social interactions, with flatter or exaggerated tones masking true emotional content (Paul et al., 2005; McCann & Peppé, 2003). A systematic review and meta-analysis reported significantly reduced prosody recognition accuracy in adults with ASD (Zhang et al., 2021b)., and a 2023 study found distinctive acoustic prosodic signatures predicting ASD severity in preschoolers (Godel et al., 2023)

For instance, non-verbal communication-facial expressions, gestures, eye contact body language-provides added emotion that the spoken message cannot offer. Individuals with ASD generally cannot identify and display these non-verbal cues, adding to their general social difficulties. It is the inability to read facial expressions-not only simple emotions of happiness, sadness, and anger but also complex ones such as empathy and sarcasm-which impacts their ability to respond appropriately in social situations (Bolis et al., 2018). Abnormal contact may be the result of decreased activation in the superior temporal sulcus and amygdala, and sometimes it conveys the wrong impression of boredom or evasion (Pelphrey et al., 2011). Non-verbal gestures, such as pointing or nodding, tend to look awkward or out of sync as well; hence, communications do not seem very natural with these individuals (de Marchena & Eigsti, 2010).

Such difficulties have an impoverishing effect on daily life and relationships, functioning in school and work settings. Social communication problems often manifest themselves as social isolation where development of anxiety interferes with making friends,or keeping jobs due to poor ability to navigate social interactions successfully (Bauminger & Kasari, 2000; Hendricks, 2010). These impairments affect classroom participation, group work, and peer and teacher interactions within a school setting and lead to academic underachievement or difficulties and lost social potentials. This can be viewed to hinder job performance, relationships, and the social demands of a particular professional setting in the work environment. These impairments constrain independence and participation in community activities and make everyday living, the resolution of conflict, and decision-making based on social feedback challenging. As a matter of fact, Volkmar et al. (2004) state that it is very important to understand the neural and cognitive underpinnings of these deficits to develop targeted interventions to improve social communication.

1.3. Literature review of emotion perception in ASD

Emotion processing is a cornerstone of social interaction, requiring integration across auditory, visual, and audiovisual systems (Adolphs, 2002; Kober et al., 2008), yet this process is disrupted in ASD, impairing social communication (Pelphrey et al., 2011). Recent reviews highlight deficits in multisensory emotion perception in ASD, suggesting age- and task-dependent variability in emotional decoding (Zhang et al., 2021b; Chen et al., 2022)

1.3.1. Neural basis underlying emotion perception

Neuroimaging implicates the amygdala, fusiform gyrus (FG), superior temporal gyrus (STG), insula, and prefrontal cortex in emotion processing, with the amygdala central to fear and anger recognition (Baron-Cohen et al., 2000). Recent fMRI research underscores aberrant amygdala reactivity to emotional stimuli in ASD, exhibiting either hyper- or hypo-activation linked to social disengagement (Kleinhans et al., 2008, 2016)

The fusiform gyrus (FG) is primarily involved in face perception and enables facial expression recognition. The superior temporal gyrus (STG) integrates auditory-visual social signals, such as matching the movements of faces to speech (Allison et al., 2000).

The insula contributes to the process of emotional awareness and empathetic responses by way of processing the self and others' emotions. The prefrontal cortex was engaged in higher-order social cognition, such as decision-making and regulation of emotion (Craig, 2009). Disruptions in these regions perturb an overall perception of emotion and result in fragmented social interactions, as in the subject with ASD.

A growing body of neuroimaging research has clarified how neural disturbances contribute to atypical emotion perception in autism spectrum disorder (ASD). These difficulties have been linked to abnormalities in both the functioning and connectivity of a distributed neural network involving the amygdala and fusiform gyrus. The amygdala, which evaluates emotional salience, shows reduced habituation to repeated emotional stimuli in ASD, suggesting sustained hyper-responsivity that may hinder social engagement (Kleinhans et al., 2009). Beyond local reactivity, individuals with ASD also exhibit abnormal functional connectivity between the amygdala and regions such as the fusiform gyrus and prefrontal cortex during face processing, pointing to broader disruptions in social information networks (Kleinhans et al., 2008). Complementing these findings, Schultz (2005) proposed that developmental abnormalities in the amygdala and fusiform face area may underlie core deficits in social perception, particularly in processing socially relevant facial cues. Together, these studies suggest that both regional dysfunction and impaired network integration contribute to the altered processing of emotional and social information in ASD.

Techniques such as fcMRI, more recently, have allowed a much better understanding of how the interaction of different brain regions during emotion processing is made. Indeed, atypical connectivity between superior temporal gyrus (STS) and prefrontal cortex in ASD is associated with weakness in integrating visual and auditory social signals, with putative consequences for emotional understanding of others (Just et al., 2012). Of course, these findings encourage the use of targeted interventions to enhance neural connectivity, with consequent improvement in emotion perception in ASD.

1.3.2. Emotion perception difficulties in ASD

Difficulties in perceiving and interpreting emotional cues are characteristic of ASD, often affecting both the recognition and understanding of facial expressions, prosody, and body language (Baron-Cohen et al., 2000; Uljarevic & Hamilton, 2013). These challenges span from basic emotions—such as happiness, sadness, or anger—to more complex socio-communicative constructs such as empathy, sarcasm, or irony, reflecting broader differences in social cognition. Neuroimaging studies have implicated atypical processing in regions such as the amygdala, fusiform gyrus, and superior temporal sulcus—key areas involved in emotional and social signal processing (Pelphrey, Morris, & McCarthy, 2005).

For example, Kleinhans et al. (2008) reported amygdala hyperactivity and reduced habituation to facial stimuli in individuals with ASD, rather than a simple blunted response. The fusiform gyrus, a critical region for face perception, has frequently shown hypoactivation in ASD, which contributes to difficulties in recognizing emotional expressions (Pierce et al., 2001). However, as Schultz (2005) emphasizes, this region is also involved in processing the structural aspects of faces, not limited solely to emotional content. These neural differences are thought to underlie the social communication challenges observed in ASD.

Another major problem associated with ASDs is prosodic perception-that is, interpretation of emotional tone in speech. Prosody recognition deficits may further result in flat, monotonous speech and reduce the ability to perceive the emotional nuances in other people's voice tones, complicating the understanding of sarcasm, empathy, or seriousness (McCann & Peppé, 2003; Diehl et al., 2008). Such prosodic processing is common to cause social miscommunication; individuals with ASD may misinterpret the emotional content of conversations, which might be disruptive to their social responses and interactions (Paul et al., 2005). Recent acoustic and machine-learning analyses have demonstrated that atypical pitch contours and reduced prosodic variability in natural speech reliably differentiate ASD from neurotypical controls (Ma et al., 2024)

Body language and gesture also pose problems for individuals with ASD because it is vital in the expression of emotions. They mostly fail to comprehend the non-verbal cues from posture, gestures, and eye movements that give critical context to the spoken communication. For example, individuals with ASD may misunderstand or fail to recognize the emotional salience of gestures and thereby make inappropriate social responses that facilitate their further social isolation. (de Marchena & Eigsti, 2010; Capps, Kehres, & Sigman, 1998).

1.3.3. Emotion perception from prosody in ASD

The term emotional prosody refers to the contour of voice including tone and intonation to convey, through the voice, one's feelings. In human communication, it reflects affective information accompanying the literal meaning of speech. Emotional prosody is typically processed by right-lateralized neural networks, including the inferior frontal and superior temporal regions, as consistently demonstrated in neuroimaging studies (Belyk & Brown, 2017; Ethofer et al., 2006). In ASD, prosody processing is atypical: neuroimaging shows reduced right-hemisphere dominance and compensatory bilateral activation (Jou et al., 2011), and a behavioural meta-analysis has demonstrated that individuals with ASD exhibit moderate deficits in prosody recognition, with more pronounced impairments observed for complex emotional expressions (Zhang et al., 2021b).

In ASD, however, emotional prosody processing is typified by atypical neural responses of reduced activity in these right hemisphere regions and altered patterns of lateralization (Jou et al., 2011; Wang et al., 2014). Indeed, most of the neuroimaging studies have detected a failure of ASD individuals to activate the typical right-dominant network in prosody processing. In fact, they reported a more bilateral or even left-hemisphere bias in ASD participants during prosody processing (Buchanan et al., 2000; Klouda et al., 1988; Redcay & Courchesne, 2008). This may demonstrate an atypical neural pattern in which difficulties in distinguishing between different emotional intonations pose significant challenges for social communication (Rosenblau et al., 2016).

Behavioral studies indeed confirm that the results indicate individuals with ASD commonly experience difficulties in emotional prosody perception and its interpretation. Indeed, while a range of empirical evidence has indicated that individuals with ASD-both children and adults-are less accurate than neurotypical controls in detecting the emotional tone of speech, this is quite significant in discriminating between close emotions, such as between happiness and surprise or sadness and fear (Golan et al., 2006b; Grossman et al., 2010; Rutherford, Baron-Cohen, & Wheelwright, 2002). These deficits have been related not only to atypical neural activation but also to reduced sensitivity to prosodic cues, which can then show themselves as a flat or monotonous speech pattern commonly adopted by individuals with ASD (Shriberg et al., 2001; Peppe et al., 2011).

Such impaired emotional prosody processing in ASD may imply more generalized effects on social interactions. This may be misconstraining emotional tone, failing to differentiate when someone is being sarcastic, for instance, or taking a serious comment as a joke. Such a reinterpretation of social cues results in inappropriate responses, thus shaping further development of social problems and negative social experiences (McCann & Peppe, 2003; Eigsti et al., 2012). For instance, not noticing irritation in a peer's tone of voice could lead to further behavior of social unacceptability, thus resulting in conflict and social rejection (Chevallier et al., 2011).

Moreover, deficits in emotional prosody can influence broader social communication, as individuals on the autism spectrum may struggle to engage in emotionally nuanced and contextually appropriate discourse (Paul et al., 2005; McCann & Peppe, 2003). Misinterpretation of prosodic cues may reduce one’s ability to respond empathetically or to modulate emotional expression in alignment with conversational signals (Golan et al., 2006b; Globerson et al., 2015). This emotional disconnect is often perceived by others as social withdrawal or lack of interest, which may further compound the interpersonal challenges faced by autistic individuals (Chevallier et al., 2012; Sasson et al., 2017).

The research also points out that in the case of ASD, there is a strong link between emotional prosody impairments and decreased emotional involvement and empathy. In other words, if the patients with ASD are unable to identify or understand correctly the emotional tone of speech-then that will make it even more challenging for them to become emotionally attached to others or behave appropriately in social settings (Wang et al., 2006) This may cause them to feel more socially alienated, anxious, and isolated, as individuals with ASD might find it difficult to conduct daily interactions based on emotional dynamics.

Moreover, difficulties in processing emotional prosody in individuals with ASD may contribute to a limited emotional vocabulary, as they may be unaware of the full range of affective cues conveyed through speech. This limitation can hinder both the expression of one's own emotions and the accurate interpretation of others' emotional states—core abilities that are crucial for effective communication and relationship-building (Rieffe et al., 2000; Baron-Cohen et al., 2004). The cumulative result of these challenges may be a fragmented understanding of social interactions, where the emotional impact of verbal communication is either missed or misinterpreted, leading to further social misunderstandings (Golan & Baron-Cohen, 2006a).

1.3.4. Emotion perception from gesture in ASD

Emotional gestures—such as facial movements, hand gestures, and body posture—are essential in conveying social meaning (Grèzes et al., 2009; Philip et al., 2010). However, individuals with ASD often experience significant difficulties in recognizing these cues (de Marchena & Eigsti, 2010; Capps et al., 1998). Recent meta-analytic evidence indicates moderate to large deficits in interpreting emotional bodily expressions, particularly in subtle or context-dependent gestures (Mazzoni et al., 2020). Neuroimaging studies also report reduced activation in regions such as the fusiform gyrus and amygdala during gesture or face-related emotion processing in ASD (Dalton et al., 2005), aligning with behavioral underperformance in subtle gesture recognition tasks.

Neuroimaging studies have noted that individuals with ASD show atypical activation in the fusiform gyrus (FG), a region involved in face perception, and in the amygdala, which plays a central role in processing emotional information (Pelphrey et al., 2007; Dalton et al., 2005). These regions typically work together to support the rapid and accurate interpretation of facial and bodily expressions of emotion. In ASD, reduced activation and altered connectivity in these areas have been linked to difficulties in recognizing emotional expressions, including both facial and bodily gestures, often leading to misinterpretation of social cues (Sato et al., 2012; Grèzes et al., 2009).

Behavioral findings further complement these results, in those individuals with ASD exhibit diminished interpretation of the emotional content of gestures. Numerous studies have demonstrated that individuals with ASD, both children and adults, are less accurate than neurotypical controls at recognizing emotions from facial expressions and body language, particularly when emotional signals are subtle or complex (Gross, 2004; Philip et al., 2010). This difficulty is especially pronounced when emotional cues are embedded in complex social contexts (Philip et al., 2010). Recent meta-analyses further indicate that autistic participants consistently underperform in dynamic gesture recognition, especially for ambiguous or subtle affective movements (Mazzoni et al., 2020). These findings support the view that affective kinetic decoding is a core challenge in autism.

Individuals with ASD can also interpret through a negative interpretation bias, meaning neutral or ambiguous gestures may be taken as threatening or hostile (Maddox et al., 2017). Such a bias would only further raise social anxiety and avoidance behaviors in the alienation of individuals from social contact. For example, a facial expression that is kept neutral may be misread as disapproval, thereby discouraging interaction and reinforcing patterns of social withdrawal.

The misunderstanding of affective gestures influences broader aspects of empathy and emotional involvement with the individuals with ASD. The inability to perceive emotional gestures correctly results in a lack of emotional resonance with others and hinders the growth of deep interpersonal relations. This may further cause a disconnection leading to communicative asociality where individuals with ASD fail to express empathy or respond appropriately to the other person's emotional states. (Hobson, 1993; Bird et al., 2007).

This defective processing of emotional gestures in ASD is again going to have cascading effects on other social skills such as conversational turn-taking and nonverbal reciprocity, which depend on the ability to quickly respond to social cues. In this respect, Lartseva et al. (2014) suggest that these affective and communicative deficits further exacerbate social communication challenges in individuals with ASD, complicating their ability to engage successfully in everyday social contexts.

1.3.5. Emotion perception from prosody-gesture (audiovisual) in ASD

What matters, multisensory integration incorporates fragments of information from multiple senses that create a coherent perception. It is also important in emotion recognition, where facial expressions combined with the voice tones and other contextual clues for a match. Multisensory integration—the coordination of emotional information across modalities—is impaired in ASD (Stevenson et al., 2014; Cascio et al., 2012). A recent neurocognitive review confirmed that ASD individuals exhibit atypical integration of audiovisual cues, partly due to extended temporal binding windows and reduced cross-modal neural coherence (Feldman et al., 2018). Longitudinal studies also suggest that integration of linguistic and prosodic content improves with age, while non-linguistic multisensory integration remains delayed in ASD (Resolution of impaired multisensory processing in autism, 2022; Grossman et al., 2013).

Behavioral investigations emphasize that people with ASD perform poorly in tasks that require integration of audiovisual emotional signals, such as matching facial expressions with vocal tone or identifying emotions in dynamic scenes (Russo et al., 2010; Foss-Feig et al., 2010). Deficits in such integration possibly result in misunderstandings during social interchange because perception from emotive cues underpinning communication is compromised without the integration of information between senses. It also points to new evidence that links disturbed multisensory integration in ASD with altered temporal processing-meaning the timing of the sensory inputs is not synchronized, leading to delays or errors in emotional perception and contributing to the social and sensory problems commonly observed in ASD (Feldman et al., 2018; Wallace & Stevenson, 2014).

Simultaneous prosody and gestures processing basically previews full emotional context in understanding a conversation where both, in effect, are some of those non-verbal ingredients which work together to enrich the communicative message. For instance, a sarcastic tone of voice paired with an exaggerated hand gesture can convey humour or sarcasm, while a comforting tone and a soft touch express empathy (McNeill, 1992). It effectively embeds prosodic processing so the listener can perceive not only the explicit verbal message but also the underlying emotional and social shades. In neurotypicals, prosody processing interlinks closely with gesture; in fact, both these aspects bake one single unified meaningful interpretation of social interactions.

In the case of individuals with ASD, however, prosody and gesture often fail to integrate, making complex social signals difficult to decipher. This could reflect a disconnect between what one hears and what one sees, leading to confusion and misunderstandings. For example, a person with ASD may hear a warm tone but fail to recognize the supportive gesture accompanying it or may observe an exaggerated gesture without detecting the sarcastic tone that conveys humor. Such mismatches between sensory modalities can have significant implications for social communication, potentially causing the intended emotional message to be lost or misinterpreted (de Gelder & Vroomen, 2000; Stevenson et al., 2014).

Neuroimaging findings implicate these deficits to atypical patterns of activation and connectivity within insula, superior temporal gyrus (STG), and prefrontal cortex (PFC) that underlie multisensory integration (Calvert et al., 2000; Oberman et al., 2005). The insula also seems to be more responsive to the integration of emotional clues through multiple sensory modalities about the self and others. Abnormalities in emotional awareness in individuals with ASD have been associated with reduced activation of the insula during completion of prosody and gesture tasks and may contribute to impaired recognition and response to complex social cues (Di Martino et al., 2009).

These neurological findings are reinforced by several behavioral studies indicating that people with ASD often do not merge prosodic information with appropriate gesture. For instance, studies have shown incompetence in performance about tasks related to the interpretation of vocal tone in combination with gestures in individuals with ASD, as compared with neurotypical controls (Grossman et al., 2013; Kushki et al., 2013).
The difficulty extends to social contexts where rapid, dynamic adjustments need to be performed in ongoing interactions, such as being a part of group conversation or nuances in social signals that are interpreted with conflict or emotional arousal.

The disrupted integration of prosody and gesture also leads to misinterpretations in prosodic and gestural cues such as failing to recognize that a sarcastic tone combined with a dismissive gesture indicates jest rather than literal intent. This becomes an even greater challenge in dynamic social contexts in which multiple cues must be processed and integrated in real time. Indeed, there is evidence that individuals with ASD may have difficulty updating their interpretation of social events based on shifting prosodic and gestural information, leading to rigid or contextually inappropriate responses (Rosenblau et al., 2017).

Moreover, these difficulties with integration affect the acquisition of social skills and empathy. Prosody and gesture are quite central to emotional expression, and damaged integration in ASD itself reduces the capacity for appropriately affective response, for emotional interchange, and for showing empathy effectively. According to Hobson (1993) and Bird et al., (2007), such integration defects in ASD yield a lack of capacity for appropriately affective response, for emotional interchange, and for showing empathy effectively. The result of this may become manifested as a perceived lack of emotional sensitivity by others, further complicating social relationships and negative social experiences.

Taken together, the literature reviewed highlights a consistent pattern of difficulties in perceiving and interpreting emotional signals across modalities—such as facial expressions, prosody, and gestures—in individuals on the autism spectrum. These difficulties are not limited to isolated channels but often emerge in the integration of multimodal emotional cues, resulting in challenges in decoding nuanced social information and in adapting communicative responses accordingly. Although individual aspects of emotional signal processing (e.g., prosody or facial expression) have been well documented, relatively few studies have directly examined how these cues are jointly processed, particularly in ecologically valid contexts that mimic real-life social interactions.

Moreover, neuroimaging findings point to atypical activation and connectivity in key brain regions involved in social-emotional perception, including the amygdala, fusiform gyrus, and superior temporal sulcus. Yet, the specific neural mechanisms underlying multimodal emotional processing—such as how congruent or incongruent prosody and gesture are interpreted—remain underexplored in autistic populations. Understanding these mechanisms is crucial not only for refining theoretical models of social cognition in autism (e.g., the Double Empathy Problem) but also for informing interventions that target socially meaningful communication skills.

The present research seeks to address this gap by examining how adults with varying levels of autistic traits process emotional prosody and gesture—both independently and in combination—using behavioral measures and functional MRI. Specifically, it aims to determine:

- Whether individuals with high autistic traits differ from those with low traits in their ability to recognize emotions from prosody, gesture, and combined audiovisual cues;
- The neural correlates of emotional processing across these modalities, and how they differ between groups;
- The extent to which congruency effects (e.g., matching vs. mismatching emotional cues) influence emotional recognition performance and brain activation.

By focusing on these questions, the present research aims to deepen our understanding of how autistic traits influence multimodal emotion processing and to provide a more nuanced account of the social-communicative profile associated with autistic traits.

1.4. Overview of the research

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by variability in social communication, interaction skills, repetitive behaviors, and sensory processing abnormalities. It may range in severity from severe impairments in communication and intellectual functioning to mild challenges in which the affected individuals have intelligence in the average or above-average range but struggle with social subtleties. The prevalence of ASD has been increasing, with current estimates suggesting that about 1 in 54 children in the United States are now affected, a finding similarly replicated internationally (Maenner et al., 2020; Lord et al., 2020). This rise underlines the need to understand the neural and behavioral underpinnings of ASD, especially those related to social communication and emotion processing.

Social communication and emotion recognition are important components of daily interaction. Such differences can create substantial challenges in social functioning, education, and employment for individuals on the autism spectrum. More specifically, emotional prosody, gestural interpretation and integration of multisensory information are more impaired, disrupting this ability to perceive and appropriately respond to emotional and social clues. Each of these specific difficulties is explored in this thesis, through combinations of behavioral assessments and neuroimaging techniques like fMRI, aimed at defining the neural and cognitive correlates of such impairments.

1.4.1. Background of the research

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental diagnosis characterized by persistent difficulties in social communication and interaction, along with patterns of restrictive and repetitive behaviors combined with atypical sensory processing (American Psychiatric Association, 2013). In recent decades, there has been a notable increase in ASD diagnoses, highlighting the importance of understanding the experiences and challenges faced by individuals on the autism spectrum (Baio et al., 2018). Individuals with ASD often encounter a wide range of challenges in social communication, which can have meaningful impacts on daily functioning and quality of life. These challenges extend beyond surface-level conversational issues and include difficulties in interpreting and responding appropriately to complex verbal and non-verbal social cues that are essential for effective communication (Pelphrey et al., 2011).

One of the most prominent challenges for individuals with ASD involves reading both verbal and non-verbal cues, such as facial expressions, speech prosody, posture, and gestures, which convey important emotional and social information (Grossman et al., 2010). Difficulties in processing these cues can significantly hinder social interaction (Tager-Flusberg et al., 2005). For example, individuals with ASD may experience a reduced ability to infer emotions from facial expressions, such as interpreting a smile as neutral or even negative, which may lead to social misunderstandings and inappropriate responses (Adams et al., 2010; Tousignant et al., 2017). These challenges can contribute to experiences of social isolation, heightened anxiety, and difficulties in forming and maintaining relationships, which in turn can affect overall well-being (Bellini, 2004).

Beyond facial expressions, individuals with ASD may face additional challenges in the auditory domain, particularly in interpreting prosody—the rhythm, stress, and intonation of speech that conveys emotional content beyond literal meaning (Peppé et al., 2007). Difficulties in understanding tone, sarcasm, implied meanings, and contextual cues can lead to misinterpretation in conversation. Irony and sarcasm, for instance, rely heavily on prosodic cues, and individuals with ASD may interpret such statements literally without grasping the intended emotional nuance (Klin et al., 2002). In addition, challenges in interpreting non-verbal cues such as gestures and body language may further complicate effective communication (Philip et al., 2010).

Due to differences in processing social information, individuals with ASD may frequently be misunderstood in social settings. Even simple gestures—like a thumbs-up—may be missed or misinterpreted, leading to communication breakdowns. The difficulty in accurately reading these signals can put individuals with ASD at a disadvantage in social situations that require the integration of multiple cues (Lord et al., 2000). These characteristics in social communication are believed to arise from neurodevelopmental differences that affect the processing of social and emotional information. Neuroimaging studies have shown that individuals with ASD often exhibit differential activation in brain regions responsible for processing social cues. For example, Pelphrey et al. (2007) highlighted that dynamic aspects of social information, such as eye gaze, facial expressions, and body movements, involve the superior temporal gyrus (STG), a region that shows reduced or atypical activation in individuals with ASD (Allison et al., 2000; Zilbovicius et al., 2006).

Another key brain region implicated in ASD is the fusiform gyrus (FG), which plays a crucial role in facial recognition. In neurotypical individuals, this region is strongly activated when viewing faces, enabling rapid and accurate emotion recognition (Haxby et al., 2000). However, individuals with ASD frequently show hypoactivation in this area, which may contribute to difficulties in distinguishing between various facial expressions—especially subtle ones such as fear or disgust that require fine perceptual discrimination (Schultz, 2005).

The amygdala, essential for processing the emotional significance of social stimuli, is also frequently implicated in ASD. Differences in amygdala activation patterns in response to social and emotional signals have been observed in individuals with ASD compared to neurotypical individuals (Baron-Cohen et al., 2000; Pelphrey et al., 2005). These differences may impact the ability to assess emotional context, such as recognizing whether a facial expression conveys friendliness or threat. Moreover, altered connectivity between the amygdala and prefrontal cortex may affect emotional regulation during social interactions (Ibrahim et al., 2019; Alaerts et al., 2018).

Atypical sensory processing is another frequently observed characteristic in ASD. Sensory hypersensitivity or hyposensitivity can significantly influence social communication. For instance, hypersensitivity to auditory stimuli may make it difficult to follow conversations in noisy environments, as all sounds may be perceived as overwhelming. Conversely, reduced sensitivity may hinder the perception of socially relevant cues, such as changes in voice tone indicating a shift in emotional context (Robertson & Baron-Cohen, 2017; Ben-Sasson et al., 2009; Rogers & Ozonoff, 2005). These sensory processing differences often underlie specific challenges that individuals with ASD face in filtering and integrating social information from the surrounding environment.

Social communication is greatly dependent on the integration of several sensory inputs-auditory, visual, and somatosensory-to achieve a coherent understanding of social interactions (Stevenson et al., 2014). Multisensory integration enables neurotypicals to match what they see, such as facial expressions and gestures, with what they hear, like vocal tone and prosody, which in turn enhances the interpretation of complex emotional and social cues. However, in individuals with ASD, multisensory integration is often disrupted, leading to fragmented or delayed perception of emotions and misinterpretations of social cues (Brandwein et al., 2012). Neuroimaging studies have also identified abnormal activation in regions responsible for the processing and integration of multisensory information, which includes superior temporal gyrus (STG), insula, and posterior parietal cortex (Cascio et al., 2012). These disruptions in sensory integration interfere with the coordination of visual and auditory cues, such as aligning facial expressions with corresponding vocal tones.

Difficulties in multisensory integration in ASD may become particularly evident in emotionally incongruent situations where verbal and non-verbal signals are not aligned. While neurotypicals could promptly resolve such the conflict of incongruities because of integrating contextual information, individuals with ASD typically face increased cognitive load; hence, the reconciliation of conflicting signals is decidedly slower and less accurate. Noël et al. (2018). This may lead to gross misinterpretations, such as viewing a neutral expression as hostile or not catching sarcasm or irony when the tone of voice and facial expressions do not match. Such misinterpretations may lead to the maintenance of social anxiety and social withdrawal; individuals with ASD may find the social encounter confusing, overwhelming, or even threatening (Kerns et al., 2014). Fundamentally, these findings signal deeper impacts of social communication impairments in ASD, which are based on complex interactions between atypical neural functioning and sensory processing differences. Notably, the parameters of this challenge bring out the need to instill more nuanced awareness of the ways in which social communicational deficits express their influence in everyday interaction.

1.4.2. Aims of the research

The aim of the present study is to determine how different levels of autistic traits affect the processing of emotional information. This study, thus, compares individuals with high and low levels of autistic traits, to understand how such traits influence the cognitive and neural bases of emotional processing regarding the detection and interpretation of emotional prosody and gestures.

The AQ is a widely administered tool used in assessing autistic features, generally understood to yield a dimensional approach in the broader autism phenotype, allowing the researcher to investigate the gradations of autistic features affecting social communication. The present research employs behavioral measures and neuroimaging with the aim of testing which if individual differences in the processing of emotional signals are associated with variation in the extent to which autistic traits are manifest

In general, this kind of knowledge about how autistic traits drive the disadvantages in emotion processing can inform improvements to interventions for social communication. The results from this study are expected to give far more specific insights into the mechanisms underlying challenges to social communication in ASD and the broader autistic phenotype. This investigation of how autistic traits modulate the perception of emotional prosody, gesture, and multisensory social cues makes a relevant contribution to identifying candidate biomarkers for deficits in emotional processing and underscores the need for targeted interventions addressing specific difficulties in emotional recognition. By identifying such an association, support strategies for individuals with high autistic traits may be better informed, leading to increased social engagement and helping them to enjoy a better quality of life.

1.4.3. The research questions

In this thesis, the following crucial questions about the neural and behavioral levels of emotion perception and social communication are being investigated in a population of adults with high autistic traits, which will be assessed and validated by this sample:

1. How do autistic traits influence the processing of emotional information from different domains (prosody, gesture, prosody-gesture)? What differences will be found from comparing neurotypical individuals with low-autistic traits and individuals with high autistic traits.
2. What are the neural correlates of impaired social communication and emotion processing from different domains -prosody, gesture, prosody-gesture- in individuals with high-autistic traits?
3. How does the brain behave in congruent and incongruent emotional situations? Are people with high-autistic traits different in terms of brain response? Further, does this also vary with autistic traits?
4. Whether individuals with a high level of autistic traits have different brain activities as compared to neurotypicals during the multisensory integration process, and how autistic traits influence brain activities.

1.4.4. Structure of the research

The structure in the chapters of this thesis will include:

Chapter 1 (Introduction): A literature review of difficulties in social communication associated with ASD, particularly in emotion processing, provides the background necessary to understand neural and behavioral mechanisms.

Chapter 2 (Perception of emotions from speech intonation): Examines how individuals with ASD recognize emotions from speech intonation and indicates the neural differences between high and low autistic traits in interpreting emotional prosody.

Chapter 3 (Perception of emotions from body gestures): Investigates the means whereby individuals with high-autistic traits recognize the emotions of others through body gestures, considering neural differences between high- and low-autistic traits that influence the interpretation of emotional gestures.

Chapter 4 (Perception of emotional congruence in audiovisual information): Assesses how high- and low- autistic traits affect the processing of congruent and incongruent audiovisual emotional signals, focusing on the differences between adults with high- and low-autistic traits while they processing conflicting emotional information simultaneously presented.

Chapter 5 (Multisensory integration from emotional social cues): Tests the differences in multisensory integration in high- and low-autistic traits when processing emotional cues.

Chapter 6 (Discussion): Discusses implications of the findings, neural and cognitive underpinnings of deficits in social communications, and suggests future research and intervention strategies.

2. Emotion Perception from Prosody in Adults with High-Autistic Traits

2.1. Abstract

Social communication impairments are diagnostic hallmarks of ASDs, and several studies have shown that difficulties in emotional prosody processing-one term for the pattern of rhythm, intonation, and emphasis in speech that signals its emotional aura-are important components of social communication impairment. Although individuals with high autistic traits commonly self-report problematic perception and interpretation of emotional prosody, the exact behavioral and neural differences from individuals with low autistic traits are less well-defined. These differences were investigated in the current chapter, which used behavioral experiments and fMRI to investigate the detection of emotional prosody in auditory-only contexts. Participants in the research were divided into two groups based on their AQ results: those with high-autistic traits, HAQ, and those with low-autistic traits, LAQ. Five behavioral experiments reported here investigated the recognition of emotions in sentences and dialogues: angry, happy and neutral. Overall, the HAQ group performed less accurately, especially for happy and angry prosody. Results from fMRI showed that the HAQ group demonstrated reduced activity within emotional processing areas, such as the amygdala and prefrontal cortex, whereas both groups similarly activated the superior temporal gyrus. The LAQ group showed stronger interregional connectivity between emotional and auditory processing regions, reflecting more efficient neural integration. These findings point to emotional prosody processing deficits in individuals with high autistic traits, thereby contributing to overall social communication difficulties, and a need for interventions that focus on building up emotional recognition.

2.2. Introduction

Autism Spectrum Disorders are a group of neurodevelopmental disorders characterized by pervasive impairment in social communication and social interaction, and restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2000; American Psychiatric Association, 2013). This symptom set occurs on a wide continuum of skills and difficulties, resulting in great heterogeneity in the forms in which ASD individuals experience and interact with the world.

Another important aspect of ASD that has recently gained increasing attention from both researchers and the public is sensory processing difficulties (Marco et al., 2011; Robertson & Baron-Cohen, 2017). Individuals with ASD frequently exhibit atypical sensory responsivity—ranging from hypersensitivity to hyposensitivity—across modalities, including auditory, tactile, and visual domains (Foss-Feig et al., 2010; Kwakye et al., 2011). These sensory issues are now considered core to the diagnostic criteria for ASD (American Psychiatric Association, 2013). Recent neuroimaging and behavioral studies have highlighted how altered sensory reactivity directly impacts social communication, suggesting that differences in sensory integration are linked to decreased engagement with emotional cues in speech and gesture (Feldman et al., 2018; Wallace & Stevenson, 2014; Baum et al., 2015).

Prosody is the rhythmic, intonational, and stress patterns of speech that carry a great deal of information concerning the speaker's mood, intentions, and emotional states. Typically developing individuals learn to interpret prosody naturally from an early age; for those with ASD, however, prosody represents one of the biggest challenges. Abnormal prosodic features among the ASD population include speech that sounds monotonous or emotionless, difficulty with pitch modulation, or poor and inappropriate pattern of stress which may make them sound flat or disengaged (Paul et al., 2005).

It is not only in the production that deficits in prosody occur, but in individuals with ASD, there is a problem even with the perception and interpretation of prosodic cues. Previous studies showed that children with autism have highly significant difficulties both in recognizing and producing affective prosody, compared to their typically developing peers (Peppé et al., 2007). These persist into adulthood, leading to misunderstandings in social interactions and emotional communications. This is another important reason to understand prosody-to improve social communication as it can help the listeners catch up with cues concerning what emotions and intentions another person is communicating.

Apart from behavioral challenges, neuroimaging studies have begun to explore the neural mechanisms underlying these deficits. Functional MRI has shown that affective prosody is processed in a network of brain regions, including the superior temporal gyrus, inferior frontal gyrus, and supplementary motor cortex, which are involved in auditory and emotional processing. These regions are part of a larger fronto-temporal network integrating auditory and emotional information. Subcortical structures, such as the amygdala and basal ganglia, are also involved, particularly in processing emotionally salient prosodic cues. The amygdala, known for detecting emotionally charged stimuli, shows reduced activation in individuals with ASD during tasks involving emotional prosody. This reduced activation may explain the diminished sensitivity to emotional prosody seen in individuals with high-autistic traits, especially in emotionally charged situations like anger or happiness (Baron-Cohen et al., 2000).

Despite the significance of prosody in everyday social communication, much of the research to date has focused on children with ASD, with fewer studies examining prosody's neural processing in adults. Furthermore, while behavioral studies have documented difficulties in recognizing and producing prosody among individuals with ASD, its neural basis remains less understood. This remains a comparatively uncharted area, particularly concerning emotional prosody processing in adults with high levels of autistic traits who may not have a clinical diagnosis of ASD. Understanding how individuals with high-autistic traits perceive and process emotional prosody, both behaviorally and neurologically, is essential for developing targeted interventions aimed at improving social communication.

The present chapter compares the recognition of emotional prosody between adults with high and low autistic traits by means of both behavioral experiments and neuroimaging techniques, fMRI. Because this study is to examine the differences in pecific neural and behavioral alterations in prosody perception among those with high and low levels of autistic traits, specifically during auditory-only condition. By isolating prosody from other contextual cues, this study aims to identify the neural and cognitive mechanisms that underlie emotion recognition in these groups and to pinpoint the specific challenges faced by individuals with high-autistic traits in interpreting emotional speech patterns.

2.3. Autism Spectrum Quotient (AQ)

The Autism Spectrum Quotient (AQ) is a widely used self-report questionnaire designed to measure the extent of autistic traits in both clinical and non-clinical populations (Baron-

Cohen et al., 2001). The AQ provides a valuable tool for assessing the presence and severity of autistic characteristics across a range of individuals, including those who may not meet the full diagnostic criteria for autism spectrum disorder (ASD), but still exhibit significant traits associated with the condition. By evaluating these traits, the AQ helps researchers and clinicians understand the broader autism phenotype and its impact on cognitive, emotional, and social functioning. In the present study, the AQ was selected due to its strong psychometric foundation, established cut-off values, and widespread use in similar research contexts, which facilitates comparability with previous findings.

Importantly, it is necessary to distinguish between diagnosed autism and high levels of autistic traits as measured by tools such as the AQ. While the two constructs are related, they are not interchangeable; individuals with high AQ scores may exhibit subclinical traits that do not meet diagnostic thresholds for ASD. Nonetheless, previous studies have sometimes conflated these groups or generalized findings from clinically diagnosed autistic individuals to those with high autistic traits (Ruzich et al., 2015; Lai et al., 2015; Austin, 2005; Hurst et al., 2007). Such assumptions risk misrepresenting the evidence base unless care is taken to specify sample characteristics. This dimensional approach aligns with current perspectives in autism research that emphasize trait variability across the general population, rather than strict categorical boundaries between clinical and non-clinical groups.

Moreover, the AQ is not the only tool available to assess autistic traits. Other instruments such as the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005) and the Broad Autism Phenotype Questionnaire (BAPQ; Hurley et al., 2007) have also been developed to measure autistic features across a spectrum of severity and contexts. While each tool has unique strengths and psychometric characteristics, the AQ remains widely adopted due to its brevity, ease of administration, and strong integration with existing research on subclinical autistic traits. Broader literature on autistic traits also includes findings from family studies showing elevated traits among siblings and parents of autistic individuals (e.g., Piven et al., 1997), which supports the concept of a broader autism phenotype. This notion emphasizes that autistic traits can be continuously distributed across the general population and are not confined to clinical diagnostic boundaries. Understanding this distributional nature of autistic traits helps contextualize the use of the

AQ within population-level variability and underscores its relevance in both clinical and subclinical research domains.

The AQ consists of 50 items distributed across five dimensions: social skill, attention switching, attention to detail, communication, and imagination. Each domain comprises ten items, and responses are dichotomously scored (0 or 1) based on alignment with typical autistic features, yielding a total score ranging from 0 to 50. A commonly used cut-off score of 32 is considered indicative of elevated autistic traits and a potential need for further evaluation (Baron-Cohen et al., 2001). However, variations in cut-off points have been proposed depending on the population being studied. For instance, a study using a clinical sample referred for Asperger's syndrome assessment suggested a lower threshold of 26, which optimized sensitivity and specificity in that context (Woodbury-Smith et al., 2005). These variations highlight the importance of considering contextual and sample-specific factors when interpreting AQ scores.

Despite its usefulness, the AQ has certain psychometric limitations. One key concern involves the dimensional structure of the questionnaire. Several factor analytic studies have questioned the original five-factor model, suggesting alternative solutions such as two- or three-factor models that may better capture underlying constructs (Austin, 2005; Hurst et al., 2007). Furthermore, gender bias has been identified as a potential limitation of the AQ: male respondents often score higher than females even when autistic traits are clinically comparable, possibly due to differences in social compensation strategies or item wording (Kirkovski et al., 2013; Lai et al., 2015).

Nevertheless, the AQ remains a valuable tool in autism research, particularly for identifying traits in non-clinical populations. Its utility extends beyond diagnostic screening, as it facilitates the study of subclinical autistic features and their associations with cognitive, neural, and behavioral outcomes. The AQ has also supported broader investigations into the genetic and environmental underpinnings of autistic traits, contributing to a more dimensional and inclusive understanding of autism across the population spectrum (Ruzich et al., 2015). Its continued use, when interpreted with appropriate caution regarding its limitations, allows researchers to explore nuanced aspects of neurodiversity and social cognition.

2.4. Emotional prosody recognition: A Behavioral study

2.4.1. Research questions

The present experiment examined differences between individuals with low- and high-autistic traits in prosody perception in conversational and social context.
The research questions of the experiment were:

1. How do individuals with high-autistic traits react differently when selecting the correct emotion from a sentence or conversation compared to individuals with low-autistic traits?
2. How is difficulty in perceiving the emotions in sentences and conversation displayed by high-autistic traits individuals?

2.4.2. Experimental methods

2.4.2.1. Screening measure for participants

In this study, participant grouping was based on Autism Spectrum Quotient (AQ) scores. The AQ served as a standardized screening tool to categorize individuals into high- and low-autistic-trait groups, thereby allowing for systematic investigation into how individual differences in autistic traits influence emotional prosody processing, both behaviorally and neurally. Participants with AQ scores of 29 or above were classified into the high-autistic-traits group (HAQ), while those scoring 18 or below were placed in the low-autistic-traits group (LAQ). This classification approach was informed by previous research suggesting various diagnostic and subclinical thresholds: for instance, a score of 32 has been associated with clinically significant autistic traits (Baron-Cohen et al., 2001), while a cut-off of 26 has been proposed in clinical settings for identifying Asperger's syndrome (Woodbury-Smith et al., 2005).

The choice of 18 as the cut-off for the LAQ group was made to reflect a conservative and empirically grounded threshold for low autistic traits. Specifically, this value lies approximately one standard deviation below the mean AQ score reported in neurotypical populations, which typically ranges between 16 and 18 (Austin, 2005; Ruzich et al., 2015). Additionally, previous large-scale studies examining AQ in the general population have employed similar cut-offs to define low-trait subgroups (Voracek & Dressler, 2006). By adopting this stratification method, the research ensures both theoretical consistency and methodological comparability with prior research.

2.4.2.2.Participants

Participants in the experiment consisted of 68 individuals who took part in the behavioral study. These participants were recruited primarily through the university's subject pool system, which included both undergraduate/postgraduate students and local community members who voluntarily registered to participate in research. The initial sample spanned a broad range of AQ scores, from 4 to 47, allowing for both dimensional and categorical analyses of autistic traits. Participant characteristics and group breakdowns are presented in Table 2.1.

All participants were native English speakers, aged between 18 and 40 years. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971), and cognitive ability was screened using the Wechsler Abbreviated Scale of Intelligence (WASI). Participants were stratified into two groups based on their Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001) scores: those scoring 29 or above were assigned to the high-autistic-traits group (HAQ), and those scoring 18 or below were placed in the low-autistic-traits group (LAQ). Based on this criterion, 40 participants (10 men, 30 women) were included in the LAQ group and 28 participants (9 men, 19 women) in the HAQ group.

Of the 28 individuals in the HAQ group, 2 participants had received a formal diagnosis of Autism Spectrum Disorder, while the remaining 26 participants had no prior clinical diagnosis. The inclusion of both formally diagnosed and undiagnosed individuals within the HAQ group allowed for examination of autistic traits across the spectrum, including both clinical and subclinical manifestations.

Table 2. 2 Demographics and psychological data for low and high AQ group

	Low AQ group	**High AQ group**	**p-value**

Cut-off score (AQ)	Below 18	Above 29	-
Number	40 (M:10, F: 30)	28 (M:9, F: 19)	p = 0.588 (fisher's exact test)
Handedness	40 R	28 R	-
Age	23.28±5.36	24.18 ±6.96	p = 0.858 (Mann-Whitney U)
AQ	12.51±4.68	34.04±4.73	$p < .001^{***}$ (Mann-Whitney U)
VIQ	118.90±10.21	119.32±11.79	p = 0.879 (t-test)
PIQ	115.56±11.51	117.11±8.96	p = 0.617 (t-test)
FSIQ	119.38±10.04	120.79±9.37	p = 0.586 (t-test)

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

2.4.2.3.Stimuli

This study presented stimuli selected from two different emotional stimuli databases that were also used in below.

Stimuli Set 1 (Eigsti, Schuh, Mencl, Schultz, & Paul, 2012): This database was an audio-only corpus containing declarative sentences (3-5 words each) of high-frequency standard norm words (Gilhooly & Logie, 1980; Kucera, 1967), spoken by a native English female (e.g., "It is five o'clock"; "She is typing fast"). Such that a sentence could either fall into an affective (Neutral, Angry) or grammatical category (Statement intonation, Question intonation), and thus results in the two-by-two design. The pitch for Neutral-Statements ranged from 108.8 to 302.4 Hz with a falling pitch pattern, while Neutral-Questions ranged from 165.5 to 486.4 Hz with a rising pitch. For Angry-Statements, the pitch ranged from 127.0 to 338.5 Hz with a falling pattern, and for Angry-Questions, it ranged from 270.0 to 506.0 Hz with a rising pitch. All stimuli were matched in pitch, intensity and duration across all conditions by acoustic manipulation using Praat. The stimuli used in the experiment was 3 seconds long. Three prosody tasks (Task 1, Task 2 and Task 3) employed emotional sentences from this database.

Stimuli Set 2 (Piwek, Pollick, & Petrini, 2015): This stimuli set was selected from 20 UK-born male actors, aged 17 to 43, all native English speakers. The actors were instructed to speak and act naturally in predetermined scenarios designed to express emotions. In total, 242 displays were created, consisting of 9 actor pairs, 2 emotions (Angry and Happy), 3 intensities (low, medium, high), 2 dialogue versions (inquiry, deliberation), 2 repetitions, and 26 neutral conditions. The audio stimuli were around 60 dB dialogues, which were exported as a resolution of 44.1 kHz and a 24-b sampling in WAV format. The length of the audio dialogues were 3 seconds and were of medium intensity. In this study, 72 audio dialogues were used specifically in two prosody tasks (Task 4 and Task 5).

2.4.2.4.Procedure

The experiment was conducted using an Apple Macintosh Mac Pro 3.1 desktop computer running OS 10.5 and equipped with an NVIDIA GeForce 8800GT video card. The visual stimuli were presented on a 21 viewsonic graphics series g220f crt monitor with a display resolution of 1024 x 768 pixels and refresh rate of 60 hz. Auditory cues were presented through high-quality Beyerdynamic DT770 headphones. The stimuli were delivered using the Psychophysics Toolbox (PTB3) extensions (Brainard, 1989; Pelli, 1997) for MATLAB 2007b (MATHWORKS Inc., Natick, MA).

All of the participants wore headphones during the experiment and responded by hitting a number key on the keyboard. Prior to the start of the experiment, the participants were briefed and permitted to control the volume and to get comfortable in their seats. Then were given the stimuli and told to pick the appropriate answers for the prosody tasks like what emotions were expressed in the sentences or dialogues. They would perform the tasks while listening to a stream of sentences or conversations between two people and they would have to click the corresponding number key as soon as they heard the right one. Every task session is about 5 or 6 minutes, and the whole experiment took about 30 minutes. And also the answers and response times were tracked on the emotional recognition tasks.

The experiment consisted of five individual sub-prosody tasks, and the order of the tasks was pseudo-randomized for each subject.

1. Select the correct emotion from an affective sentence (Angry/Neutral).
2. Recognize the correct intonation in a grammatical sentence (Question/Statement).
3. Select the correct answer from the given combinations of affective and grammatical sentences (Angry-Question, Angry-Statement, Neutral-Question, Neutral-Statment).
4. Choose the speaker's emotion from three emotional categories (Angry/Happy/Neutral) in a conversational question.
5. Choose the speaker's emotion from three emotional categories (Angry/Happy/Neutral) in a conversational statement.

Table 2. 3 Description of prosody experiment tasks

	Stimuli set	Conditions	Num. of trials
Task 1	Set 1	Angry, Neutral	32
Task 2	Set 1	Question, Statement	32
Task 3	Set 1	Angry-Question, Angry-Statement, Neutral-Question, Neutral-Statement	64
Task 4	Set 2	Inquiry: Angry, Happy, Neutral	36
Task 5	Set 2	Deliberation: Angry, Happy, Neutral	36

2.4.2.5. Data analysis

All statistical examinations were performed employing the R software (R Development Core Team, 2008). Demographic characteristics and other cognitive scores differences between the LAQ and HAQ groups were compared in terms of age, gender, AQ, VIQ, PIQ and FSIQ. First, the study conducted the Shapiro–Wilk test to determine the normality of data on the continuous variables; they include age, AQ, VIQ, PIQ, and FSIQ. Where variables were normally distributed ($p > 0.05$), two-sample t-tests were performed to compare between the two groups. For the variables that did not follow normal distribution ($p < 0.05$), Mann-Whitney U test was used. For the categorical variable gender, thus Fisher's exact test was used to compare proportion between the two groups.

The objective was to compare the number of correct responses and response time for each emotional prosody between the two groups. For each emotional prosody, t the mean, standard deviation (SD), and standard error (SE) were first calculated for each group. To that end, a Mixed-Effects Beta Regression Model was run for the correct response rate of participants on all tasks, using the group factor as the fixed effect, and prosody in the stimulus as the covariate, and participants as a random effect using the glmmTMB package in R. The correct response rates were presented as proportions and these values are bounded to the interval [0, 1] so the β–regression was considered adequate to analyze the data. Fixed effects were prosody and group and their interaction. Participant ID was nested into random intercepts to control for within-subject variations.

The model was defined as: *Correct Response Rate ∼ Prosody × Group + (1 | Participant ID)*

During the preparation of data, response rates for each prosody type were bounded at the limits for the beta responses of the boundary problem in the beta regression model by adding epsilon close to zero, which would equate to '0' and '1'. Before model fitting, the data were reshaped in long format, and prosody and group became the categorical variables. Mixed-Effects Beta Regression analysis using logit link was performed, and the final model was subjected to model summary to assess the Prosody, Group, and their interaction as fixed effects.

Preliminary results showed that analysis of variance revealed significant differences in the correct response rate as a function of prosody, group, and their combined influence. Post-hoc analysis was conducted using estimated marginal means through the use of emmeans package to compare individual differences between various types of prosody and the various groups. The reaction times were compared using the Wilcoxon rank-sum test (Mann-Whitney U test) to compare the LAQ and HAQ groups. This non-parametric test has been chosen because the distributions of the reaction time might be non-normal.

Correlation analysis was performed to assess the correlation between the autistic traits and the performance on intelligence test, correct reponse rate, and reaction time. These correlations looked at the relations between the correct response rate for emotions recognition, AQ, time reaction, and values of VIQ, PIQ, and FSIQ. The correlation analysis included both the LAQ and HAQ groups together. For all statistical tests, the alpha level was set at $p = 0.005$ to prevent Type 1 error for multiple comparisons.

2.4.3. Results

2.4.3.1. Correct response rate and reaction time

The aim of this experiment was to compare the abilities of subjects with high autistic traits and subjects with low autistic traits of identifying emotions and reaction time regarding different types of prosodies. The participants were asked to identify the intended emotion when recognizing emotional prosody under different conditions, and their correct response rates and response time were collected to compare the efficiency of the participants' identification of the intended emotion.

Two different stimuli sets were used in this experiment: Stimuli Set 1 was used in Tasks 1 through 3, such as the stimuli illustrating anger and no emotion prosody with grammatical intonations of statements and questions. Stimuli Set 2 was used in Tasks 4 and 5 involving two speakers and the emotional prosodies selected as angry, happy, and neutral. This was advantageous since it created a more holistic approach to evaluation of the participants' competencies on how to decode affective features in various contexts.

(1) Task 1

Task 1 aimed to assess participants' ability to recognize emotional prosody, specifically focusing on angry and neutral prosody. Participants were supposed to identify the emotion in the speech given and decide whether anger or neutrality is conveyed through the presented stimuli. The accuracy of participants in this particular instance and the speed with which they sensed the emotions were measured by correct reaction rate and the correct reaction time, respectively.

As demonstrated in Table 2.3, compared with the HAQ group, the LAQ group was able to achieve a higher mean correct response rate related to the recognition of emotion.

Although the performance of the HAQ group was quite accurate in identifying angry prosody, the differences in proportions of correct responses across the groups or types of emotional prosody were too small and not statistically significant enough, with $p > 0.05$. For angry prosody, the LAQ group was, in fact, somewhat better, though only statistically non-significantly so, than the HAQ group by their respective rates of correct responses ($p > 0.05$). It is also evident that the LAQ group evidenced a small increase for angry prosody relative to the HAQ group. The interaction of Prosody type × Group was also small and not significant in magnitude, indicating there is no difference in the size of the prosody effect between the two groups (see Table 2.4).

Reaction times, however, were tiny, at 2.17 sec ± 0.524 sec for the HAQ group versus 2.04 sec ± 0.249 sec for the LAQ group. However, these differences did not reach significance, $p = 0.121$, indicating that both groups responded with similar quickness to identify emotional prosody.

Overall, the Task 1 results point to the better performance of the LAQ group, especially in terms of identifying neutral prosody, whereas in recognizing angry prosody, it acts on par with the other group. In general, both groups yield lower overall correct response rates when identifying angry prosody.

(2) Task 2

Task 2 aimed at testing participants' ability to differentiate between two grammatical intonations -statement and question— of speech. Correct response rate measurements were taken as a way to show how well the participant was able to identify whether the speech was delivered as a statement or a question. Measures also included reaction time, indicating how fast they were able to do so.

The LAQ group provided a slightly higher number of correct responses to both question and statement prosody than the HAQ group in this task. Further, both groups provided higher numbers of correct responses to statement prosody than to question prosody (see Table 2.3). This analysis indicates that the distinction between the two groups was due to the greater number of correct responses of the LAQ group to statement prosody, not to question prosody, to which both groups responded similarly. The prosody of the questions was more difficult for both groups, providing an overall lower correct response rate. Statistical analysis did not reveal any significant effects of prosody type, group, or the interaction between the two. That is, differences in prosody type (questions versus statements) or the group effect (HAQ versus LAQ) did not result in a statistically significant effect on correct response rate, $p > 0.05$ (see Table 2.4).

Regarding reaction times, no significant differences were recorded within the HAQ group, which had a median of 2.10 s and an IQR of 0.226 s, as compared to the LAQ group, which had a median of 2.05 s and an IQR of 0.285 s, since the p-value was 0.165, showing both groups gave responses at similar speeds.

These findings point to the relatively better performance of the LAQ group, especially in detecting statement prosody, while both groups showed quite similar abilities in the identification of question prosody. For both groups, question prosody was more challenging, which overall resulted in lower correct response rates.

(3) Task 3

Task 3 tested the interaction of two emotional prosodies (angry, neutral) with two grammatical intonations (statement, question), as four separate conditions. As presented in Table 2.3, across all types of prosody, the LAQ group usually demonstrated higher correct response rates than the HAQ group, but with the highest effect sizes presented in the angry-question and neutral-question conditions.

Results showed that the HAQ group was significantly more likely to respond correctly to angry statements and neutral questions than to angry questions. The performance for both groups was best under the angry-statement and neutral-statement conditions, with correct response rates exceeding 0.85. In the neutral-statement condition, the mean values for the two groups were close in value, reflecting the lowest variability and most consistent performance. The highest level of dispersion for the HAQ group was derived from the neutral-question condition.

Mixed effects beta regression analysis showed that condition had a significant effect on correct response rates ($F(2, 282) = 5.49$, $p = 0.0046$). Both the Angry_Statment and Neutral_Question conditions yielded significantly higher correct response rates than the Angry_Question condition; no other pairwise comparisons were significant. The overall group effect was marginal, $p = 0.068$, with general trends for the LAQ group outperforming the HAQ group. No significant interactions between prosody and group were found except for a marginally significant interaction between neutral-question and group, $p = 0.057$, which suggests that the performance gap between the LAQ and HAQ groups may be narrowed in this condition (see Table 2.4). Indeed, post-hoc comparisons indicated a significantly higher HAQ difference score than in conditions of Angry-Question versus Angry-Statement conditions, ($p = 0.040$) and that the angry-question HAQ participants differed from LAQ participants ($p = 0.033$).

In terms of reaction times, the two groups gave very similar medians: The variability within the HAQ group was higher compared to the LAQ—the median was 3.46 s with an IQR of 1.068 s for LAQ and a median of 3.45 s with an IQR of 1.379 s for HAQ, reflecting greater inconsistency in response times among the HAQ group. These results suggest that the performance of the LAQ group was marginally better, especially in identifying statement prosody; however, both groups were equally proficient in recognizing question prosody. For both groups, question prosody proved to be more challenging and lowered the overall percentage for correct responses.

(4) Task 4

Tasks 4 and 5 utilized a different set of stimuli compared to Tasks 1 through 3, consisting of angry, happy, and neutral emotions spoken by two speakers. On the whole, the HAQ group revealed lower correct response rates across all prosody types than did the LAQ group except for neutral prosody, as can be viewed in Table 2.3.

The highest rates of correct responses for neutral prosody were above the average of 0.90 for both groups. On the other side, the lowest rates of correct responses provided evidence that angry prosody was the most difficult for the participants to decode. Overall, the LAQ group performed better in recognizing happy prosody (LAQ-mean: 0.669 vs. HAQ-mean: 0.551), but their recognition of angry prosody was just as good.

The intercept in the mixed-effects model represents the baseline performance of the HAQ group for angry prosody. This intercept is not significant, indicating no clear difference from baseline. In the HAQ group, correct response rates for neutral prosody were significantly enhanced relative to angry prosody ($p < 0.001$), suggesting that the neutral stimuli were more readily interpreted. However, happy prosody did not differ from angry prosody in correct responses, suggesting that for participants in the HAQ group, performance was not different across the two prosodies. Overall, there was no significant group effect, LAQ versus HAQ, or interaction between group and prosody to suggest performance differences between the two groups as a function of prosody type (see Table 2.4).Indeed, the outcome of posthoc testing was that there were significant differences between the angry and neutral condition in both groups, with neutral always yielding higher correct response rates.

This has slightly longer reaction times for the HAQ group, with a median of 3.67 s and an IQR of 0.657 s, compared to the LAQ group, with a median of 3.56 s and an IQR of 0.435 s. However, this was not statistically different between the groups, $p = 0.439$, indicating both groups responded at similar speeds. These results indicate that the LAQ group slightly outperformed the HAQ group in recognizing happy prosody, while recognition for neutral prosody was equally good for both groups. The poorest correct response rates for both were for angry prosody.

(5) Task 5

Among these, there is neutral prosody in Task 5, which prompts the highest percentage of correct responses in both the LAQ group and the HAQ group, though extremely slight differences between the groups remain in mean values of 0.925 and 0.935, respectively. In perceiving happy prosody, the HAQ did worse, as reflected in its lower mean value and greater scatter compared to the LAQ. Angry prosody remained the most difficult overall; however, the LAQ group EDTs for prosody were slightly better and more homogeneous than those of the HAQ group (see Table 2.3).

Mixed-effects beta regression analyses used the correct response rate for the HAQ group with angry prosody as the baseline and were statistically significant. Prosody effects were found for HAQ: happy prosody was associated with a significant reduction in correct response rates relative to angry prosody, and neutral prosody was associated with a significant increase in correct response rates. Collectively, angry and neutral prosodies have an insignificant group effect, but in happy prosody, LAQ performed significantly better than HAQ ($p < 0.001$, highly significant) (see Table 2.4). Post-hoc analysis showed that across both groups, the rates of correct responses were significantly higher in neutral prosody than in angry and happy prosody, which in turn were challenging and had the lowest response rates. However, no significant differences were found between LAQ and HAQ groups under such conditions.

Even though no statistically significant difference in reaction times were found between groups, $p = 0.410$, during Task 5, the LAQ group showed slightly faster and more consistent reaction times, median = 3.74 s, IQR = 0.409 s, compared to the HAQ group, median = 3.86 s, IQR = 0.639 s. These results indicate that overall, the performance of the LAQ group was better, especially for the detection of happy prosody. Neutral prosody recognition was equally achieved by both groups, but angry prosody turned out to be the most difficult, with the lowest percentage of correct responses in both groups.

Table 2. 4 Summary of mean, standard deviation (SD), and standard errors (SE) for each task

Task	Prosody	Group	Mean	SD	SE
Task1	Angry	LAQ	0.959	0.077	0.012
		HAQ	0.924	0.140	0.026
	Neutral	LAQ	0.994	0.019	0.003
		HAQ	0.960	0.064	0.012
Task2	Question	LAQ	0.964	0.081	0.013
		HAQ	0.911	0.121	0.023
	Statement	LAQ	0.998	0.010	0.002
		HAQ	0.984	0.028	0.005
Task3	Angry-Question	LAQ	0.809	0.198	0.0312
		HAQ	0.752	0.192	0.0363
	Angry-Statement	LAQ	0.914	0.114	0.0180
		HAQ	0.871	0.133	0.0251
	Neutral-Question	LAQ	0.867	0.168	0.0265
		HAQ	0.783	0.237	0.0447
	Neutral-Statement	LAQ	0.861	0.0996	0.0157
		HAQ	0.862	0.0804	0.0152
Task4	Angry (inquiry)	LAQ	0.546	0.206	0.033
		HAQ	0.565	0.182	0.034
	Happy (inquiry)	LAQ	0.669	0.161	0.025
		HAQ	0.551	0.179	0.034
	Neutral (inquiry)	LAQ	0.927	0.093	0.015
		HAQ	0.908	0.137	0.026
Task5	Angry (deliberation)	LAQ	0.629	0.135	0.021
		HAQ	0.619	0.175	0.033
	Happy (deliberation)	LAQ	0.498	0.160	0.025
		HAQ	0.348	0.194	0.037
	Neutral (deliberation)	LAQ	0.925	0.080	0.013
		HAQ	0.935	0.119	0.022

Table 2. 5 Mixed-Effects Beta Regression Analysis of Fixed Effects for Correct Response Rates Across Tasks 1 to 5 (parameters, z values, and p-values)

Task	Parameter	z value	Pr(>|z|)
Task1	Intercept (Angry HAQ)	61.333	$p<0.001^{***}$
	Prosody (Neutral vs. Angry)	1.591	0.111
	Group (LAQ vs. HAQ)	1.250	0.211
	Interaction (Prosody x Group)	-0.179	0.858
Task2	Intercept (Question HAQ)	11.019	$p<0.001^{***}$
	Prosody (Question vs. Statement)	1.536	0.125
	Group (LAQ vs. HAQ)	1.226	0.220
	Interaction (Prosody x Group)	-0.208	0.835
Task3	Intercept (Angry-Question HAQ)	5.746	$p<0.001^{***}$
	Prosody (Angry-Question vs.Angry-statement)	3.109	0.002^{**}
	Prosody (Angry-Question vs. Neutral-Question)	2.911	0.004^{**}
	Prosody (Angry-Question vs. Neutral-statement)	0.202	0.840
	Group (LAQ vs. HAQ) in Angry-Question	2.135	0.033^{*}
	Interaction (Angry-statement x LAQ)	-0.422	0.673
	Interaction (Neutral-Question x LAQ)	-1.902	0.571
	Interaction (Neutral-statement x LAQ)	-1.086	0.277
Task4	Intercept (Angry HAQ)	0.250	0.194
	Prosody (Angry vs. Happy)	0.132	0.601
	Prosody (Angry vs. Neutral)	2.872	$p<0.001^{***}$
	Group (LAQ vs. HAQ)	0.223	0.375
	Interaction (Happy x LAQ)	00009	0.979
	Interaction (Neutral x LAQ)	-0.254	0.469
Task5	Intercept (Angry HAQ)	0.743	$p<0.001^{***}$
	Prosody (Angry vs. Happy)	-1.599	$p<0.001^{***}$
	Prosody (Angry vs. Neutral)	2.712	$p<0.001^{***}$
	Group (LAQ vs. HAQ)	-0.282	0.197
	Interaction (Happy x LAQ)	1.116	$p<0.001^{***}$
	Interaction (Neutral x LAQ)	-0.094	0.778

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

2.4.3.2.Correlation analysis

The correlation analysis was conducted to examine the relationships between all variables, including the AQ score, correct response rate, reaction time, VIQ score, PIQ score, and FSIQ score. The normality of the data was evaluated using the Shapiro-Wilk test, with Pearson's correlation applied to normally distributed variables and Spearman's correlation applied to non-normally distributed variables.

None of the tasks gave an r-value over 0.4 and no significant results could be shown in the correlation analysis.

2.5. Emotional prosody recognition: An fMRI study

2.5.1. Research questions

The main goal of the present research was to compare brain activations evoked by angry, happy, and neutral prosody in listened-only audio conversation that includes social context in adults with high-autistic traits to that in age- and IQ-matched adults with low-autistic traits.

The following questions were addressed in the experiment:

1. How does brain activation differ between individuals with high-autistic traits and those with low-autistic traits when they perceive emotional prosody in conversations based on social context?
2. How does neural activity respond differently to various emotional prosodies (angry, happy, neutral) in adults with high-autistic traits compared to those with low-autistic traits?

2.5.2. Experimental methods

2.5.2.1.Participants

Thirty individuals who had already completed the emotional prosody behavioral experiment were recruited and take part in this fMRI study. Due to one participant of the high-autistic traits group's corrupted data upon analysis, only 29 participants whose data will be analyzed are involved. The demographics of those 29 participants can be seen in Table 2.5. All participants spoke English natively, were aged between 18-40 years of age and were categorised into one of two participant groups according to their scores on the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001). Individuals who scored above

29 on the AQ were included in the high-autistic traits (HAQ) group, while participants with an AQ score below 18 comprised the low-autistic traits (LAQ) group. Handedness was assessed using the Edinburgh Handedness Inventory. Based on this classification, 16 participants (5 males, 11 females) were determined to have low-autistic traits and 13 participants (5 males, 8 females) to have high-autistic traits. All participants also completed a standardized test of general cognitive ability, the Wechsler Abbreviated Scale of Intelligence, WASI.

Table 2. 6 Summary of demographic information for the low and high AQ groups

	Low AQ group	**High AQ group**	**Group comparison**
Cut-off score (AQ)	Below 18	Above 29	-
Number	16 (M:5, F: 11)	13(M:5, F: 8)	p=0.714 (Fisher's exact test)
Age	23.3±5.6	24.2 ±7.3	p =0.706 (Mann-Whitney U)
Handedness	16 R	13 R	-
AQ	13.8±4.5	33.7±5.1	$p < 0.001^{***}$ (Mann-Whitney U)
VIQ	113.81±8.8	121.69±9.4	$p = 0.028^{**}$ (t-test)
PIQ	116.81±14.1	119.08±8.5	p =0.615 (t-test)
FSIQ	117.06±10.5	122.85±7.1	p =0.102 (t-test)

(*p<.05, **p<.01, ***p<.001)

2.5.2.2.Stimuli

The audio-only stimuli set was adapted from the study 'Audiovisual integration of emotional signals from others' social interaction'. For this, audio capture involved actors exchanging simple, single-sentence dialogues; for example, Actor 1: "Where have you been?", Actor 2: "I've just met with John" to portray happy and angry interactions. Twelve repetitions of these emotional interactions were recorded between eight pairs of actors whose ages range between 17 to 43 years. Actors were instructed to interact naturally while imagining short, simple emotional scenarios designed to induce the target emotions.

To make this process as natural as possible, the actors were asked to relate personal experiences to the scenarios; the scenarios themselves were of situations one would come across in everyday life that may induce emotions; Scherer, 1986. The actors were given verbal instructions such that they tried to avoid touching each other during interactions; Clarke et al., 2005. Audio dialogues were recorded at a sampling rate of 44.1 kHz and 24-bit resolution. First, the captured dialogues were increased by 10 dB; then noise-reduced and normalized to maintain their volume at roughly 65 dB. Each audio clip was exported as a WAV file. The final audio set consisted of 192 unique audio clips, ranging in length seconds. In the current experiment, a total of 60 audio-only clips, each 3 seconds long with medium intensity, were used to test the perception of emotional prosody.

2.5.2.3.Design

A block-design fMRI experiment with two runs performed to investigate the differential brain activation in individuals with low-autistic traits and high-autistic traits during the presentation of emotional sentences. The presentation order of the runs was counterbalanced across participants: half of the participants completed the runs in ascending order, while the other half completed them in descending order. Blocks were presented in the pseudo-randomized order. There were 60 stimuli for each run, 3 emotions × 10 conversations × 2 repetitions, and each display was no longer than 3 s. Every run lasted for 410 s and was divided into 12 blocks. The video trials began after a 10-s black screen at the beginning and ended with a 12-s black screen. Each block was 16 s long and contained 5 stimuli in the same modality and expressing the same emotion, with the emotional expression varying across blocks.

2.5.2.4.Data acquisition

Participants were invited to the Centre for Cognitive Neuroimaging at the University of Glasgow. MRI data were acquired using a 3T Tim Trio MRI scanner (Siemens, Germany) with a 32-channel head coil. A T1-weighted, high-resolution anatomical whole-brain scan lasting 5 minutes was obtained using a 3D magnetization-prepared rapid acquisition gradient echo (MP-RAGE) T1-weighted sequence (192 contiguous 1 mm axial slices, dimensions: 256 mm × 256 mm, TR = 1900 ms, TE = 2.52 ms, inversion time = 900 ms, flip angle [FA] = 9°). Functional T2-weighted images were acquired using an echo-planar, T*-weighted gradient echo pulse sequence (TR = 2000 ms, TE = 62 ms, FA = 9°). A total of 32 axial slices (3 mm thick, 0.3 mm gap) were acquired in an ascending interleaved sequence for whole-brain coverage. Functional data were collected in two separate runs, each consisting of 205 volumes and lasting 6 minutes and 50 seconds per run. For each run, the first two volumes were preceded by two dummy volumes without stimuli, and they were excluded from the fMRI data analysis.

2.5.2.5. Procedure

All participants received extensive information about the experiment and were given an opportunity to ask questions before the consent form was signed. Participants were interviewed for scanner safety, prior to scanning, to ensure that they could safely receive a scan. Then they received a short description of the experimental procedure. During the experiment, the subjects were exposed to a series of audio-only conversations and were asked to judge the emotional states of the speakers. During each run, three different emotions served as stimuli: Angry, Happy, Neutral, presented over the black background; subjects judged the emotion of the speakers in the conversations. The task was designed as a forced-choice task: Subjects responded by pressing one of three buttons on a response box and chose an answer. Stimuli were presented according to design using Presentation 14.9 software (NeuroBehavioural Systems [NBS]) coupled with electrostatic earphones at a sound pressure level of as much as 80 dB (NordicNeuroLab, Norway). Before the beginning of the scan, the operator was checking that the sound pressure level would be comfortable for the participants and loud enough to compensate for scanner noise.

2.5.3. Analysis

2.5.3.1. fMRI pre-processing

BrainVoyager QX Version 2.8 was used for both pre-processing and analysis of all fMRI data. The first two functional volumes were excluded from the analysis to allow for signal stabilization. A standard pre-processing pipeline was applied to the functional data for each participant (Goebel, Esposito, and Formisano, 2006). Slice timing correction was performed using sinc interpolation, and 3D motion correction was applied to account for small head movements by spatially aligning all volumes to the first volume using rigid-body transformations. The estimated translation and rotation parameters never exceeded 3 mm or 3 degrees. The functional MR images were temporally filtered using a high-pass filter with a cut-off of three cycles and were further spatially smoothed using a Gaussian filter (FWHM 6 mm). The last two volumes of the functional scans were excluded to eliminate potential filtering artifacts. The data were then aligned with the AC–PC plane (anterior commissure–posterior commissure plane) and transformed into Talairach standard space (Talairach and Tournoux, 1988). For each participant, the functional time-series data were co-registered with the corresponding anatomical data, resulting in normalized 4D volume time-course (VTC).

2.5.3.2.Data analysis

A second-level, multi-subject, random effects GLM was applied in these prosody experiments. A 2 (Group: LAQ, HAQ) × 3 (Emotion: Angry, Happy, Neutral) repeated-measures ANOVA was conducted, with group as the between-subject factor and emotion as the within-subject factor. To investigate significant brain activation within each group, one-sample t-tests were conducted for each condition (angry, happy, and neutral) and each contrast (angry > neutral, happy > neutral, angry > happy, happy > angry, neutral > angry, and neutral > happy). Additionally, a univariate ANOVA was performed to examine the effects of group and emotion on each contrast. To correct for multiple comparisons, an FDR correction at $q = 0.05$ was applied to control for false discovery rates. Following this, cluster thresholding was performed to eliminate small clusters, using the minimum cluster size ($p<0.05$) threshold determined through 1000 iterations of Monte Carlo simulations. All clusters reported in this study survived correction for multiple comparisons at the whole-brain level.

The "Talairach Client" software, described by Lancaster et al. (2000), was employed to map the anatomical regions of interest by using the Talairach coordinates of the activated voxels, aiding in functional brain mapping. Correlation analyses were performed separately in the LAQ and HAQ groups, using the clinical variable AQ and the IQ subdomains, Verbal IQ and Performance IQ. Correlated areas were identified and reported using a lenient threshold of uncorrected $p = 0.001$ in both groups.

2.5.4. Results

2.5.4.1. Main effect of group, emotion, and interaction between the factors

A 2 × 3 repeated-measures ANOVA [Group: LAQ, HAQ] × Emotion: Angry, Happy, Neutral] was performed. This showed a significant main effect of emotion in several regions bilaterally, including the superior temporal gyrus (STG), supplementary motor cortex (SMC), right inferior frontal gyrus (IFG) and right precentral gyrus (PreCG), left precuneus, caudate, left parahippocampal gyrus (PHG), as well as some subcortical regions (see Table 2.6 and Figure 2.1 in below). Significantly, no significant group differences or interactions between group and emotion were found.

Table 2. 7 The significant clusters from the results of a 2 x 3 ANOVA with group as a between-subjects factor and emotion as a within-subjects factor

Contrast	Region	Talairach coordinate of peak voxel x, y, z	L/R	F	p	Number of Voxels
Main effect of group	n. s					
Main effect of emotion	Heschl's Gyrus	51,-10,4	R	70.19	<0.000001	30531
	Inferior Frontal Gyrus, pars opercularis	48,14,31	R	19.57	<0.000001	1233
	Precentral Gyrus	48,-7,46	R	20.17	<0.000001	1470
	Globus pallidus	18,2,7	R	15.83	0.000004	2380
	Brain Stem	12,-25,-11	R	15.38	0.000005	335
	Supplementary Motor Cortex	9,-4,52	R	16.00	0.000003	289
	Supplementary Motor Cortex	-6,5,58	L	16.92	0.000002	1242
	Precuneus	-6,-46,40	L	20.88	<0.000001	412
	Caudate	-12,5,7	R	14.21	0.000011	761
	Parahippocampal Gyrus, anterior division	-24,-13,-8	L	18.29	0.000001	1513
	Superior Temporal Gyrus, posterior division	-48,-19,1	L	87.38	<0.000001	38728
Interaction	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)

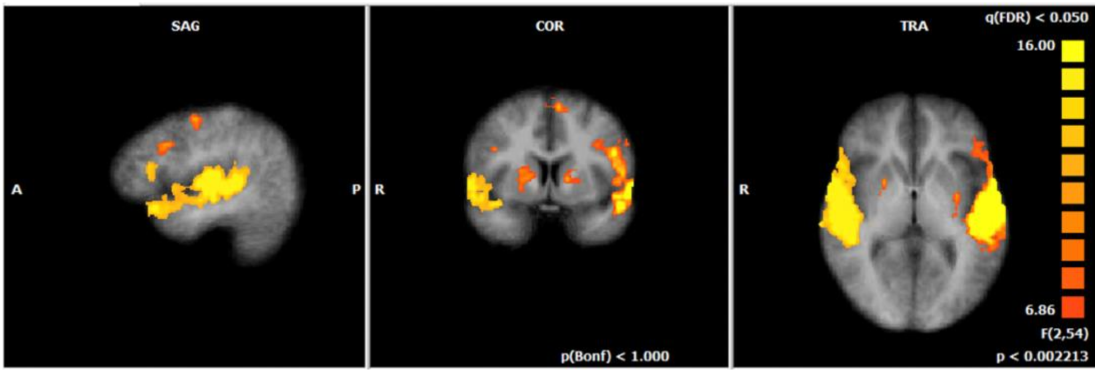


Figure2. 1 Brain regions across both groups showed a significant main effect of emotion during prosody processing

2.5.4.2.Individual condition

Since neither the main effects of group nor the interactions reached statistical significance, we conducted follow-up one-sample t-tests separately within and across groups to further explore condition-specific activations. These analyses focused on four conditions representing three emotional states—angry, happy, and neutral—and six pairwise contrasts: angry > happy, angry > neutral, happy > angry, happy > neutral, neutral > angry, and neutral > happy.

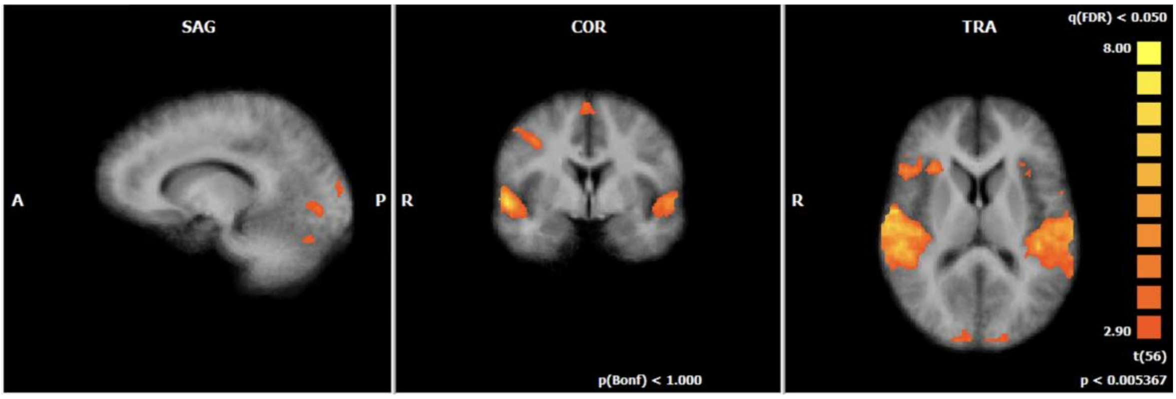
(1) Angry prosody

Findings for the angry prosody analysis are summarised for each group in Table 2.7. The left superior temporal gyrus (STG) and the right supplementary motor cortex (SMC) were the overlapping regions that showed increased activation in both the LAQ and HAQ groups. Significant activations in the LAQ group were found in the bilateral superior temporal gyrus (STG), bilateral precentral gyrus (PreCG), right inferior frontal gyrus (IFG), right insula, and left lingual gyrus. In the HAQ group, significant neural activities was evident in several regions including bilateral postcentral gyrus (PostCG), right planum polare, right globus pallidus, right supplementary motor cortex (SMC), left dorsal caudate, and left superior temporal gyrus (STG). No significant difference was observed between the groups regarding angry prosody (Table 2.7, Figure 2.2).

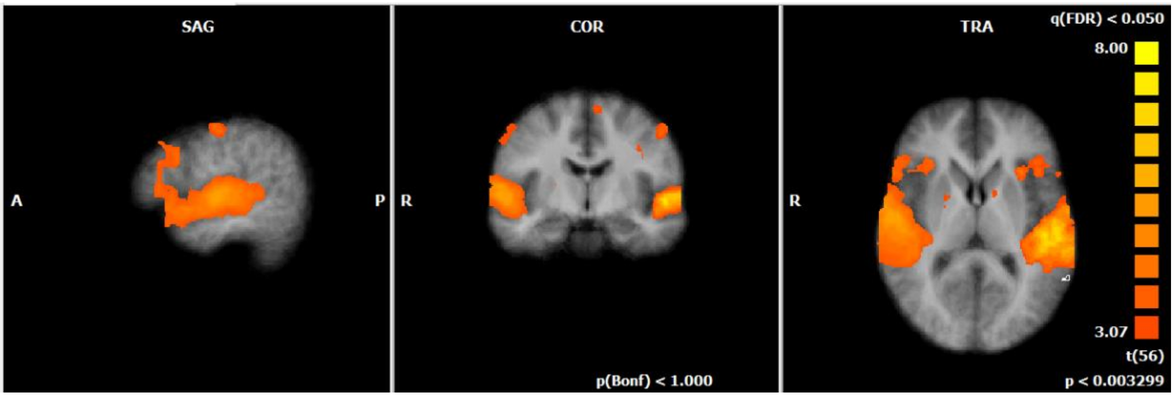
Table 2. 8 Significant brain activity in the LAQ Group, HAQ Group, and Group Comparisons during the processing of angry prosody

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Emotion: Angry						
LAQ group	Superior Temporal Gyrus, posterior division	60,-16,7	R	9.05	<0.000001	22718
	Inferior Frontal Gyrus, pars triangularis	48,23,19	R	5.88	<0.000001	4623
	Precentral Gyrus	36,-4,40	R	4.83	0.000011	1580
	Lingual Gyrus	-9,-82,-8	L	5.83	<0.000001	4097
	Supplementary Motor Cortex	3,-1,61	R	4.15	0.000114	513
	Cerebellum	-18,-67,-26	L	4.24	0.000085	532
	Insula	-33,20,7	L	3.86	0.000299	434
	Superior Temporal Gyrus, posterior division	-57,-25,4	L	9.11	<0.000001	18631
HAQ group	Planum Polare	51,-10,1	R	9.72	<0.000001	37403
	Postcentral Gyrus	48,-10,49	R	4.47	0.000038	994
	Globus pallidus	18,2,10	R	4.91	0.000008	532
	Supplementary Motor Cortex	6,8,55	R	5.69	<0.000001	2341
	Dorsal caudate	-6,2,13	L	3.94	0.000228	302
	Superior Temporal Gyrus, anterior division	-51,-13,1	L	9.27	<0.000001	32061
	Postcentral Gyrus	-48,-13,46	L	5.12	0.000004	1751
LAQ > HAQ	n. s					
HAQ > LAQ	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Significant brain regions activated in the LAQ group during the processing of angry prosody



(b) The significant brain activity in the HAQ group during the processing angry prosody

Figure 2.2 Significant brain activations were observed in both the (a)LAQ and (b)HAQ (below) groups during the processing of angry prosody, but notable differences between the groups were found, as presented in Table 2.7.

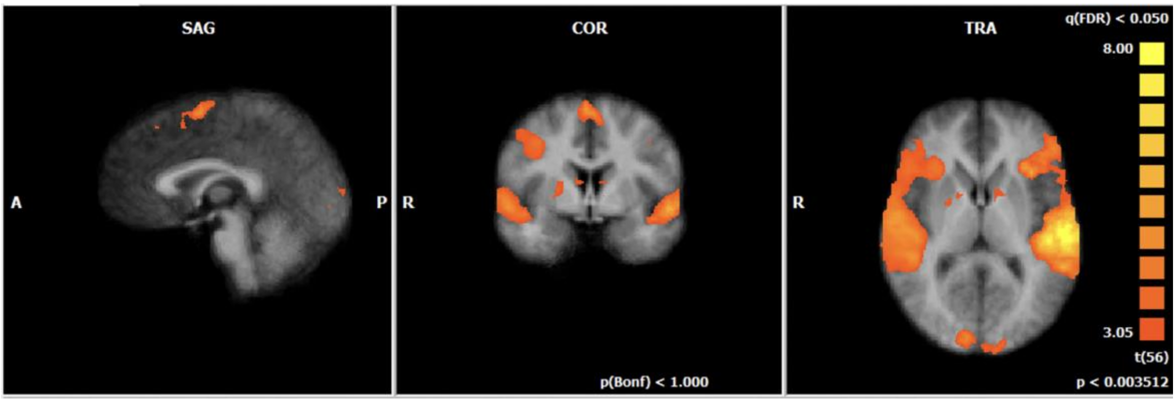
(2) Happy prosody

The results of happy prosody processing in each group and the group comparisons are presented in Table 2.8. Regions that commonly showed increased activity in both groups during happy prosody processing included the right occipital pole (OP), the right supplementary motor cortex (SMC), and the left caudate. In addition to these common regions, the LAQ group showed significant neural activity in the bilateral superior temporal gyrus (STG), right putamen, left cerebellum, left superior temporal gyrus (STG), and left precentral gyrus (PreCG). In HAQ group, besides the above common areas, the most active were the bilateral planum polare, bilateral thalamic areas, right globus pallidus, left occipital pole, and left cerebellar lobule IV. Group comparison did not show any significant differences in activation when happy prosody was processed (Table 2.8, Figure 2.3).

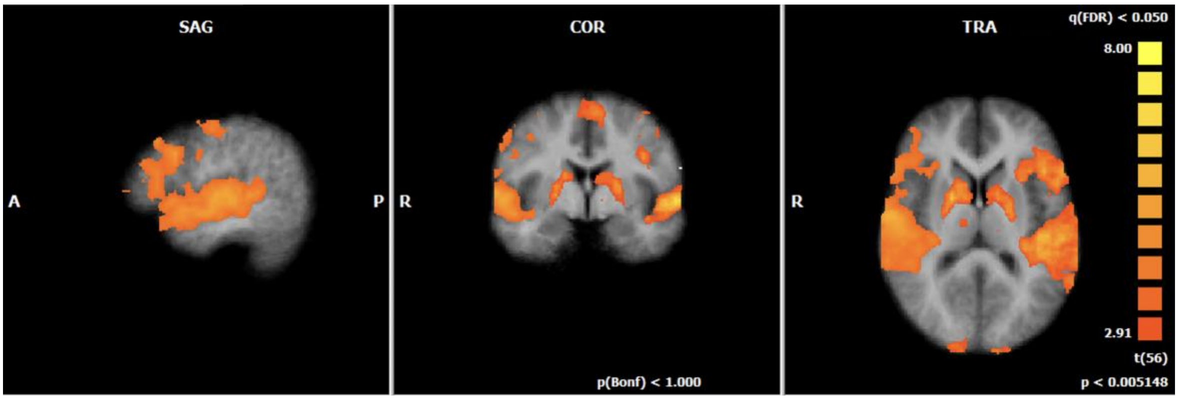
Table 2.8 Significant brain activations during the processing of happy prosody in the LAQ group, the HAQ group, and the group comparison results

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Emotion: Happy						
LAQ group	Superior Temporal Gyrus, posterior	54,-10,1	R	9.60	<0.000001	48360
	division	21,-4,10	R	4.20	0.000097	933
	Putamen	15,-94,13	R	5.67	0.000001	5045
	Occipital Pole	3,-1,61	R	5.69	<0.000001	3489
	Supplementary Motor Cortex	-6,2,13	L	4.65	0.000021	474
	Caudate	-18,-70,-27	L	4.73	0.000016	988
	Cerebellum	-57,-25,4	L	10.29	<0.000001	39225
	Superior Temporal Gyrus, posterior	-42,-4,43	L	4.89	0.000009	481
	division					
	Precentral Gyrus					
HAQ group	Planum Polare	51,-10,1	R	9.70	<0.000001	55128
	Globus pallidus	18,2,10	R	6.68	<0.000001	3876
	Occipital Pole	16,-97,13	R	4.53	0.000031	885
	Medial premotor thalamus	9,-13,4	R	4.58	0.000026	485
	Supplementary Motor Cortex	6,5,58	R	5.93	<0.000001	7746
	Dorsal caudate	-6,2,13	L	5.65	0.000001	3645
	lateral prefrontal thalamus	-9,-13,4	L	5.16	0.000003	704
	Occipital Pole	-12,-97,4	L	5.45	0.000001	1183
	Cerebellar lobule VI	-27,-55,-26	L	4.05	0.00016	996
	Planum Polare	-48,-13,1	L	9.70	<0.000001	53870
LAQ > HAQ	n. s					
HAQ > LAQ	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Brain areas activated during happy prosody processing observed in the LAQ group



(b) Brain regions activated during the processing of happy prosody in the HAQ group

Figure 2.3 Regions significantly activated in each group during the processing of happy prosody: (a) LAQ group, (b) HAQ group

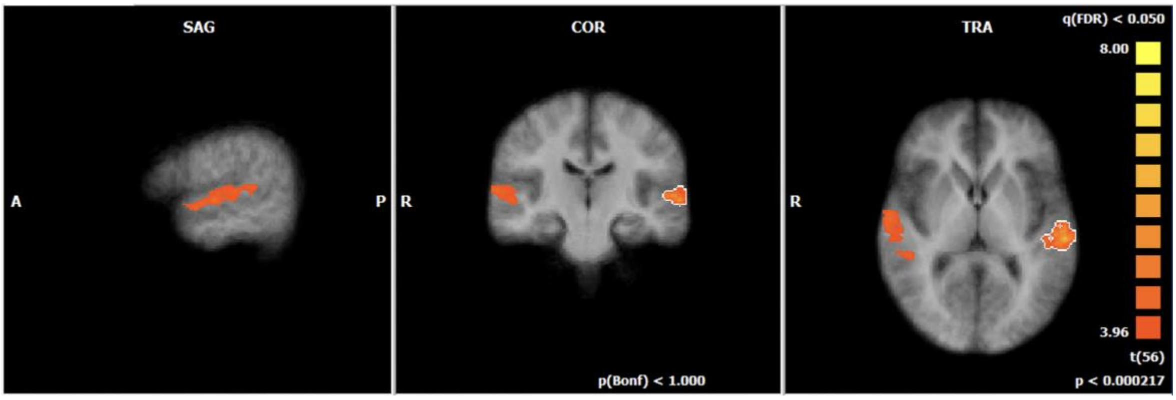
(3) Neutral prosody

The following Table 2.9 lists all significant activated brain regions in each group and the comparison between two groups, respectively. Significant activations in the LAQ group included the bilateral superior temporal gyrus (STG), while for HAQ group, greater activities were seen in the bilateral superior temporal gyrus (STG), left planum temporale (PT), right middle frontal gyrus (MFG), and left frontal operculum cortex in the HAQ group. Comparing the groups, no significant differences could be observed for neutral prosody processing (Table 2.9, Figure 2.4).

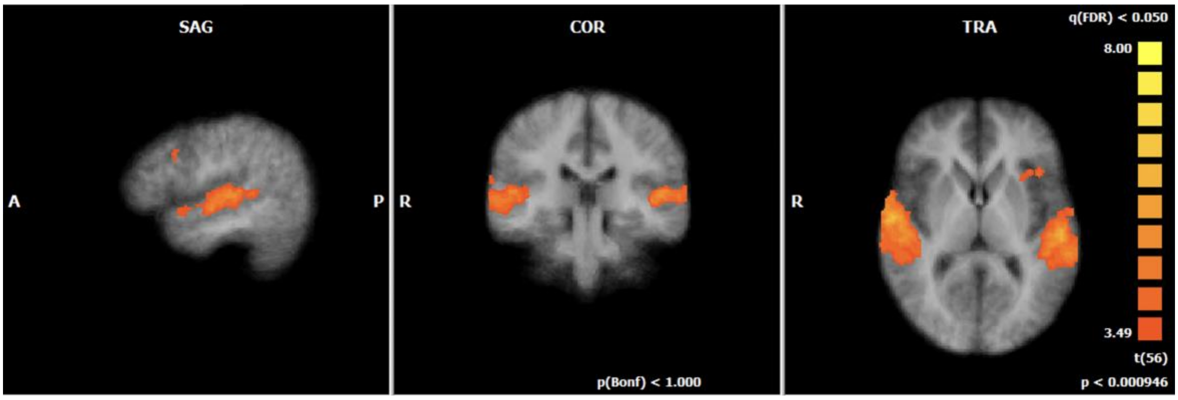
Table 2.9 Brain regions with significantly increased activation in the LAQ group, HAQ group, and group comparison during neutral prosody processing.

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Emotion: Neutral						
LAQ group	Superior Temporal Gyrus, posterior division	60,-16,7	R	6.26	<0.000001	3508
	Superior Temporal Gyrus, posterior division	-57,-25,4	L	6.72	<0.000001	2251
HAQ group	Superior Temporal Gyrus, anterior division	54,-10,1	R	7.31	<0.000001	13380
	Middle Frontal Gyrus	45,14,31	R	4.16	0.000109	391
	Frontal Operculum Cortex	-39,20,4	L	4.63	0.000022	397
	Planum Temporale	-54,-19,4	L	6.84	<0.000001	10913
LAQ > HAQ	n. s					
HAQ > LAQ	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Areas of increased activity during the processing of neutral prosody in the LAQ group



(b) Regions of the brain with increased activity observed in the HAQ group during neutral prosody processing

Figure 2.4 The figures above illustrate the brain regions that showed increased activity in each group during neutral prosody processing: (a) LAQ group, (b) HAQ group.

(4) Contrasts of emotional prosody

The prosody contrast analysis results of the two groups are summed up in Table 2.10 and Figure 2.5. In the *angry* > *neutral* contrast, neural activity for the LAQ group was observed in the right Heschl's gyrus (HG) and left superior temporal gyrus (STG), while the HAQ group showed activation bilaterally in the superior temporal gyrus (STG), right Heschl's gyrus (HG), and left temporal pole (TP).

In the *happy* > *neutral* contrast, both groups showed greater activation. There was increased activity in the LAQ group in areas such as the right Heschl's gyrus (HG), left precentral gyrus (PreCG), right amygdala, right putamen, and left superior temporal gyrus (STG). In the HAQ group, significant activations related to this contrast were observed in the right supramarginal gyrus (SMG), right planum polare, right inferior frontal gyrus (IFG), right insular cortex, left superior frontal gyrus (SFG), among others.

The *angry* > *happy* and *happy* > *angry* contrasts, did not yield any significant activations for either group, and group comparisons also did not reveal significant differences. Similarly, no significant activations were noticed within and between the *neutral* > *angry* and *neutral* > *happy* contrasts.

Table 2.10 Results of emotional prosody contrast analysis in the LAQ group, HAQ group, and group comparisons

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Contrast: Angry > Happy						
LAQ group	n.s					
HAQ group	n.s					
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Angry > Neutral						
LAQ group	Heschl's Gyrus	51,-10,4	R	8.00	<0.000001	7668
	Superior Temporal Gyrus, posterior division	-57,-25,4	L	8.81	<0.000001	4926
HAQ group	Superior Temporal Gyrus, anterior division	60,-4,7	R	6.93	<0.000001	1475
	Heschl's Gyrus	36,-22,7	R	5.60	0.0000010.	96
	Superior Temporal Gyrus, anterior division	-51,-16,1	L	6.77	<0.000001	1156
	Temporal Pole	-57,5,-2	L	4.91	0.000008	78
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Happy > Angry						
LAQ group	n.s					
HAQ group	n.s					
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					

Contrast: Happy > Neutral

LAQ group	Heschl's Gyrus	51,-16,7	R	8.66	<0.000001	22779
	Precentral Gyrus	48,-7,46	L	4.43	0.000045	297
	Amygdala	27,-10,-2	R	4.97	0.000007	1752
	Putamen	-30,-7,-2	L	5.08	0.000004	1662
	Superior Temporal Gyrus, posterior division	-48,-19,1	L	10.12	<0.000001	2939
HAQ group	Supramarginal Gyrus, posterior		R	5.31	0.000002	290
	division	60,-37,19	R	6.49	<0.00000	3820
	Planum Polare	57,2,4	R	4.85	1	149
	Inferior Frontal Gyrus, pars triangularis	54,29,16	R	5.11	0.00001	251
	Insular Cortex	33,-22,7	L	4.89	0.000004	133
	Superior Frontal Gyrus	-12,2,55	L	6.92	0.000009	3858
	Superior Temporal Gyrus, anterior	-51,-16,1	L	4.77	<0.00000	269
	division	-30,5,31	L	4.60	1	158
	Middle Frontal Gyrus	-48,-19,37	L	5.38	0.000014	382
	Postcentral Gyrus	-48,8,-11			0.000025	
	Temporal Pole				0.000002	

LAQ > HAQ n. s

HAQ > LAQ n. s

Contrast: Neutral > Angry

LAQ group n.s

HAQ group n.s

LAQ > HAQ n.s

HAQ > LAQ n.s

Contrast: Neutral > Happy

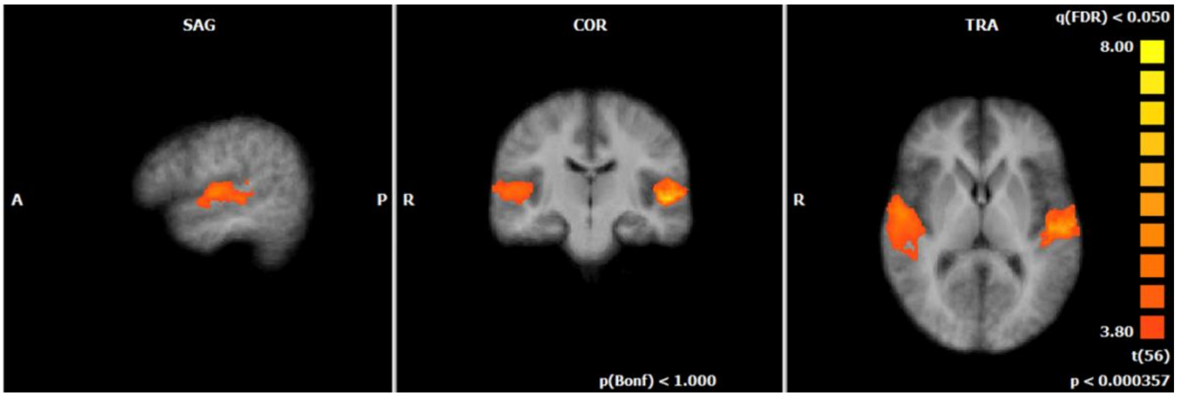
LAQ group n.s

HAQ group n.s

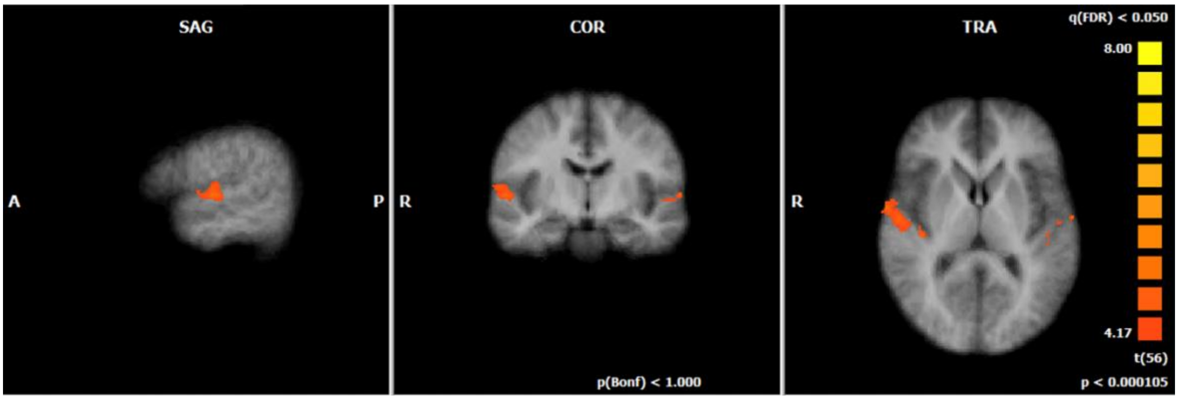
LAQ > HAQ n.s

HAQ > LAQ	n.s

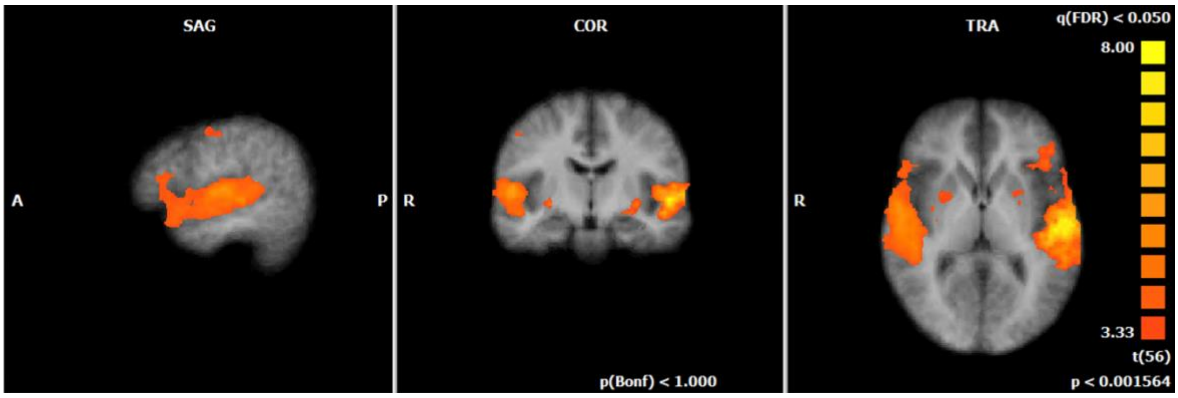
(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



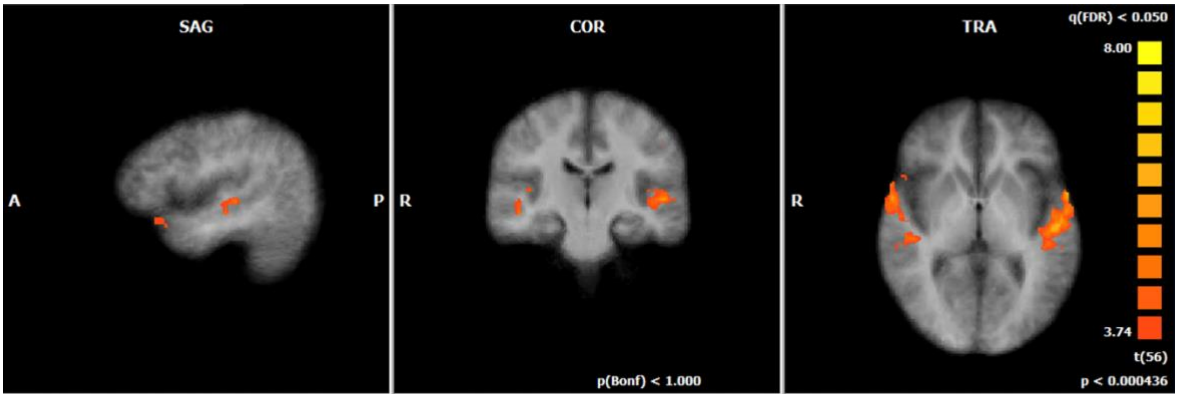
(a) In the *angry* > *neutral* contrast analysis, the LAQ group showed increased brain activity in two regions



(b) Significant brain regions were observed in the HAQ group in the analysis of the *angry* > *neutral* contrast



(c) In the *happy* > *neutral* contrast analysis, there was significantly increased brain activity in the LAQ group



(d) In the results of the h*appy* > *neutral* contrast, several clusters of significantly increased neural activity were observed in the HAQ group.

Figure 2.5 The figure demonstrates significant areas of increased activity in each group when analyzing emotional prosody contrasts.

2.5.4.3.Correlation analysis

Correlation analysis results in each group, correlations were computed between autistic traits and between verbal IQ and performance IQ and emotional prosody processing. No significant correlations were obtained within either group between verbal IQ, performance IQ, and emotional prosody processing; however, within both LAQ and HAQ groups, significant correlations were found between autistic traits and emotional prosody processing in several regions. As shown in Table 2.11, in the HAQ group, brain activation in the right central opercular cortex (COC) and left lingual gyrus (LG) to happy prosody in response was positively correlated with AQ, and negatively correlated with AQ in the right intra-calcarine cortex (see Figure 2.6).

These suggest that certain area of the brain is more likely to involve in processing happy prosody compared to other types of emotional prosody. By contrast, the the LAQ group revealed regions that were negatively correlated with AQ in neutral prosody, including the right middle frontal gyrus (MFG), left insula, right superior frontal gyrus (SFG), left superior frontal gyrus (SFG), and left angular gyrus (AG). Furthermore, left MFG was positively associated with AQ in the *happy* > *neutral* contrast.

Table 2.11 Results of correlation analysis between AQ scores and emotional prosody for each LAQ and HAQ group

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	r	p	Number of Voxels
Condition: happy						
LAQ group	n.s					
HAQ group	Central Opercular Cortex	41,-4,20	R	0.95	0.000001	190
	Intra-calcarine Cortex	18,-85,7	R	-0.92	0.000007	214
	Lingual Gyrus	-35,-52,-4	L	0.92	0.000011	189
condition: neutral						
LAQ group	Middle Frontal Gyrus	36,2,52	R	-0.85	0.000034	339
	Middle Frontal Gyrus	27,23,49	R	-0.90	0.000002	414
	Cingulate Gyrus, posterior division	-3,-46,22	L	-0.81	0.000122	298
	Superior Frontal Gyrus	0,17,55	R	-0.89	0.000003	255
	Superior Frontal Gyrus	-3,47,40	L	-0.95	<0.00000	413
	Superior Frontal Gyrus	-24,20,52	L	-0.90	1	295
	Angular Gyrus	-48,-52,31	L	-0.84	0.000003	261
					0.000049	
HAQ group	n.s					
Condition: happy > neutral						
LAQ group	Middle Frontal Gyrus	-28,30,48	L	0.87	0.000009	505
HAQ group	n.s					

(x, y, z are stereotaxic coordinates of peak-height voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at p<0.001 at the uncorrected level)

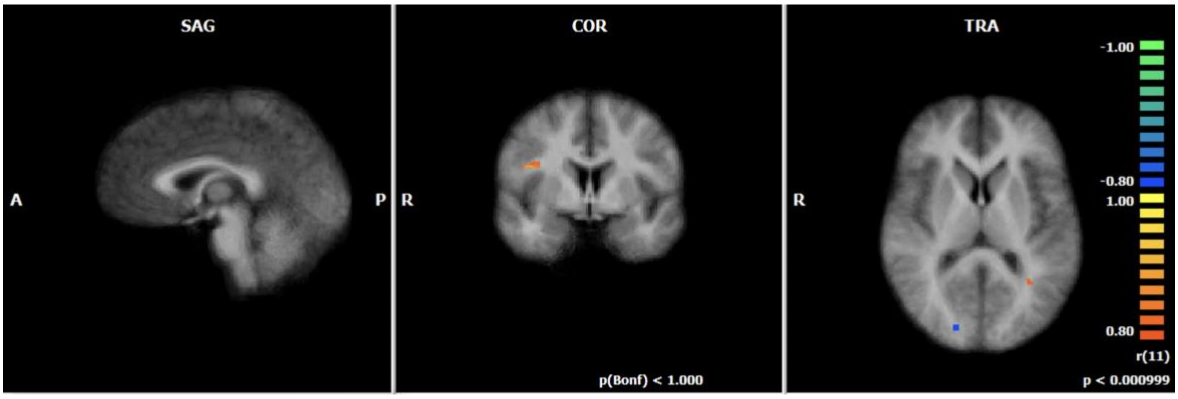


Figure 2.6 Brain regions significantly correlated with AQ in the HAQ group during happy prosody processing (orange: positive correlation, blue: negative correlation)

2.6. Summary and Discussion

The present study investigated differences in the perception of emotional prosody between high- and low-autistic traits using both behavioral and fMRI methodologies. While the study initially hypothesized robust group-level differences, the findings revealed only limited behavioral differences and no statistically significant differences in fMRI activation. These results suggest that while some trends may point toward differential sensitivity to prosodic cues, these differences were not consistently strong enough to support definitive conclusions about group-level deficits.

Behavioral findings revealed a trend toward lower accuracy in the recognition of emotionally prosodic speech in the HAQ group compared to the LAQ group, particularly in the happy and angry categories. Although these group effects were not statistically robust across all conditions, they align with prior studies that have reported challenges in affective prosody processing in individuals with higher autistic traits (Paul et al., 2005; Peppé et al., 2007). This may manifest as a monotone voice, irregular rhythm, or atypical pitch, all of which can impair both the expression and perception of emotion in communication. However, given the variability in performance and the absence of significant findings in many conditions, these results should be interpreted as suggestive rather than conclusive.

These findings tentatively support the hypothesis that individuals with higher autistic traits show diminished sensitivity to affective prosody, especially for positive and high-arousal emotional categories. However, the limited statistical significance of these effects calls for cautious interpretation. It is also important to consider that the AQ identifies autistic traits dimensionally, and not all individuals in the HAQ group had clinical diagnoses. The inclusion of primarily undiagnosed participants may have reduced the likelihood of observing categorical group effects. These findings extend previous work that suggested prosodic deficits among individuals with high-autistic traits reflect broader difficulties in multisensory integration and social communication (Stevenson et al., 2014; Massaro & Cohen, 1983).

Neuroimaging results did not reveal statistically significant differences between the HAQ and LAQ groups. Both groups exhibited similar patterns of activation in core auditory and prosodic processing areas, including the superior temporal gyrus (STG), a region consistently associated with the perception of vocal emotions (Fecteau et al., 2007; Kotz et al., 2011). While the overall activation patterns were comparable, descriptive trends suggested relatively lower activation in the amygdala and prefrontal cortex (e.g., precentral gyrus) in the HAQ group during emotional prosody processing. However, these differences did not reach statistical significance and should therefore be interpreted with caution.

The amygdala plays a critical role in detecting and responding to emotionally salient auditory stimuli, and reduced engagement in this region may suggest subtle differences in emotional salience attribution. Although these findings align with previous studies implicating amygdala hypoactivation in autism and related conditions (e.g., Baron-Cohen et al., 2000), the present data do not permit strong conclusions regarding neural impairment.

Similarly, weaker trends of activation were observed in the HAQ group within the anterior cingulate cortex (ACC) and insula—regions involved in empathy, interoception, and broader socioemotional processing. These patterns are consistent with existing literature on autism spectrum traits (Iarocci & McDonald, 2006), but again, they were not statistically significant in this sample.

Taken together, the integration of behavioral and fMRI results suggests that individuals with high levels of autistic traits may exhibit subtle differences in the processing of emotional prosody. While behavioral data indicated some difficulty in interpreting affective tone, especially in emotionally salient contexts, corresponding neural patterns—such as reduced activation in the amygdala, anterior cingulate cortex, and insula—did not reach statistical significance. Therefore, the current findings do not provide sufficient evidence to support claims of categorical neural impairment, and any interpretations should remain cautious.

Rather than recommending interventions based on non-significant group differences, these findings highlight the importance of refining experimental paradigms and improving measurement sensitivity. Future research may benefit from utilizing ecologically valid, multimodal emotional stimuli and recruiting larger, more diverse samples, including individuals with formal ASD diagnoses. Longitudinal studies could further elucidate whether prosody-related difficulties vary over time or with intervention. Additionally, exploring how cognitive factors such as attention, working memory, and executive function influence prosody perception could shed light on potential compensatory mechanisms or moderators of difficulty.

Despite the limitations, this study offers preliminary insights into how prosody perception may vary along the autistic trait continuum. Prosody plays a vital role in emotional expression and social interaction, and even subtle disruptions may contribute to broader communication challenges. By encouraging more precise and comprehensive investigation, these results underscore the value of understanding prosody perception as a continuous, neurocognitively grounded construct relevant across both subclinical and clinical populations.

3. Emotion Perception from Gesture in Adults with High-Autistic Traits

3.1 Abstract

The present research set out to investigate the behavioral and neurobiological differences uniquely characterizing high-AQ versus low-AQ individuals in perception related to emotional gestures. Indeed, emotional gestures are an important way of communicating during moments when speech may be ambiguous. Individuals with high levels of autistic traits have been found to have impaired interpretation of such nonverbal social cues. These findings were confirmed by accuracy and reaction time in a behavioral experiment that showed, overall, the LAQ group outperformed the HAQ group, at times on the identification of positive, happy emotions. The two groups did not differ significantly on neutral gestures-a result important for emotional salience in the process of recognition. Reaction times were slower for the HAQ group, indicating differences in cognitive processing. Neuroimaging scans showed that the LAQ group had higher activity related to such aspects of social cognition like the fusiform gyrus and superior temporal sulcus. On the other hand, peaks of activity occurring in the HAQ group were related to interoception and body movement awareness, such as parts of the insular cortex and precuneus, which suggests recruitment of other neural pathways as a means of compensating for difficulties. However, compensatory mechanisms do not fill the gap in efficiency between groups in terms of the processing of emotional material. This generally underlines various neural and behavioral profiles of emotional gesture perception in individuals with high autistic traits, targeting the need for appropriate interventions that would consider not just the social-cognitive deficit but also the compensatory strategies such persons would employ for the enhancement of social communication skills.

3.2 Introduction

Gesture perception follows the flow of human communication and, therefore, bridges the gap between what is represented non-verbally and what is uttered to show emotions, intentions, and social cues. Since non-verbal displays of gestures help in situations where the verbal interaction is unclear or absent, it helps in steering through the complexities of social interactions. Gestures enhance the interpretation when the verbal expressions of emotions are sparse or ambiguous. Generally, in normally developing individuals, the recognition of gestures intuitively depends on integrating global visual information and biological motion for making meaningful interpretations of body movements. However, for individuals with Autism Spectrum Disorder (ASD) or high-autistic traits (HAQ), interpreting these non-verbal cues poses a significant challenge (Dakin & Frith, 2005; Koldewyn et al., 2013). The difficulty appears to be most pronounced in the perception of emotional gestures, where disruptions in both neural structure and function—particularly within regions associated with social cognition—contribute to impaired emotional recognition (Pelphrey, Morris, & McCarthy, 2005; De Gelder, 2006).

Understanding subtle emotional gestures is central to social interaction, as these cues often clarify or complement spoken language. In typically developing individuals, emotional gesture perception is supported by both visual and motor systems, which enable the recognition of body movements and an embodied understanding of others' emotional states. This process is facilitated by the mirror neuron system, which allows the observer to simulate the observed actions internally, resulting in intuitive emotion recognition (Gallese & Goldman, 1998; Iacoboni & Dapretto, 2006; Piwek et al., 2015). These mechanisms are further enhanced through multisensory integration, where visual, auditory, and proprioceptive inputs are combined to ground external signals in internal affective experience (Keysers & Gazzola, 2009). The interaction between motor and mentalizing systems contributes to the efficient interpretation of emotional gestures in dynamic social contexts (Van Overwalle & Baetens, 2009).

However, individuals with Autism Spectrum Disorder (ASD) or high-autistic traits (HAQ) often struggle with this process. Gesture perception in ASD is frequently impaired, particularly when emotional content is involved (Dakin & Frith, 2005; Koldewyn et al., 2013). This difficulty has been attributed to disruptions in both neural structure and function, particularly in regions responsible for social cognition (Pelphrey, Morris, & McCarthy, 2005; De Gelder, 2006). A key element of emotional gesture perception—biological motion—is also compromised. Biological motion, such as walking or gesturing, plays a critical role in social perception by conveying meaningful affective and intentional information (Johansson, 1973). Yet, individuals with high-autistic traits demonstrate reduced sensitivity to such motion, leading to challenges in interpreting social-emotional cues (Blake et al., 2003; Kaiser et al., 2010).

Point-light display studies, which isolate joint movement cues, have shown that individuals with ASD exhibit slower and less accurate emotional recognition, further implicating atypical neural responses in motion-sensitive brain regions (Nackaerts et al., 2012; Todorova et al., 2019). These difficulties are associated with atypical functioning in a social-cognitive neural network that includes the superior temporal gyrus (STG), fusiform gyrus (FG), and amygdala (Herrington et al., 2007; Freitag et al., 2008; Just et al., 2007; Pelphrey et al., 2005). Neuroimaging findings show that individuals with ASD and high-autistic traits exhibit reduced superior temporal gyrus (STG) and middle temporal complex (MT+) activation during biological motion tasks (Herrington et al., 2007) and altered activation patterns across fusiform gyrus (FG), superior temporal gyrus (STG), amygdala, and prefrontal cortex (PFC) during emotion perception (Liu et al., 2025; Saygin et al., 2010; Eigsti et al., 2012).

Despite increasing insights from previous studies, significant gaps remain in our understanding of how individuals with high-autistic traits perceive emotional gestures. Much of the literature has focused on isolated sensory modalities—such as facial expressions or prosody—rather than on the integration of emotional information across multiple channels. Moreover, many studies have relied on static or unimodal stimuli, which do not capture the multisensory and dynamic nature of real-life emotional communication (Edey et al., 2017). This limits the ecological validity of previous findings and hinders a comprehensive understanding of how emotional gestures are processed in natural contexts.

In light of these challenges, individuals with ASD or high-autistic traits may engage compensatory neural mechanisms to support emotional gesture recognition. Studies have reported increased activation in regions associated with self-referential processing and bodily awareness, such as the insular cortex and precuneus, possibly reflecting a reliance on internally generated cues when external signals are ambiguous or difficult to interpret (Uddin & Menon, 2009; Gepner & Féron, 2009; Odriozola et al., 2016; Rudie et al., 2013; Libero, Stevens, & Kana, 2014). In parallel, increased activation in motor-related regions such as the dorsal parietal cortex has also been observed, suggesting an embodied simulation strategy that may partially compensate for reduced activation in typical social-perceptual areas (Brown et al., 2019; Van der Cruijsen et al., 2019). However, these alternative neural routes are often insufficient to fully restore performance, and individuals with ASD typically continue to show lower accuracy in emotional gesture recognition, particularly in tasks involving dynamic expressions (Masoomi et al., 2025; Mazzoni et al., 2020). fMRI studies reinforce this, as shown by Pelphrey et al. (2005), who identified diminished superior temproal gyrus (STG) and amygdala responses to emotional gestures.

These findings imply that individuals with high-autistic traits may show atypical neural activation during emotional gesture processing in brain regions associated with social cognition, including the superior temporal gyrus (STG), fusiform gyrus (FG), and amygdala. Understanding these atypical and compensatory patterns is essential not only for theoretical insight but also for practical application. Several studies suggest that targeted interventions focusing on both sensory and emotional processing can lead to improvements in social-communication outcomes (Bhat et al., 2011; Pfeiffer et al., 2011). Mapping these neural mechanisms may thus provide a foundation for evidence-based interventions tailored to the specific needs of individuals with high-autistic traits.

To address these gaps, the present study employs both behavioral and fMRI methods using ecologically valid, multimodal emotional stimuli. Specifically, it examines how individuals with high and low autistic traits perceive emotional information conveyed through prosody, gesture, and their integration. This approach aims to offer a more comprehensive understanding of the neural and behavioral profiles associated with emotion processing in this population and to clarify how compensation or divergence in brain activity may shape perceptual outcomes.

This chapter aims to further investigate these mechanisms by integrating behavioral and neuroimaging data to provide a detailed account of emotional gesture perception in adults with high-autistic traits. Building on previous findings, the research hypothesizes that participants in the HAQ group will demonstrate lower accuracy and slower response times in identifying emotions from gestures compared to those in the LAQ group.

3.3 Emotional Recognition in Gesture: A Behavioural Study

3.3.1 Research questions

The present study aims to investigate the understanding of emotional gestures in communication and the differences in gesture processing between the LAQ and HAQ groups. This gesture experiment tested the following research questions:

1. High-autistic traits will show lower correct response to identify the emotion from gesture when compared to typically developed individuals, and
2. Individuals with high autistic traits will have slower reaction times when perceiving emotion from gestures.

3.3.2 Experimental methods

3.3.2.1 Participants

Participants were recruited for the behavioral study according to the following eligibility criteria described below (Table 3.1). All participants were native English speaking and between the ages of 18 and 40 years of age. Edinburg Handedness Inventory measured handedness (Oldfield, 1971). The participants were divided into two groups based on their scores on the AQ: low autistic traits (LAQ) and high autistic traits (HAQ). The HAQ group included only those participants whose AQ score was above 29, while participants who scored less than 18 were allocated in the LAQ group. Accordingly, 40 participants (10 males, 30 females) were assigned to the LAQ group and 28 (9 males, 19 females) to the HAQ group. As well as the AQ, all participants completed the Wechsler Abbreviated Scale of Intelligence (WASI), a standardized measure of cognitive ability.

Table 3.1. Demographic data and group matching for low and high AQ groups

	Low AQ group	High AQ group	Group comparison
Cut-off score (AQ)	Below 18	Above 29	-
Number	40 (M:10, F: 30)	28 (M:9, F: 19)	p = 0.588 (fisher's exact test)
Handedness	40 R	28 R	-

Age	22.3±5.3	24.2 ±7.0	p = 0.858 (Mann-Whitney U)
AQ	12.4±4.7	34.04±7.0	p <.001*** (Mann-Whitney U)
VIQ	119.13±10.7	119.32±11.8	p = 0.879 (t-test)
PIQ	115.7±11.4	117.12±9.0	p = 0.617 (t-test)
FSIQ	119.55±10.1	120.79±9.4	p = 0.586 (t-test)

(*p<.05, **p<.01, ***p<.001)

3.3.2.2 Stimuli

The stimuli set used in this study was originally selected and prepared by Piwek, Pollick, and Petrini (2015). Their study involved recordings from 20 native UK male actors, aged 17 to 43, who spoke English. The actors were instructed to speak and act naturally according to specific scenarios designed to express different emotions. The dataset included 242 displays featuring 9 actor pairs, 2 emotions (angry and happy), 3 intensity levels (low, medium, high), 2 dialogue versions (inquiry and deliberation), and 2 repetitions, along with 26 neutral conditions ($9 \times 2 \times 3 \times 2 \times 2 + 26 = 242$). Motion capture was conducted at the University of Glasgow’s School of Psychology using a 12-camera Vicon MXF40 system, which recorded 3D motion signals at 120 frames per second (fps).

During capture sessions, actors were positioned facing each other at a distance of approximately 1.3 meters, which varied between 1 and 1.6 meters depending on their movements during interactions. Three types of emotional interactions—angry, happy, and neutral—were captured, with angry and happy interactions recorded at three different intensity levels. Actors used consistent dialogues for each interaction type, with dialogues involving either inquiry (e.g., "Where have you been?" "I have just met with John") or deliberation (e.g., "I want to meet with John." "I will speak to him tomorrow").

All displays, including truncated start and end points, were exported to AVI format in three versions: auditory-only (dialogues), visual-only (point-light displays), and audio-visual (dialogues combined with point-light displays). The final stimulus set comprised 242 unique displays across these versions, featuring variations in modality format: visual point-light displays, auditory dialogues, and combined audio-visual displays. Post-processing included amplification and noise reduction of audio dialogues, and each video was adjusted to ensure consistent quality. For the present study, 72 visual-only dialogues, each 3 senconds long with medium intensity, were selected from this set were used.

3.3.2.3 Procedure

The experiment was conducted using an Apple Macintosh MacPro 3.1 desktop computer running OS 10.5, equipped with an NVIDIA GeForce 8800GT video card. Visual stimuli were displayed on a 21-inch ViewSonic Graphics Series G220f CRT monitor with a resolution of 1024 x 768 pixels and a refresh rate of 60Hz. Auditory stimuli were delivered through high-quality Beyerdynamic DT770 headphones. The stimuli presentation was controlled using MATLAB 2007b (MATHWORKS Inc., Natick, MA) and Psychophysics Toolbox (PTB3) extensions (Brainard, 1989; Pelli, 1997).

During the experiment, participants wore headphones and responded by pressing a number key on the keyboard. At the start of the session, participants received instructions regarding the task and were allowed to adjust their sound levels and seating position. Participants were presented with visual-only stimuli in the form of point-light displays, which depicted the body movements of actors expressing different emotions. The stimuli did not include any auditory information, focusing solely on the visual aspects of gesture perception.

Participants were asked to observe the point-light displays and identify the emotion conveyed by the movements. They were instructed to respond as quickly as possible by selecting the appropriate number on the keyboard corresponding to their emotion choice. This setup allowed the study to isolate the impact of visual gestures on emotional recognition without the influence of auditory cues. The experimental session lasted approximately 10 minutes. Throughout the session, the accuracy of responses and reaction times were recorded as the emotional gestures were displayed. The sequence of stimuli presentation was pseudo-randomized for each participant, and all participants were required to identify the speakers' emotions (Angry/Happy/Neutral) during the conversation between the two individuals.

3.3.2.4 Data analysis

All statistical analyses were carried out using R (R Development Core Team, 2008). Group differences in demographic variables and cognitive measures (age, gender, AQ, VIQ, PIQ, FSIQ) between the LAQ and HAQ groups were examined. Initially, the Shapiro-Wilk test was applied to assess the normality of continuous variables (age, AQ, VIQ, PIQ, and FSIQ). For variables that exhibited a normal distribution ($p > 0.05$), independent t-tests were performed to compare the two groups. In contrast, for non-normally distributed variables ($p < 0.05$), the Mann-Whitney U test was used. Fisher's exact test was utilized to compare the categorical variable gender between the groups.

The primary objective was to evaluate differences in correct response rates and reaction times between the two groups in relation to emotional prosody. Descriptive statistics, including the mean, standard deviation (SD), and standard error (SE), were calculated for each prosody-group combination. A Mixed-Effects Beta Regression Model was applied to assess the impact of prosody and group on correct response rates across all tasks. The glmmTMB package in R was used for this purpose. Since correct response rates were expressed as proportions ranging between 0 and 1, beta regression was considered appropriate for modeling the data. The model included prosody and group as fixed effects, along with their interaction, while participant ID was included as a random effect to account for within-subject variability.

The model was defined as: *Correct Response Rate ~ Prosody × Group + (1 | Participant ID)*

To handle boundary issues in the beta regression model, response rates of 0 or 1 were adjusted by adding a small epsilon value. The data were then transformed into long format, treating prosody and group as categorical predictors. A logit link function was used in the model, and the summary output revealed significant effects of prosody, group, and their interaction on correct response rates. Post-hoc pairwise comparisons were conducted using

the estimated marginal means via the emmeans package to further explore significant differences between prosody types and groups.
Reaction time differences between the LAQ and HAQ groups were assessed using the Wilcoxon rank-sum test (Mann-Whitney U test), a non-parametric test chosen due to the potential non-normality of reaction time distributions.

To investigate the relationship between autistic traits and cognitive performance on emotional prosody perception. These correlations examined the relationships between correct response rates for emotion perception, Autism Spectrum Quotient (AQ), reaction times, and intelligence measures, including Verbal IQ (VIQ), Performance IQ (PIQ), and Full-Scale IQ (FSIQ). Data from both the LAQ and HAQ groups were combined for these analyses. A significance level of $p = 0.005$ was applied to account for multiple comparisons and reduce the likelihood of Type I error.

3.3.3 Results

3.3.3.1 Correct response rate and reaction time

In the gesture recognition experiment, descriptive statistics, including the mean, standard deviation (SD), and standard error (SE), were calculated for the correct response rates across angry, happy, and neutral emotional gestures in both the HAQ and LAQ groups.

As shown in Table 3.2, the LAQ group consistently demonstrated higher correct response rates across all emotion types compared to the HAQ group, except for neutral gestures, where both groups performed similarly (mean = 0.921 for LAQ vs. 0.935 for HAQ). Neutral gestures yielded the highest correct response rates for both groups, with mean values exceeding 0.90, indicating that these gestures were the easiest to recognize. Angry gestures, however, produced the lowest correct response rates for both groups (mean = 0.429 for LAQ vs. 0.417 for HAQ), suggesting that these gestures were more challenging to interpret. In the happy condition, the LAQ group performed significantly better than the HAQ group (mean = 0.669 for LAQ vs. 0.472 for HAQ), reflecting a clear advantage in recognizing happy gestures (see Table 3.2).

The intercept, representing the baseline performance of the HAQ group in recognizing angry gestures, was statistically significant ($p = 0.0103$), indicating that the HAQ group had a lower likelihood of correct responses when recognizing angry gestures. When comparing emotion types, neutral gestures significantly increased the likelihood of correct responses in the HAQ group compared to angry gestures ($p < 0.001$), suggesting that neutral gestures were easier to interpret. However, there was no significant difference between angry and happy gestures in the HAQ group ($p = 0.2424$), meaning participants responded similarly to both emotion types.

Regarding group differences, no significant effect was observed between the HAQ and LAQ groups for angry gestures ($p = 0.669$). However, a significant interaction was found for happy gestures, with the LAQ group outperforming the HAQ group ($p = 0.0045$) (see Table 3.3). Post-hoc analysis revealed significant differences between angry and neutral gestures in both groups, with neutral gestures consistently producing higher correct response rates. Additionally, the LAQ group significantly outperformed the HAQ group in recognizing happy gestures ($p = 0.0001$). No significant group differences were observed for neutral gestures ($p = 0.766$).

In terms of reaction times, the HAQ group (median = 4.33 s, IQR = 0.736 s) had slightly longer reaction times compared to the LAQ group (median = 4.15 s, IQR = 0.428 s), but this difference was not statistically significant ($p = 0.546$), indicating that both groups responded at similar speeds when recognizing emotional gestures.

These findings suggest that the LAQ group outperformed the HAQ group in recognizing happy gestures, whereas both groups performed equally well in identifying neutral gestures. Angry gestures presented the greatest challenge for both groups, as reflected in the overall lower correct response rates.

Table 3.2 Means, standard deviations (SD), and standard errors (SE) in recognizing emotional gestures for LAQ and HAQ group

Task	Emotion	Group	Mean	SD	SE
Gesture recognition	Angry	LAQ	0.429	0.132	0.021
		HAQ	0.417	0.167	0.032
	Happy	LAQ	0.669*	0.116	0.018
		HAQ	0.472*	0.170	0.032
	Neutral	LAQ	0.921	0.110	0.017
		HAQ	0.935	0.087	0.016

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

Table 3.3 Summary of mixed-effects beta regression model: Fixed effects estimates, z values, and p-values for gesture recognition task

Task	Parameter	z value	Pr(>|z|)
Gesture recognition	Intercept (Angry HAQ)	-2.565	0.010**
	Prosody (Angry vs. Happy)	1.169	0.242
	Prosody (Angry vs. Neutral)	16.337	p<0.001***
	Group (LAQ vs. HAQ)	0.427	0.669
	Interaction (Happy x LAQ)	2.845	0.005**
	Interaction (Neutral x LAQ)	-1.336	0.181

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

3.3.3.2 Correlation analysis

A correlation analysis was conducted to explore the relationships between correct response rates for different emotions (angry, happy, and neutral), reaction time, demographic variables (age, gender), and cognitive measures (AQ, VIQ, PIQ, and FSIQ). The normality of the data was evaluated using the Shapiro-Wilk test, with Pearson's correlation applied to normally distributed variables and Spearman's correlation applied to non-normally distributed variables.

The analysis revealed significant positive correlations among the intelligence measures. Specifically, VIQ and FSIQ were strongly correlated (r = 0.817, $p < 0.001$), as were PIQ and FSIQ (r = 0.799, $p < 0.001$), indicating a strong link between verbal and performance intelligence and overall intelligence. However, no correlation coefficient greater than 0.4 was observed for the correct response rates (angry, happy, neutral) or reaction time, cognitive or demographic variables. Reaction time did not show any significant relationships with age or AQ scores, suggesting that these factors do not significantly influence performance in this task.

3.4 Emotional Prosody Recognition: An fMRI Study

3.4.1 Research questions

The purpose of this experiment was to compare brain activation in response to angry, happy, and neutral gestures during visual-only conversations, including social context, between adults with high and low autistic traits, matched by age and IQ.

This experiment explored the following research questions:

1. How does brain activation differ between individuals with high-autistic traits and low-autistic traits when they perceive emotions from conversational gestures within a social context?
2. How does neural activity differ between adults with high-autistic traits and those with low-autistic traits in response to each distinct emotional gesture when different emotional gestures are presented?

3.4.2 Experimental Methods

3.4.2.1 Participants

Thirty individuals who had previously participated in a behavioral study were recruited for this fMRI study. However, data from one participant in the high-autistic traits group (HAQ) were excluded due to data damage, leaving a total of 29 participants whose data were analyzed. The demographics of these 29 participants are presented in Table 3.4.

All participants were native English speakers between the ages of 18 and 40. They were divided into two groups based on their scores from the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001): the low-autistic traits group (TD) and the high-autistic traits group (HAQ). A score above 29 on the AQ placed participants in the high-autistic traits group, while a score below 18 placed them in the low-autistic traits group. Hand dominance for all participants was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Based on this, 16 individuals (5 males, 11 females) were categorized into the low-autistic traits group, and 13 individuals (5 males, 8 females) were categorized into the high-autistic traits group. Additionally, all participants completed the Wechsler Abbreviated Scale of Intelligence (WASI) to assess cognitive ability.

Table 3.4 Demographic information of participants in the low and high AQ groups

	Low AQ group	**High AQ group**	**Group comparison**
Cut-off score (AQ)	Below 18	Above 29	-
Number	16 (M:5, F: 11)	13(M:5, F: 8)	p=0.714 (Fisher's exact test)
Age	23.3±5.6	24.2 ±7.3	p =0.706 (Mann-Whitney U)
Handedness	16 R	13 R	-
AQ	13.8±4.5	33.7±5.1	$p < 0.001^{***}$ (Mann-Whitney U)
VIQ	113.81±8.8	121.69±9.4	$p = 0.028^{**}$ (t-test)
PIQ	116.81±14.1	119.08±8.5	p =0.615 (t-test)
FSIQ	117.06±10.5	122.85±7.1	p =0.102 (t-test)

(*p<.05, **p<.01, ***p<.001)

3.4.2.2 Stimuli

The stimuli used in this experiment originally were selected and prepared by Piwek, Pollick, and Petrini (2015). These authors recorded 20 native UK male actors who spoke English, aged between 17 to 43. The actors were also instructed to speak and act naturally regarding what a particular per framework scenario would call for in the expression of emotions. The dataset contained 242 displays providing 9 actor pairs with 2 emotions-happy and angry, 3 levels of intensity-low, medium, high, 2 versions of dialogue-inquiry and deliberation, and 2 repetitions added to 26 neutral conditions: $9 \times 2 \times 3 \times 2 \times 2 + 26 = 242$. The purpose of motion capture was served by recording 3D motion signals at 120 fps using a 12-camera Vicon MXF40 system at the School of Psychology, University of Glasgow.

During capture sessions, actors faced one another, separated by about 1.3 meters. However, this distance varied between 1 and 1.6 meters depending on the movements of the interacting actors. Three kinds of emotional interactions were captured: angry, happy, and neutral. Angry and happy interactions were recorded at three different intensity levels. Actors uttered consistent dialogues across every interaction type; dialogues involved either inquiry, such as "Where have you been?" "I have just met with John", or deliberation, such as "I want to meet with John." "I will speak to him tomorrow".

Displays with all truncated points of start and end were exported to AVI format in three versions: audio-only - dialogues, visual only - point-light displays, and audio-visual - dialogues combined with point-light displays. The final stimulus set consisted of 242 unique displays across the modality format variations, including visual point-light displays, auditory dialogues, and a combined presentation of audio-visual. The audio dialogues were post-processed, amplified, and noise was reduced, and equalization of the videos was carried out so that the quality remains constant. In the present study, 72 visual-only dialogues from this set were used, each 3 seconds long with medium intensity.

3.4.2.3 Design

In assessing differences in brain activation between the low- and high-autistic trait groups while watching to emotional gestures from two persons' conversation, two runs of block-design functional magnetic resonance imaging experiments were carried out. The pseudo-randomized sequence was utilized for the blocks in both runs. Each run included 60 stimuli (3 emotions × 10 conversations × 2 repetitions), and each display was no longer than 3 seconds. The total length of each run was 410 seconds, divided into 12 blocks. A 10-second black screen at the beginning of each run preceded the video trials, and a 20-second black screen appeared at the end. Each block was 16 s long and consisted of 5 stimuli depicting the same emotion with the same modality. The type of emotion appearing in each block changed across blocks.

3.4.2.4 Data acquisition

Participants were invited to the Centre for Cognitive Neuroimaging at the University of Glasgow. MRI data were obtained with a 3T Tim Trio MRI scanner (Siemens, Germany) fitted with a 32-channel head coil. A high-resolution T1-weighted anatomical whole-brain scan lasting 5 minutes was obtained using a 3D magnetization-prepared rapid acquisition gradient echo (MP-RAGE) T1-weighted sequence. This sequence included 192 contiguous 1 mm axial slices with dimensions of 256 mm × 256 mm (TR = 1900 ms, TE = 2.52 ms, inversion time = 900 ms, FA = 9°). Functional T2-weighted images were collected using an echo-planar, T*-weighted gradient echo pulse sequence (TR = 2000 ms, TE = 62 ms, FA = 9°). A total of 32 axial slices (3 mm thick, 0.3 mm gap) were acquired in an ascending interleaved sequence to ensure whole-brain coverage. Functional data were acquired in two runs, each of 205 volumes, taking overall 6 minutes and 50 seconds. Both runs had the first two volumes in each run as dummy volumes and thus excluded from analysis. No stimuli were presented during the dummy volumes; fMRI data collection was not started.

3.4.2.5 Procedure

All participants provided full informed consent to the experiment, had the opportunity to ask any questions, and signed the consent form accordingly. Participants then completed a scanner safety check to ensure they were safe to be scanned. A brief explanation of the experimental procedure was given. Throughout the experiment, the participants watching to conversations in pairs, and indicated the speaker's emotion from the gestures. Given that each run consisted of three different emotions (Angry, Happy, Neutral) with a black background, participants were required to include their judgment regarding the speaker's emotion in conversation. Using the forced choice task format, for an answer participants had to press one of three buttons on the response box. The stimuli were delivered by using Presentation 14.9 software by NeuroBehavioural Systems [NBS].

3.4.3 Analysis

3.4.3.1 fMRI pre-processing

Pre-processing and analysis of all fMRI data were performed using BrainVoyager QX Version 2.8. To allow for signal stabilization, the first two functional volumes were discarded from the remaining analysis. The functional data of each participant underwent a standard pre-processing pipeline. Slice timing correction was performed by sinc interpolation. Three-dimensional motion correction was done by aligning all volumes to the first volume, allowing for small head movements using rigid-body transformations. For each subject, in the estimated translation and rotation parameters, less than 3 mm of translation and less than 3 degrees of rotation were allowed. Then functional MR images were subjected to high-pass temporal filtering with a cut-off of three cycles and smoothed further spatially using a Gaussian filter of FWHM 6 mm. Data were then aligned to the AC–PC plane and transformed into Talairach standard space (Talairach and Tournoux, 1988). Functional time-series data of each participant were co-registered with the corresponding anatomical data to produce normalized 4D volume time-course (VTC) data.

3.4.3.2 Data analysis

A second-level, multi-subject, random effects (RFX) GLM was used to analyze the identification of emotions in gestures. Results were then submitted to a 2 × 3 repeated-measures ANOVA with group serving as the between-subjects factor (LAQ, HAQ) and Emotion serving as the within-subjects factor (Angry, Happy, Neutral).

One-sample t-tests were calculated for each condition separately (angry, happy, neutral) and for each contrast according to condition (angry > neutral, happy > neutral, angry > happy, happy > angry, neutral > angry, and neutral > happy). After that, univariate ANOVA was performed for each contrast to determine the effects of group * emotion. Following this, to control for multiple comparisons, an FDR correction was made at $q = 0.05$ to control the false discovery rate. Cluster thresholding was performed subsequently, removing small clusters based on minimum cluster size ($p<0.05$) threshold as determined from 1000 iterations of Monte Carlo simulations. All the clusters reported in this study survived whole-brain multiple-comparison correction. The "Talairach Client" software was used according to the description of Lancaster et al. (2000) to trace the anatomical regions of interest by referencing the Talairach coordinates of the activated voxels that had been obtained, thus allowing for functional brain mapping. Analyses of correlations were carried out separately for the LAQ and HAQ groups using the clinical variable AQ and IQ subdomains, Verbal IQ and Performance IQ. Significant and correlated areas in the brains were identified and reported using a lenient threshold of uncorrected p = 0.001 in both groups.

3.4.4 Results

3.4.4.1 Main effect of group, emotion, and interaction between the factors

A 2 (Group: LAQ, HAQ) × 3 (Emotion: Angry, Happy, Neutral) repeated-measures 2×3 repeated-measures ANOVA (Group: LAQ, HAQ) × (Emotion: Angry, Happy, Neutral) was performed to probe the differential brain activations both within and between groups as a function of emotions. The main effect of emotion reached significance, whereas the group effect or interaction between group and emotion did not reach significance. Different brain regions significantly activated with the presentation of various emotions included right fusiform gyrus (FG), right middle temporal gyrus (MTG), right insular cortex, right paracingulate gyrus, and left lateral occipital cortex. These regions showed increased activation during the emotional gesture tasks, highlighting the brain’s response to angry, happy, and neutral stimuli. There were no significant group differences or interactions, suggesting that the emotions were similarly processed on a neural level in both the LAQ- and HAQ-groups (see Table 3.5, Figure 3.1).

Table 3.5 The significant activations from the results of a 2 x 3 ANOVA with group as a between-subjects factor and emotion as a within-subjects factor

Contrast	Region	Talairach coordinate of peak voxel x, y, z	L / R	F	p	Number of Voxels
Main effect of group	n. s					
Main effect of emotion	Fusiform Gyrus	42,-67,-8	R	55.44	<0.000001	61667
	Middle Temporal Gyrus, anterior division	51,-1,-23	R	26.50	<0.000001	1051
	Insular Cortex	30,20,7	R	23.33	<0.000001	13905
	Central Opercular Cortex	42,-4,16	R	14.01	0.000013	775
	Angular Gyrus	48,-49,37	R	11.07	0.000094	312
	Middle Frontal Gyrus	27,26,46	R	15.79	0.000004	3474
	Angular Gyrus	27,-52,34	R	21.69	<0.000001	5144
	Superior Frontal Gyrus	24,8,58	R	8.42	0.000657	483
	Medial amygdala	15,-4,-8	R	12.19	0.000043	268
	Parahippocampal Gyrus, posterior division	12,-28,-2	R	13.98	0.000013	648
	Paracingulate Gyrus	3,44,7	R	17.22	0.000002	12936
	Cingulate Gyrus, posterior division	0,-37,37	L	14.91	0.000007	1492
	Supplementary Motor Cortex	6,-4,61	R	10.58	0.000133	406
	Supplementary Motor Cortex	0,-7,46	L	16.15	0.000003	715
	Superior Frontal Gyrus	-3,23,52	L	10.29	0.000164	364
	Supplementary Motor Cortex	-3,-1,55	L	8.22	0.000765	319
	Precuneus	-9,-46,58	L	11.04	0.000096	622
	Angular Gyrus	-30,-49,34	L	19.72	<0.000001	4531
	lateral prefrontal thalamus	-15,-13,10	L	13.72	0.000015	800
	Cingulate Gyrus, posterior division	-12,-31,-2	L	10.43	0.000147	233
	Medial amygdala	-15,-4,-8	L	13.38	0.000019	274
	Lateral Occipital Cortex, inferior division	-42,-73,-8	L	43.23	<0.000001	29924
	Lateral Occipital Cortex, superior division	-24,-76,22	L	19.40	<0.000001	1371
	Fusiform Gyrus	-24,-46,-11	L	11.39	0.000075	242
	Inferior Frontal Gyrus, pars opercularis	-39,11,25	L	25.91	<0.000001	14876
	Ventromedial putamen	-33,-13,-8	L	11.89	0.000053	353
	Parahippocampal Gyrus, posterior division	-27,-28,-11	L	11.83	0.000055	286
	Postcentral Gyrus	-36,-25,59	L	8.22	0.000765	629
	Supramarginal Gyrus, anterior division	-45,-37,43	L	12.04	0.000047	234
	Lateral Occipital Cortex, superior division	-48,-61,19	L	11.15	0.000088	422

	Temporal Pole	-51,-1,-23	L	12.11	0.000045	676
Interaction	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)

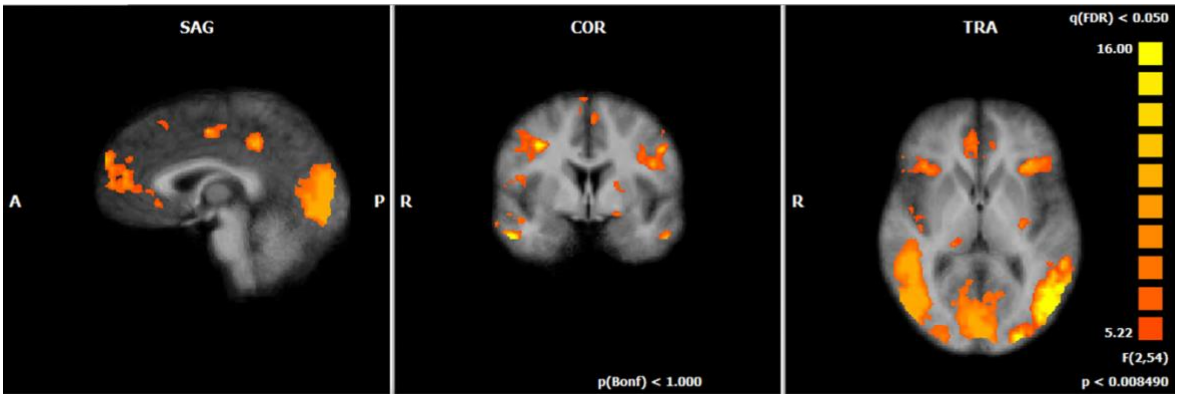


Figure 3.1 Brain regions demonstrated a significant main effect of emotion during the processing of emotional gestures, reflecting the neural responses associated with different emotional stimuli across the study.

3.4.4.2 Individual contrast

Although no group effect or interaction was significant, one-sample t-tests were conducted within and between each group for individual conditions and contrasts. The results for the four conditions will be considered separately for individual groups and the milieu of group comparisons. The analyses included three emotional gesture conditions: angry, happy, neutral and various emotional contrasts such as angry > happy, angry > neutral, happy > angry, happy > neutral, neutral > angry, and neutral > happy.

(1) Angry gestures

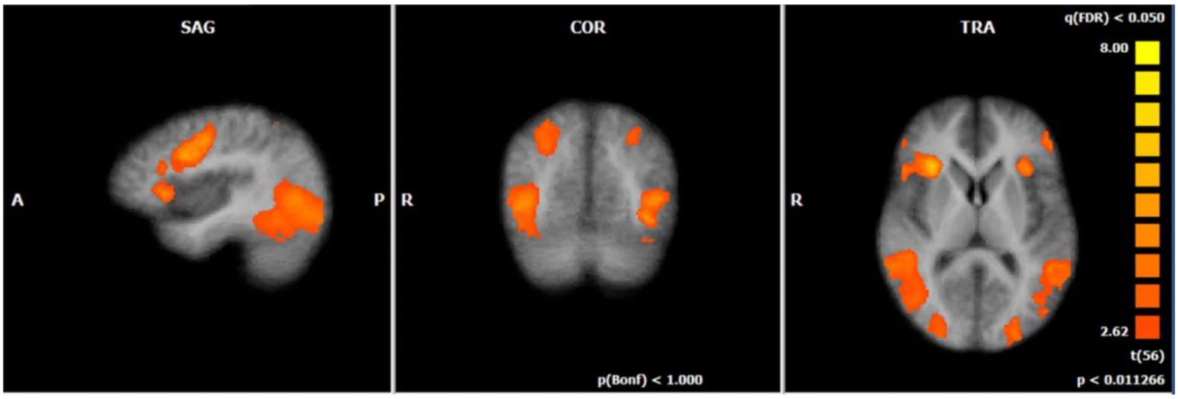
The results of angry gesture perception analysis for the two groups are summarised in Table 3.6 and Figure 3.2. In the LAQ group, significant activations were observed in the right lateral occipital cortex (LOC), right insular cortex, left fusiform gyrus (FG), left lateral occipital cortex (LOC), right superior parietal lobule (SPL), left precentral gyrus (PreCG), and left inferior frontal gyrus (IFG). This was even more so for the right insular cortex and left fusiform gyrus (FG), which in turn suggests a great response of neurons within the processing of these emotional gestures.

Significant activations within the HAQ group included the right fusiform gyrus (FG), right postcentral gyrus (PostCG), left inferior frontal gyrus (IFG), right dorsal caudate, right parahippocampal gyrus (PHG), left supplementary motor cortex (SMC), and left ventral diencephalon. Additional activations were observed in the right fusiform gyru (FG)s, left insular cortex, and left lateral occipital cortex (LOC), reflecting marked neural involvement for the task in these regions. Indeed, no significant between-group differences in brain activation emerged for angry gesture perception between LAQ and HAQ groups. Comparisons between the two groups did not reveal significant effects evidence of similar activations for the two groups in the processing of angry gestures (see Table 3.6).

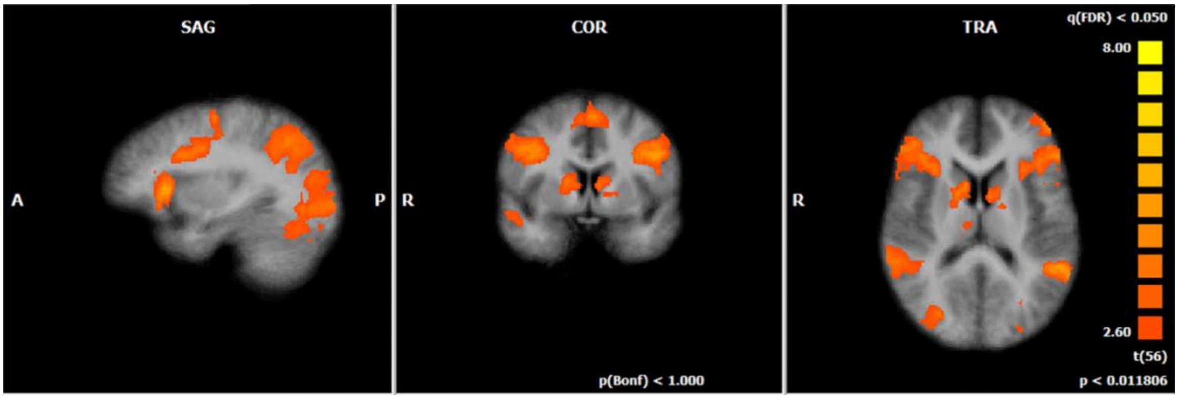
Table 3.6 Significant brain activation observed in the LAQ group, HAQ group, and group comparisons during angry gesture perception

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Emotion: Angry						
LAQ group	Lateral Occipital Cortex, inferior division	42,-70,-5	R	9.95	<0.000001	35470
	Insular Cortex	30,23,7	R	6.78	<0.000001	20856
	Fusiform Gyrus	-42,-76,-11	L	7.38	<0.000001	19459
	Lateral Occipital Cortex, superior division	-24,-73,25	L	4.76	0.000014	1074
	Superior Parietal Lobule	-30,-52,40	R	5.49	0.000001	2427
	Insular Cortex	-33,20,7	L	4.94	0.000008	1118
	Precentral Gyrus	-42,-7,43	L	4.68	0.000019	654
	Inferior Frontal Gyrus, pars triangularis	-48,35,10	L	4.25	0.000081	870
	Inferior Frontal Gyrus, pars triangularis	-42,14,25	L	3.85	0.00031	888
HAQ group	Fusiform Gyrus	42,-67,-8	R	8.55	<0.000001	42654
	Postcentral Gyrus	51,-13,28	R	4.44	0.000042	520
	Inferior Frontal Gyrus, pars opercularis	48,17,31	L	7.14	<0.000001	24243
	dorsal caudate	9,8,10	R	5.11	0.000004	2098
	Parahippocampal Gyrus, posterior division	15,-28,-2	R	4.58	0.000027	881
	Supplementary Motor Cortex	-3,11,52	L	5.55	0.000001	6477
	dorsal caudate	-6,2,13	L	4.49	0.000036	946
	Ventral Diencephalon	-9,-13,-5	L	4.91	0.000008	372
	Fusiform Gyrus	-39,-64,-11	L	7.67	<0.000001	20474
	Insular Cortex	-27,20,4	L	6.19	<0.000001	21584
	Lateral Occipital Cortex, superior division	-30,-67,28	L	5.61	0.000001	5240
	Supramarginal Gyrus, anterior division	-45,-40,34	L	4.41	0.000047	665
LAQ > HAQ	n. s					
HAQ > LAQ	n.s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Significant brain areas activated in the LAQ group during the perception of angry gestures



(b) Brain regions showing significant activation in the HAQ group during angry gesture processing

Figure 3.2 Brain activations during the processing of angry gestures showed significant effects in both (a)LAQ and (b)HAQ groups; however, specific differences were observed between the groups, as detailed in Table 3.6.

(2) Happy gestures

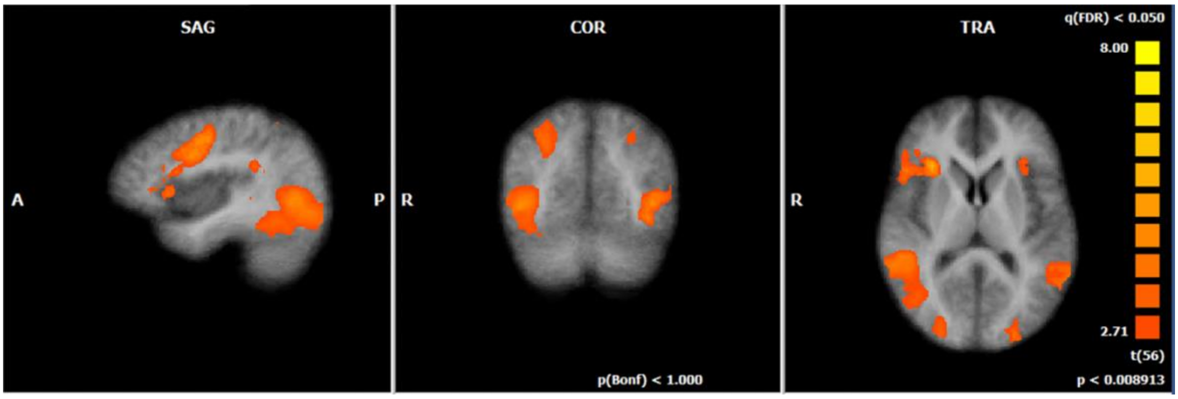
The results also for the perception of happy gestures in both groups are summarised in the following table and graph. Significant activations for the LAQ group were found in the right planum polare, right insular cortex, left fusiform gyrus (FG), superior division of the left lateral occipital cortex (LOC), left superior parietal lobule (SPL), left precentral gyrus (PreCG), and left inferior frontal gyrus (IFG). Notably, the right insular cortex and left fusiform gyrus (FG).

Indeed, it did so with very strong activations, especially in the right insular cortex and left fusiform gyrus (FG). In the HAQ group significant activations were obtained within the right fusiform gyrus (FG), brainstem, and bilateral anterior cingulate gyrus (ACG) among others. Of these, especially the right fusiform gyrus (FG), brainstem, and cingulate gyrus showed robust activations. It was found that group comparison revealed a significant difference in brain activation for the HAQ group compared with the LAQ group during the perception of happy gestures. This group showed greater activation than the LAQ group in regions of activation including the right postcentral gyrus (PostCG), superior division of the right lateral occipital cortex (LOC), right cerebellar Crus I, right dorsal caudate, and left superior frontal gyrus (SFG). No regions showed greater activation for the LAQ group relative to the HAQ group (see Table 3.7 and Figure 3.3 (c))

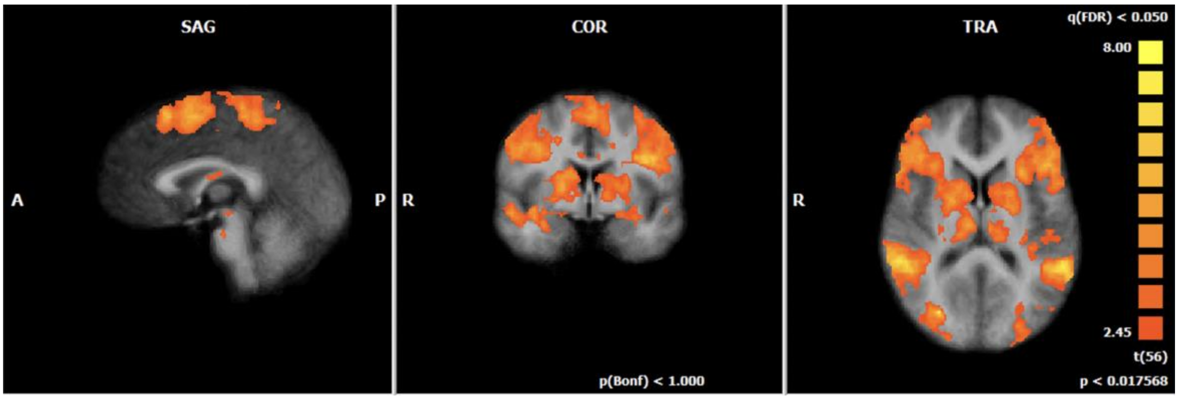
Table 3.7 Significant neural activation identified in the LAQ group, HAQ group, and through group comparisons while processing happy gestures

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L / R	t	p	Number of Voxels
Emotion: Happy						
LAQ group	Planum Polare	42,-70,-5	R	9.54	<0.000001	32786
	Insular Cortex	30,23,7	R	6.56	<0.000001	17316
	Fusiform Gyrus	-42,-73,-11	L	7.08	<0.000001	17288
	Lateral Occipital Cortex, superior division	-24,-76,25	L	4.31	0.000067	663
	Superior Parietal Lobule	-30,-49,37	L	4.65	0.000021	1749
	Superior Parietal Lobule	-30,26,10	L	3.78	0.000383	441
	Precentral Gyrus	-42,-7,43	L	5.21	0.000003	926
	Inferior Frontal Gyrus, pars opercularis	-42,5,25	L	4.08	0.000146	836
HAQ group	Fusiform Gyrus	39,-61-8	R	9.21	<0.000001	314407
	Brain Stem	-3,-25,-17	L	4.57	0.000027	1538
	Cingulate Gyrus, anterior division	3,-7,28	R	4.20	0.000097	410
	Cingulate Gyrus, anterior division	-6,-10,31	L	5.26	0.000002	418
LAQ > HAQ	n. s					
HAQ > LAQ	Postcentral Gyrus	51,-16,28	R	4.85	0.00001	322
	Lateral Occipital Cortex, superior division	39,-76,22	R	4.50	0.000035	550
	Cerebellar Crus I	43,-61,-23	R	4.33	0.000063	212
	dorsal caudate	12,-7,22	R	4.62	0.000023	294
	Precuneus	3,-37,46	R	4.86	0.00001	243
	Superior Frontal Gyrus	-12,17,55	L	5.09	0.000004	1225
	dorsal caudate	-15,-16,19	L	5.34	0.000002	417
	Precuneus	-15,-49,28	L	5.38	0.000001	222
	globus pallidus	-24,-4,7	L	4.66	0.00002	938
	Middle Frontal Gyrus	-33,-1,52	L	5.94	<0.000001	582
	Lateral Occipital Cortex, superior division	-40,-61,40	L	5.41	0.000001	1188
	Inferior Frontal Gyrus, pars opercularis	-48,11,19	L	6.00	<0.000001	393
	Inferior Temporal Gyrus, temporooccipital part	-48,-49,-14	L	5.58	0.000001	360
	Middle Temporal Gyrus, posterior division	-63,-22,-5	L	4.50	0.000035	222

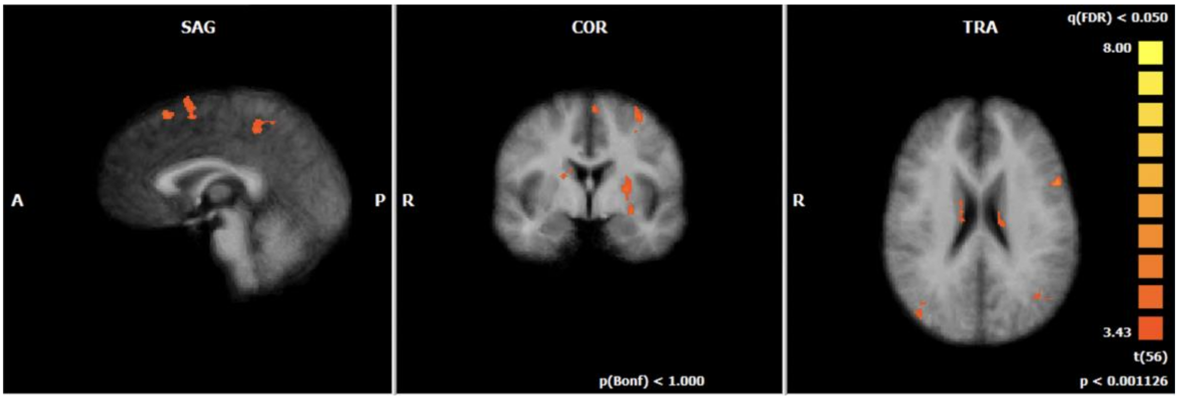
(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Brain areas that were significantly activated in the LAQ group during the perception of happy gestures



(b) Regions of brain showing significant activation in the HAQ group during the perception of happy gestures



(c) Brain areas exhibiting activation in the HAQ group compared to the LAQ group during happy gesture perception

Figure 3.3 The figures show the results for each group: (a) LAQ group and (b) HAQ group. Significant brain activations were observed during the perception of happy gestures. (c) The figure also highlights areas with increased activation in the HAQ group compared to the LAQ group during happy gesture perception

(3) Neutral gestures

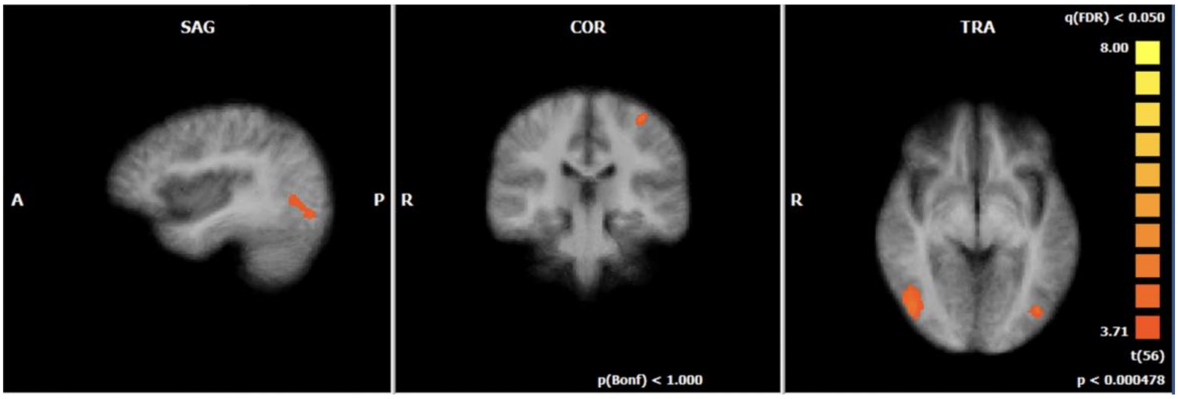
Results for neutral gesture perception analysis for the two groups are reported in Table 3.8 and Figure 3.4. In the LAQ group, significant activations were found the bilateral lateral occipital cortex (LOC) and left postcentral gyrus (PostCG). The strongest activation was found in the right lateral occipital cortex (LOC). The HAQ group showed significant activations in the right middle temporal gyrus (MTG), right precentral gyrus (PreCG), right fusiform gyrus (FG), right lateral occipital cortex (LOC), and left fusiform gyrus (FG). The right fusiform gyrus (FG) showed a considerable amount of neural activity for this task likewise (see Table 3.8 and Figure 3.4).

The group comparison analysis did not indicate any significant differences in brain activation between the LAQ and HAQ groups in neutral gesture perception. Non-significant results for the two contrasts, LAQ > HAQ and HAQ > LAQ were obtained, indicating that no regions showed significantly higher activation in one group compared to another.

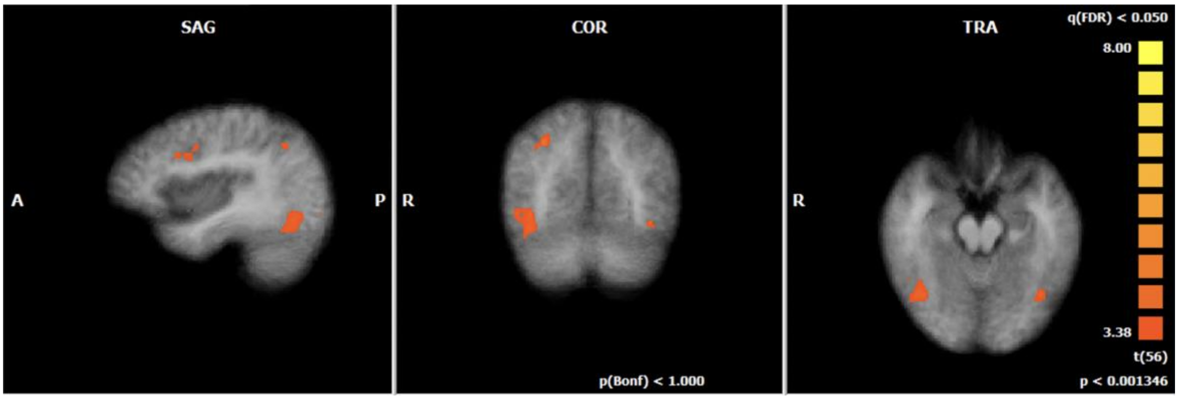
Table 3.8 Significant brain regions activated in the LAQ and HAQ groups, as well as in group comparisons, while processing neutral gestures

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Emotion: Neutral						
LAQ group	Lateral Occipital Cortex, inferior division	42,-70,-5	R	6.25	<0.000001	2066
	Postcentral Gyrus	-33,-28,52	L	4.84	0.000011	347
	Lateral Occipital Cortex, inferior division	-39,-70,-5	L	4.59	0.000026	238
HAQ group	Middle Temporal Gyrus, temporooccipital part	48,-43,4	R	4.80	0.000012	1268
	Precentral Gyrus	48,8,34	R	5.00	0.000006	1690
	Fusiform Gyrus	39,-61,-8	R	5.41	0.000001	2638
	Lateral Occipital Cortex, superior division	27,-64,37	R	4.91	0.000008	1269
	Fusiform Gyrus	30,-76,-5	R	4.55	0.000029	650
	Fusiform Gyrus	-39,-61,-14	L	4.65	0.000021	284
LAQ > HAQ	n. s					
HAQ > LAQ	n.s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Areas of significant activation in the LAQ group while responding to neutral gestures



(b) Brain regions that showed significant activation in the HAQ group during the perception of neutral gestures

Figure 3.4 Displayed in the figures are the results for each group: (a) LAQ group and (b) HAQ group. Brain activations were significant for both groups during neutral gesture perception, showing no distinct group differences.

(4) Contrasts of emotional gestures

The findings have been tabulated in the gesture contrast analysis across the two groups in Table 3.9 and Figure 3.5. For the *angry* > *neutral* contrast, greater activity for the LAQ group was observed in a variety of regions-of-interest (ROI), including the right supramarginal gyrus (SMG), right fusiform gyrus (FG), right precentral gyrus (PreCG), right insular cortex, left occipital pole (OP), left superior parietal lobule (SPL), left lateral occipital cortex (LOC), left inferior frontal gyrus (IFG), and left superior temporal gyrus

(STG). However, the HAQ group showed heightened activity in the right middle temporal gyrus (MTG), right fusiform gyrus (FG), right inferior temporal gyrus (ITG), left insular cortex, and left lingual gyrus (LG) (see Figure 3.5 (a) and (b)).

In the *happy* > *angry* contrast, HAQ showed significant activations in several ROIs including right superior parietal lobule (SPL), right dorsal caudate, right cerebellum, bilateral intracalcarine cortex, right postcentral gyrus (PostCG), left frontal pole (FP), left supplementary motor cortex (SMC), and left superior frontal gyrus (SFG) (see **Figure 3.5** (c)). No significant activations were observed in the LAQ group for this contrast.

In the *happy* > *neutral* contrast, the LAQ group exhibited greater activity in the right lateral occipital cortex (LOC). In the HAQ group, greater activity was seen in the right fusiform gyrus (FG), right temporal pole (TP), right globus pallidus, bilateral caudate nucleus, left superior frontal gyrus (SFG), left insular cortex, and left putamen (see Figure 3.5 (d) and (e)).

This is evident in the neutral > angry contrast where activation for the LAQ group included in the right fusiform gyrus (FG), right precentral gyrus (PreCG), right cuneus, and bilateral precuneus, among other regions. The HAQ group demonstrated activation in the right middle frontal gyrus (MFG), left lingual gyrus (LG), and other medial prefrontal areas(MeFC) (see Figure 3.5 (f) and (g)). No significant differences were observed between the groups in this contrast.

During the neutral > happy contrast, the LAQ group had activation in right middle temporal gyrus (MTG) and right cuneus whereas the HAQ group had only left cuneus activation see Figure 3.5 (h) and (i). Again, no significant group differences were observed.

This analysis points out different patterns of neural activity during perception of emotional gestures, specific regions being more activated all over the different contrasts in LAQ and HAQ groups. Indeed, no significant differences appear between groups in any of these contrasts.

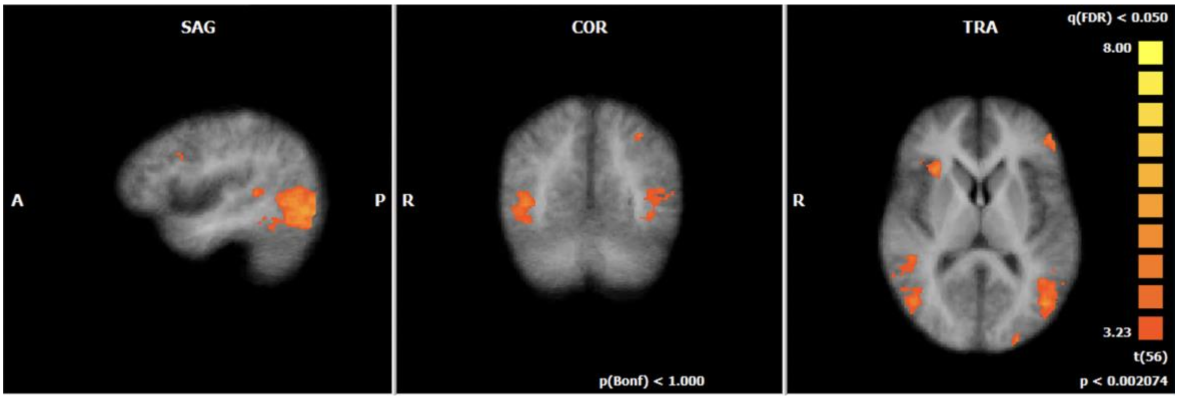
Table 3.9 Comparison of emotional gesture contrast results for the LAQ group, HAQ group, and between-group analysis

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L / R	t	p	Number of Voxels
Contrast: Angry > Happy						
LAQ group	n.s					
HAQ group	n.s					
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Angry > Neutral						
LAQ group	Supramarginal Gyrus, posterior division	54,-40,16	R	4.60	0.000024	1077
	Fusiform Gyrus	46,-67,-11	R	6.23	<0.000001	7173
	Precentral Gyrus	36,8,28	R	4.63	0.000022	317
	Insular Cortex	30,20,7	R	5.41	0.000001	557
	Occipital Pole	-24,-88,4	L	5.25	0.000002	547
	Superior Parietal Lobule	-33,-55,43	L	4.86	0.00001	439
	Lateral Occipital Cortex, inferior division	-39,-76,-8	L	6.55	<0.000001	7265
	Inferior Frontal Gyrus, pars opercularis	-42,14,25	L	5.10	0.000004	485
	Superior Temporal Gyrus, posterior division	-48,35,10	L	5.19	0.000003	603
HAQ group	Middle Temporal Gyrus, temporooccipital part	42,-46,4	R	5.94	<0.000001	2103
	Fusiform Gyrus	42,-67,-8	R	6.76	<0.000001	4469
	Inferior Temporal Gyrus, temporooccipital part	45,-46,-20	R	5.14	0.000004	678
	Insular Cortex	-33,20,1	L	4.29	0.000071	193
	Fusiform Gyrus	-39,-64,-11	L	5.61	0.000001	1773
	Fusiform Gyrus	-36,-67,-2	L	4.45	0.000041	189
	Lingual Gyrus	-57,-49,10	L	4.89	0.000009	468
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Happy > Angry						

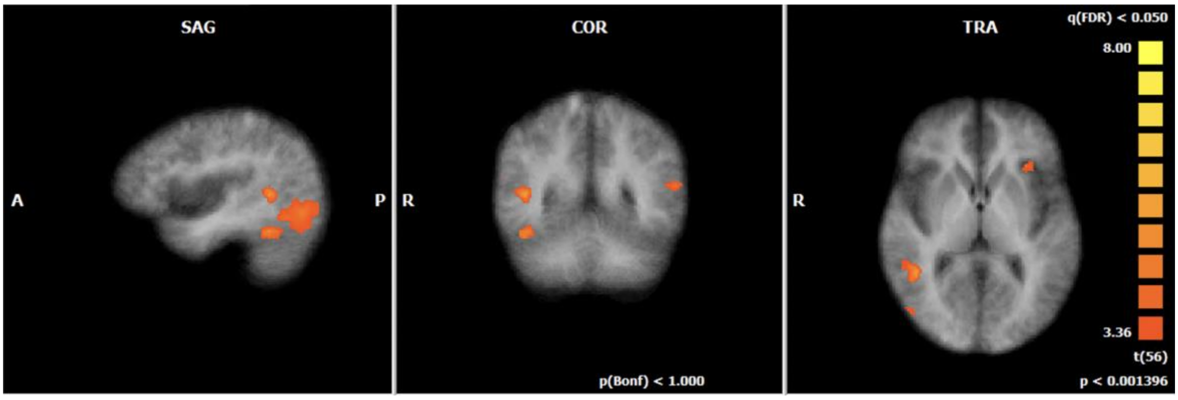
LAQ group	n.s					
HAQ group	Superior Parietal Lobule	24,-40,65	R	4.58	0.000026	595
	dorsal caudate	18,8,31	R	4.95	0.000007	637
	Cerebellum	15,-61,-20	R	4.08	0.000144	259
	Intracalcarine Cortex	18,-82,13	R	5.12	0.000004	468
	Intracalcarine Cortex	15,-73,7	R	6.03	<0.000001	11972
	Postcentral Gyrus	6,-34,68	R	5.43	0.000001	1781
	Frontal Pole	-6,60,22	L	4.62	0.000023	413
	Supplementary Motor Cortex	-9,-10,46	L	4.55	0.000029	262
	Precuneus	-9,-43,52	L	4.44	0.000043	380
	Cingulate Gyrus, posterior division	-6,-34,40	L	4.29	0.000073	301
	Frontal Pole	-12,44,31	L	4.69	0.000018	305
	Superior Frontal Gyrus	-12,23,43	L	4.89	0.000009	304
	Superior Frontal Gyrus	-18,32,28	L	5.51	0.000001	510
	Superior Parietal Lobule	-33,-52,43	L	4.95	0.000007	1408
	Insular Cortex	-30,-7,16	L	4.62	0.000023	860
	Postcentral Gyrus	-39,-34,56	L	4.97	0.000007	1768
	Postcentral Gyrus	-51,-19,25	L	5.10	0.000004	1789
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Happy > Neutral						
LAQ group	Lateral Occipital Cortex, inferior division	45,-67,-8	R	6.48	<0.000001	1514
HAQ group	Fusiform Gyrus	39,-64,-5	R	8.39	<0.000001	178471
	Temporal Pole	27,2,-17	R	4.42	0.000045	355
	globus pallidus	15,-1,-8	R	4.19	0.000101	320
	Globus Pallidus	15,-7,16	R	3.88	0.000281	637
	Caudate Nucleus	12,-25,1	R	5.52	0.000001	1732
	Superior Frontal Gyrus	-6,26,55	L	4.80	0.000012	613
	Caudate Nucleus	-3,-7,16	L	4.73	0.000015	2769
	Cingulate Gyrus, posterior division	-15,-28,31	L	4.66	0.00002	1133
	Precuneus	-12,-58,34	L	4.14	0.000118	321
	Putamen	-18,-1,-8	L	5.00	0.000006	1921
	Insular Cortex	-24,-4,13	L	4.86	0.00001	1240
LAQ > HAQ	n. s					

HAQ > LAQ	n. s					
Contrast: Neutral > Angry						
LAQ group	Fusiform Gyrus	51,-1,-24	R	6.60	<0.000001	381
	Precentral Gyrus	21,8,58	R	4.89	0.000009	265
	Cuneus	3,-79,13	R	7.60	<0.000001	8745
	Cingulate Gyrus, posterior division	0,47,13	R	4.22	0.00009	358
	Precuneus	-3,-37,40	L	4.04	0.000167	287
	Middle Frontal Gyrus	-18,32,40	L	4.58	0.000027	480
	Middle Temporal Gyrus	-45,-61,19	L	4.70	0.000017	469
HAQ group	Middle Frontal Gyrus	24,29,37	R	4.79	0.000013	998
	Lingual Gyrus	-6,-85,-2	L	6.69	<0.000001	8526
	Medial Prefrontal Cortex	3,44,7	R	4.62	0.000023	509
	Lingual Gyrus	-9,-61,-5	L	5.04	0.000005	219
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Contrast: Neutral > Happy						
LAQ group	Middle Temporal Gyrus, anterior division	51,-1,-23	R	6.42	<0.000001	315
	Cuneus	3,-79,13	R	7.10	<0.000001	4362
HAQ group	Cuneus	0,-85,4	L	3.91	0.000248	383
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					

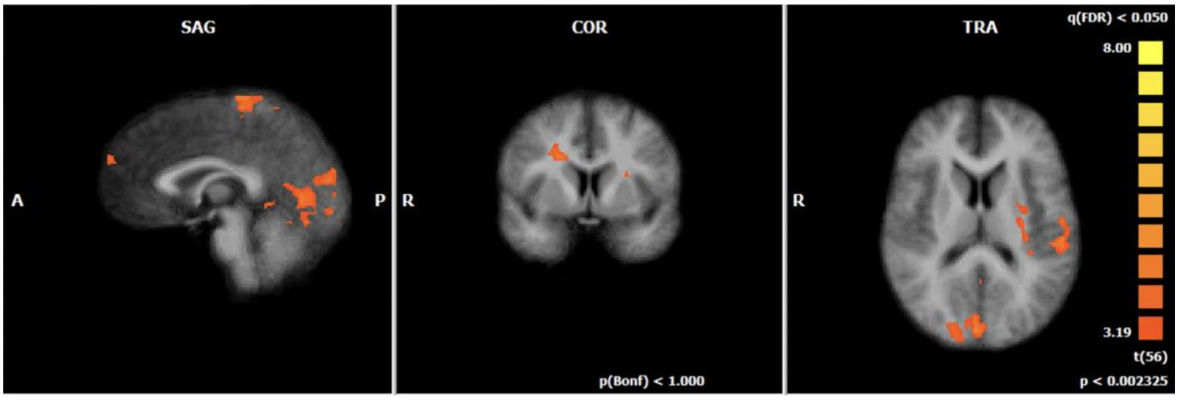
(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



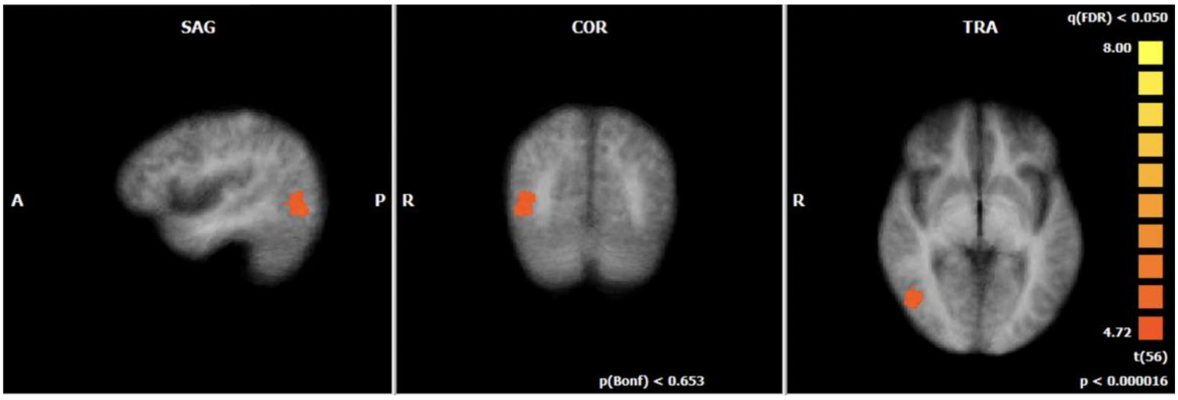
(a) Regions of notable activation in the LAQ group for the angry > neutral contrast



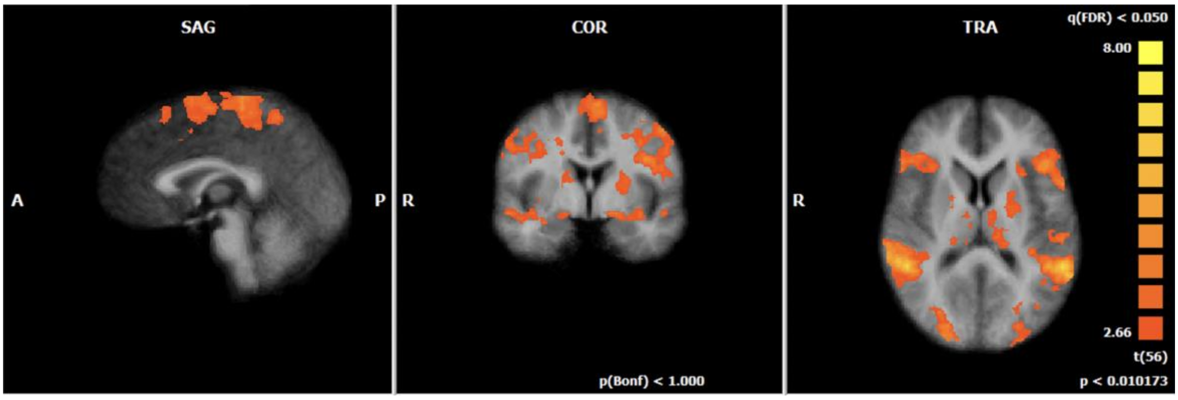
(b) Brain areas showing significant activation in the HAQ group during angry > neutral contrast



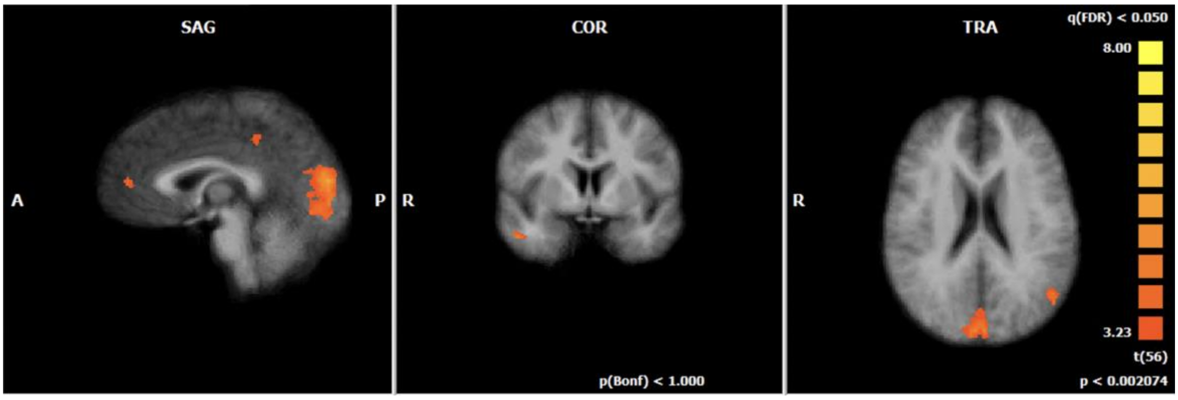
(c) Regions with significant neural activation in the HAQ group for the happy > angry contrast



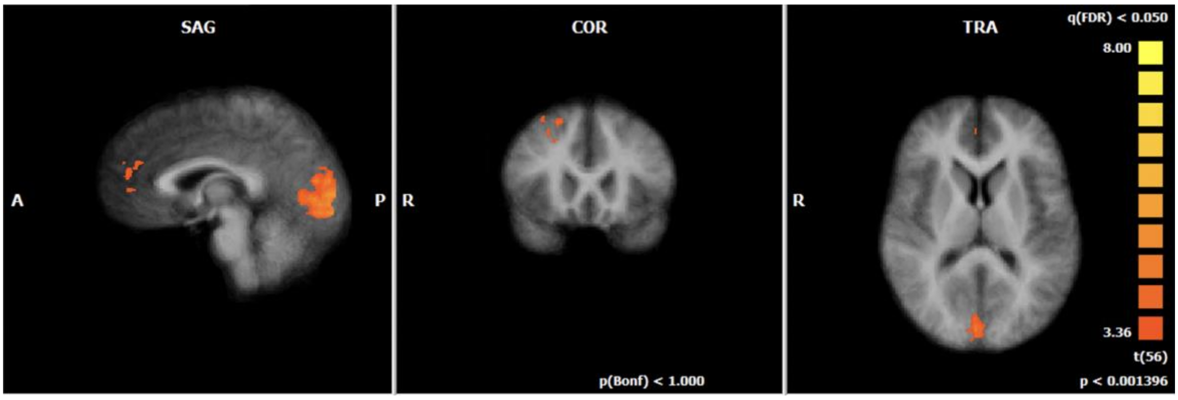
(d) Brain regions exhibiting strong activation in the LAQ group during happy > neutral contrast analysis



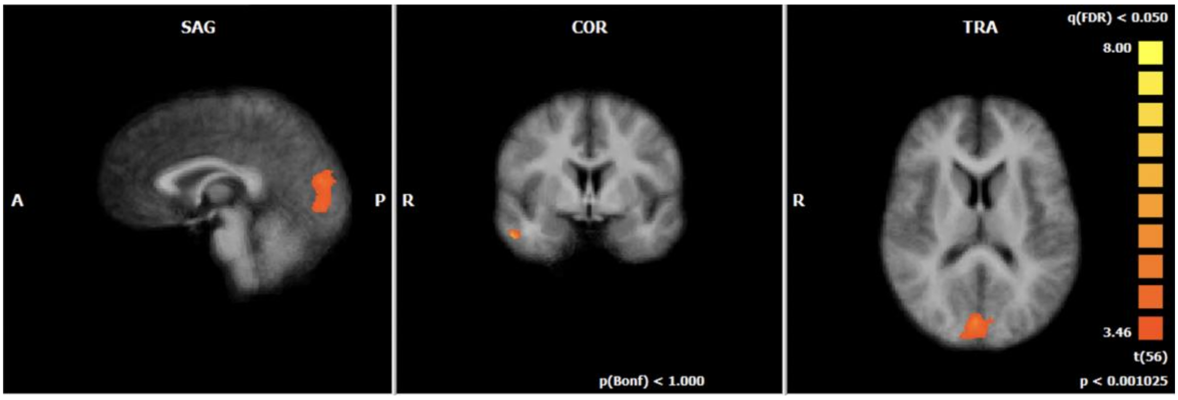
(e) Areas displaying significant neural activation in the HAQ group in the happy > neutral contrast



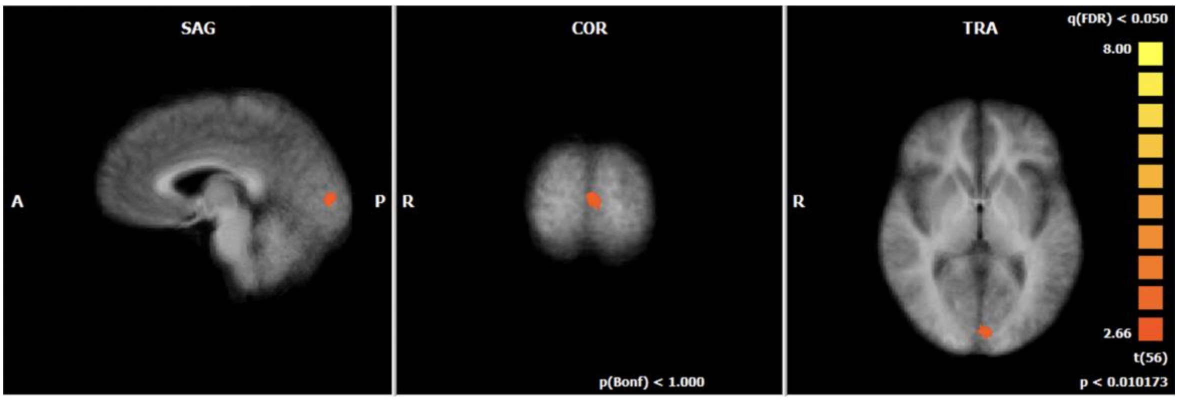
(f) Regions exhibiting notable neural activation in the LAQ group during neutral > angry contrast



(g) Key regions with significant activation in the HAQ group for neutral > angry contrast analysis



(h) Areas of the brain with increased activation in the LAQ group for the neutral > happy contrast



(i) Significant neural activation observed in the HAQ group during the neutral > happy contrast

Figure 3.5 The figures display the key brain regions with increased activation during emotional gesture processing for each group. Panels (a) through (i) illustrate the results of the respective contrast conditions analyzed within each group

3.4.4.3 Correlation analysis

This is summarized in Table 3.10, which explores the correlation of AQ scores with emotional gesture perception in different ways for the LAQ versus the HAQ groups.
No significant correlation was found within the LAQ group in the angry condition. Within the HAQ group, there was a strongly positive correlation in the left precuneus ($r = 0.91$, $p = 0.000017$) which evidences how extremely high the relationship is in this area as seen in Figure 3.6 (a).

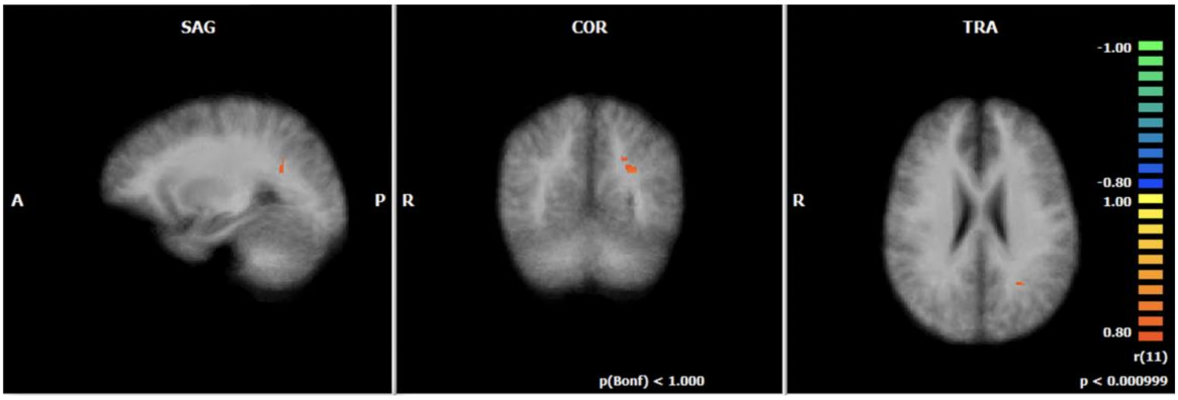
For the Happy condition, no significant correlations were identified in the LAQ group. In contrast, the HAQ group again exhibited a highly significant positive correlation in the left Precuneus ($r = 0.94$, $p = 0.000001$), reflecting a similar relationship between AQ scores and brain activity as seen in the Angry condition (see **Figure 3.6 (b)**).

In the Neutral condition, the LAQ group showed no significant correlations. However, the HAQ group demonstrated significant positive correlations in two regions: the right precuneus ($r = 0.88$, $p = 0.000082$) and the left Insular Cortex ($r = 0.92$, $p = 0.000007$), suggesting that higher AQ scores were associated with increased activity in these regions during the perception of neutral gestures (see Figure 3.6 ©).

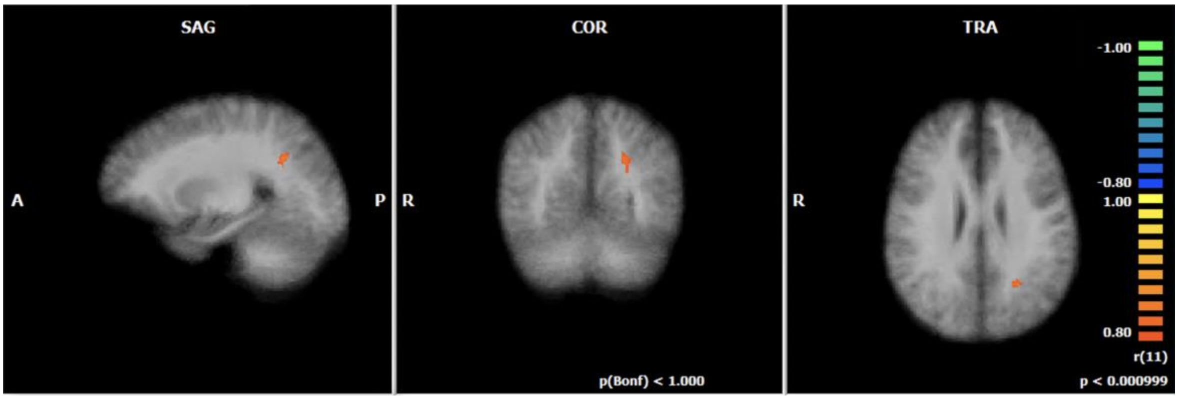
Table 3.10 Correlation analysis results between AQ scores and emotional gestures in both the LAQ and HAQ groups

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	r	p	Numbe r of Voxels
condition: Angry						
LAQ group	n.s					
HAQ group	Precuneus	-30,-55,19	L	0.91	0.000017	192
condition: Happy						
LAQ group	n.s					
HAQ group	Precuneus	-24,-55,28	L	0.94	0.000001	240
condition: Neutral						
LAQ group	n.s					
HAQ group	Precuneus	33,-49,28	R	0.88	0.000082	142
	Insular Cortex	-27,20,28	L	0.92	0.000007	163

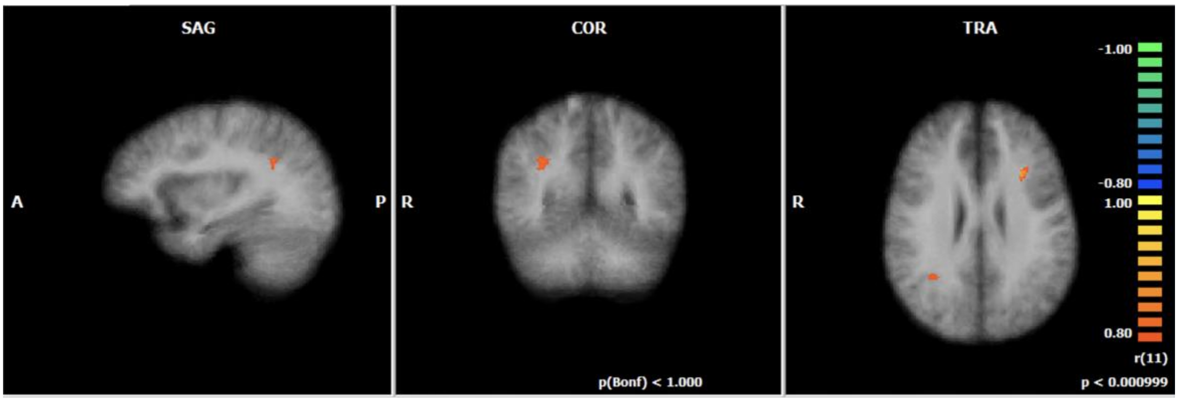
(x, y, z are stereotaxic coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at $p<0.001$ at the uncorrected level)



(a) Region of brain showing significant correlation with AQ in the HAQ group during Angry gestures



(b) Significant brain area associated with AQ scores in the HAQ group while processing Happy gestures



(c) Brain regions with significantly correlated with AQ scores in the HAQ group during the processing of Neutral gestures

Figure 3.6 The figures show the brain regions significantly correlated with AQ scores in the HAQ group during the processing of emotional gestures

3.5 Summary and Discussion

The main purpose of this study was to determine how individuals with high-autistic traits (HAQ) and low-autistic traits (LAQ) differ in both behavioral and neural responses during emotional gesture perception. Among all tested conditions, a statistically significant group difference was observed only in the recognition of happy gestures, with the LAQ group significantly outperforming the HAQ group. This result provides an anchor point for interpreting broader trends in behavioral and neural responses and extends the general knowledge of emotional perception in ASD, highlighting possible avenues for intervention and support.

This finding aligns with previous research suggesting that individuals with high-autistic traits or ASD experience specific difficulties with positive affective processing (Kuusikko et al., 2009; Rump et al., 2009), potentially due to reduced sensitivity to socially rewarding cues (Chevallier et al., 2012). The statistically significant difference in recognizing happy gestures may reflect impairments in the ability to process global, holistic features of emotional body movements, as individuals with high-autistic traits often rely more on local visual features (Dakin & Frith, 2005; Happé & Frith, 2006).

In contrast, no significant group differences were found for angry or neutral gestures. The lack of difference in angry gesture recognition may be related to specific stimulus or task characteristics, while equivalent performance for neutral gestures suggests that emotional salience plays a key role in differentiating group responses. It is important to interpret these null findings with caution, as they may reflect limited statistical power or subtle effects not detectable with current methods.

Neuroimaging results partially mirrored these behavioral patterns. For the angry > neutral contrast, the LAQ group exhibited increased activation in regions commonly associated with emotion recognition and biological motion processing, including the right supramarginal gyrus (SMG), fusiform gyrus (FG), and occipital cortex (Sato et al., 2017). This suggests efficient engagement of typical social-cognitive networks during emotional gesture perception.

In contrast, the HAQ group showed activation in the middle temporal gyrus (MTG), fusiform gyrus (FG), and anterior insula. While these results did not reach statistical significance, they may indicate reliance on interoceptive and self-referential strategies to process emotional gestures (Rudie et al., 2013; Libero et al., 2014). Again, these interpretations remain tentative and should be treated with caution.

In the happy > angry contrast, the HAQ group showed greater activation in motor-related areas such as the superior parietal lobule (SPL) and supplementary motor cortex (SMC). These areas are associated with embodied simulation processes (Gallese et al., 2004), suggesting that individuals with high-autistic traits may rely on simulating observed actions to interpret emotional content. The absence of similar activation in the LAQ group implies reliance on more specialized social-perceptual regions such as the superior temporal gyrus (STG) and amygdala.

In the neutral > angry contrast, both groups showed activation in the precuneus and middle temporal gyrus, regions associated with social cognition and self-referential thinking. However, only the HAQ group displayed additional activity in the medial prefrontal cortex. This finding supports the compensatory scaffolding hypothesis (Gepner & Féron, 2009), suggesting that individuals with high-autistic traits may recruit introspective or self-referential networks when typical social-cognitive regions are underactive or inefficient.

Together, these neural findings suggest that individuals with high-autistic traits engage alternative or compensatory systems—including interoceptive, motor, and self-referential networks—when processing emotional gestures. Although most group differences did not reach statistical significance, observed activation trends may reflect meaningful differences in neural strategies. Further research with larger samples and advanced analytic approaches (e.g., connectivity analyses, multivariate pattern analysis) could help elucidate these subtler patterns.

Importantly, the present study found only one statistically significant behavioral difference, and neural contrasts did not yield significant group effects. Therefore, interpretations of non-significant trends must remain cautious. These patterns should be viewed as exploratory and hypothesis-generating, rather than confirmatory.

This study is not without limitations. First, the modest sample size may have constrained the ability to detect statistically significant effects, particularly in the neuroimaging analyses. Second, the emotional stimuli were limited to three categories (happy, angry, neutral), which may not reflect the full spectrum of emotions encountered in real-life social interactions. Future studies should incorporate a broader range of emotions and increase statistical power through larger and more diverse samples.

Additionally, applying more sensitive analytical techniques—such as functional connectivity analysis or machine learning—may uncover group differences that remain hidden using traditional univariate methods. These approaches could provide a more nuanced understanding of the neurocognitive mechanisms underlying emotional gesture perception in individuals with high-autistic traits.

This study contributes to a differentiated understanding of how individuals with high- and low-autistic traits perceive emotional gestures. The LAQ group appeared to rely on core social-cognitive networks, while the HAQ group demonstrated evidence of compensatory reliance on motor and interoceptive systems. These findings lend support to the embodied simulation and compensatory scaffolding models of social cognition in ASD.

Understanding these distinct processing strategies provides theoretical insight and may inform the development of tailored, evidence-based interventions aimed at enhancing emotion recognition and social functioning in individuals with high-autistic traits. Future work should continue to explore the integration of visual, auditory, and other sensory modalities in emotional processing to fully capture the complexity of real-world social cognition in ASD.

4 Perception of Emotional Congruence of Audio-Visual Information in Adults with High-Autistic Traits

4.1 Abstract

The present study investigated behavioral and neuronal responses of HAQ and LAQ adults in situations of emotional congruence and incongruence between vocally expressed emotions and matching or conflicting gestures in audiovisual social displays. The fMRI and behavioral measures examined how participants decoded complex emotional signals. Results suggested that in the detection of emotional congruence, the LAQ performed better, showing faster and correct responses compared to that of the HAQ group. The HAQ group showed slower and less accurate responses during the incongruent trial. More precisely, the neuroimaging data yielded specific patterns of brain activation. For congruent conditions, the LAQ participants were most active in the sensory integration regions, such as the superior temporal gyrus and the fusiform gyrus, while HAQ participants displayed more activity in the cognitive control-related areas, such as the dorsolateral prefrontal cortex in incongruent conditions, reflecting greater cognitive effort and compensatory processing. Elevated autistic traits were associated with increased activation of classical emotional processing regions, including the amygdala and insula, reflecting a greater reliance on self-focused emotional processing strategies when exposed to conflicting emotional signals. These findings point toward specific neural and behavioral signatures associated with emotional processing in adults as a function of clinically and sub-clinically varying degrees of autistic traits. These divergent activation patterns suggest that the individuals with high autistic traits may employ different neural routes for dealing with the emotional conflict and thus emphasize the need for targeted interventions to improve emotional functioning and social communication. This work contributes to a better understanding of the neural basis of emotion perception in ASD and once again points to the urgent need to develop biomarkers and personalized therapies aiming at enhancing social communication skills among autism sufferers.

4.2 Introduction

To communicate and interact effectively, humans rely on the ability to process and integrate sensory information across multiple modalities. This process, known as multisensory integration, enables individuals to interpret subtle social and emotional cues—such as facial expressions, gestures, and vocal prosody—even in the absence of explicit verbal content. In neurotypical individuals, this integration typically occurs automatically and efficiently. However, individuals with Autism Spectrum Disorder (ASD) or high levels of autistic traits often exhibit deficits in multisensory integration, particularly when processing emotionally relevant audiovisual stimuli (Feldman et al., 2018; Kaiser & Pelphrey, 2012). These impairments may significantly contribute to the social-communicative challenges commonly observed in ASD.

Neuroimaging studies have consistently identified atypical activity in brain areas critical for multisensory integration in ASD. For instance, the superior temporal gyrus (STG), a key region involved in integrating auditory and visual inputs, shows reduced or atypical activation in individuals with ASD (Nomi et al., 2015; Zilbovicius et al., 2013). Functional connectivity between the superior temporal gyrus (STG) and other socially relevant areas, such as the fusiform gyrus (FG), is often diminished, and this disconnection has been linked to impaired emotion recognition (Surguladze et al., 2004)

Accurate emotion perception during social interaction often requires the integration of audiovisual signals—such as gestures, facial expressions, and prosody. This integration enables people to infer emotional states even when verbal content is minimal or ambiguous. Individuals with high autistic traits, however, frequently struggle with this process, leading to difficulties in identifying and responding appropriately to emotional cues (Collignon et al., 2013; Stevenson et al., 2014; Doyle-Thomas et al., 2013).

Behavioral research has demonstrated that individuals with high autistic traits perform less accurately and more slowly than neurotypical peers when interpreting both congruent (matched) and incongruent (mismatched) audiovisual emotional cues (Stevenson et al., 2014; Baum et al., 2015; Hoffmann et al., 2023). These deficits are even more pronounced under incongruent conditions, where processing discordant sensory inputs imposes greater cognitive demands.

Neuroimaging studies support these behavioral findings. For example, individuals with high autistic traits exhibit reduced activation in the fusiform gyrus (FG) during facial emotion processing, and heightened activity in the caudate and precuneus when resolving incongruent emotional cues, indicating increased cognitive effort (Critchley et al., 2000; Gao et al., 2023; Sugranyes et al., 2011). Broader disruptions in affective neural circuitry, including reduced activation or connectivity in regions such as the amygdala and orbitofrontal cortex (OFC), have also been observed (Ibrahim et al., 2019; Fishman et al., 2018).

Altered connectivity between sensory and higher-order cognitive regions has been linked to impaired multisensory emotion processing in individuals with ASD. Recent resting-state fMRI studies have reported atypical functional coupling, characterized by increased intra-sensory connectivity and reduced integration with prefrontal and temporal regions involved in socio-emotional processing. These neural patterns have also been associated with greater symptom severity (Chen et al., 202; Wang et al., 2021).

Understanding emotional congruence and incongruence in human perception offers a critical framework for examining how affective information is processed across sensory modalities. Emotional congruence occurs when visual and auditory emotional cues align in valence—for example, a smile paired with a cheerful tone—while incongruence arises when the cues conflict, such as an angry face paired with a calm voice. For neurotypical individuals, congruent stimuli are typically processed more intuitively, whereas incongruent stimuli demand additional cognitive resources to resolve cross-modal discrepancies (Collignon et al., 2008).

This added cognitive demand appears to be particularly challenging for individuals with high-autistic traits. Compared to neurotypical controls, they tend to perform less accurately and more slowly on tasks involving emotional incongruence, especially when integrating complex audiovisual cues (Liu, 2018). These findings highlight the increased cognitive load associated with resolving conflicting emotional signals and point to vulnerabilities in multisensory emotion integration in this population.

Neuroimaging research further supports this behavioral evidence by revealing differential brain activation patterns. During incongruent emotion processing, individuals with high-autistic traits show greater activity in brain regions involved in cognitive control and conflict monitoring, such as the caudate and dorsal anterior cingulate cortex (Bolis et al., 2017). This suggests that they must exert more cognitive effort to manage mismatched emotional information. Conversely, under emotionally congruent conditions, individuals with autistic traits exhibit reduced activation in regions involved in sensory convergence and integrative processing, suggesting less efficient integration of aligned audiovisual emotional cues (Dunham et al., 2023)

Additional studies have shown that individuals with high-autistic traits may be particularly impaired in processing positive emotional displays in multisensory contexts, with deficits noted in both behavioral performance and neural responses (Stevenson et al., 2014; Baum et al., 2015). These converging findings emphasize the need to further investigate how congruent and incongruent emotional signals are differentially processed in individuals with high-autistic traits, as well as the specific neural mechanisms underlying these challenges.

Although previous research has examined how individuals with autistic traits process emotional signals, most studies have focused on unimodal inputs such as facial expressions or prosody in isolation. There remains a notable gap in understanding how emotional meaning is extracted when multimodal cues—particularly prosody and gesture—are presented simultaneously and either align (congruent) or conflict (incongruent). The dynamic interplay between these cues, especially within the context of social communication, has rarely been investigated in relation to autistic traits.

To address this gap, the present research employs emotionally congruent and incongruent audiovisual stimuli, in which prosody and gesture co-occur to form either matched or mismatched pairings. This design captures the complexity of real-world interpersonal communication and provides an ecologically valid framework for assessing emotional processing. In particular, the study examines whether individuals with high-autistic traits show distinct behavioral and neural responses—especially when interpreting incongruent cues that demand the resolution of conflicting social signals, a process often impaired in Autism Spectrum Disorder (ASD).

By comparing performance and fMRI responses across individuals with high and low levels of autistic traits, this research aims to clarify the neurocognitive mechanisms underlying multisensory emotion perception. In addition to advancing theoretical models of social-emotional processing, the findings may inform early identification, and the development of more targeted intervention strategies aimed at improving emotional and social communication abilities in individuals with or at risk for Autism Spectrum Disorder (ASD).

4.3 Differences in perception of emotional congruence from audiovisual information: A Bahavioral Study

4.3.1 Research questions

In audiovisual social interactions, the perception emotional congruence and incongruence between prosody and gesture can elicit behavioral responses. The present reseach examined how individuals with high autistic traits compared to those with low autistic traits responded in these scenarios, controlling for age and IQ.
The primary research questions were:

1. How do individuals with high autistic traits differ from individuals with low autistic traits in terms of accuracy of recognition and reaction time when perceiving congruent or incongruent emotion between prosody and gesture in social conversations?
2. How do individuals with high autistic traits differ from those with low autistic traits in their behavioral performance when exposed to social conversations with congruent and incongruent emotional cues in prosody and gesture?

4.3.2 Experimental Methods

4.3.2.1 Participants

A total of 68 participants were recruited according to specific eligibility criteria. All were native English speakers between 18 and 40 years old, with hand dominance assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were classified into two groups based on their Autism Spectrum Quotient (AQ) scores (Baron-Cohen et al., 2001): the low-autistic traits (LAQ) group and the high-autistic traits (HAQ) group.

Participants with AQ scores above 29 were categorized into the HAQ group, while those with scores below 18 were placed in the LAQ group. The LAQ group included 40 participants (10 males, 30 females), and the HAQ group consisted of 28 participants (9 males, 19 females). All participants also completed the Wechsler Abbreviated Scale of Intelligence (WASI), a standardized test for measuring cognitive ability.

Table 4.1. Demographic information and group matching for low and high AQ groups

	Low AQ group	**High AQ group**	**p-value**
Cut-off score (AQ)	Below 18	Above 29	-
Number	40 (M:10, F: 30)	28 (M:9, F: 19)	p = 0.588 (fisher's exact test)
Handedness	40 R	28 R	-
Age	23.28±5.36	24.18 ±6.96	p = 0.858 (Mann-Whitney U)
AQ	12.51±4.68	34.04±4.73	$p < .001^{***}$ (Mann-Whitney U)
VIQ	118.90±10.21	119.32±11.79	p = 0.879 (t-test)
PIQ	115.56±11.51	117.11±8.96	p = 0.617 (t-test)
FSIQ	119.38±10.04	120.79±9.37	p = 0.586 (t-test)

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

4.3.2.2 Stimuli

Briefly, the stimulus set used in this study was first selected and prepared by Piwek, Pollick, and Petrini (2015). In their study, they used recordings of 20 male British actors between the ages of 17 and 43, all of whom were native English speakers. The actors received situations they were asked to reply to and react naturally to. There are pairs of actors showing happy or angry expressions with different levels of intensity and dialog forms, amounting to 242 displays, including neutral conditions. The motion capture was recorded in the School of Psychology, University of Glasgow, using a 12-camera system able to record 3D motion data. In the sessions, actors were asked to stand about 1.3 meters apart, while showing three different types of emotional interactions: angry, happy, and neutral. The same dialogue was used in each session. Subsequently, the displays were exported into audio-only, visual-only, and audiovisual format; thus, it resulted in a total of 242 unique displays. This involved post-processing, including the enhancement of audio and the adjustment of video for consistency. The length of the audio-visual dialogues ranged from 2.5 to 4.5 seconds. For this research, 64 audio-visual dialogues were used, each of 3 seconds in length with medium intensity.

4.3.2.3 Procedure

All experiments were conducted on a Macintosh MacPro 3.1 desktop computer running OS 10.5, equipped with an NVIDIA GeForce 8800GT graphics card. Visual stimuli were displayed on a 21-inch ViewSonic Graphics Series G220f CRT monitor with a resolution of 1024 x 768 pixels and a refresh rate of 60 Hz. High-quality Beyerdynamic DT770 headphones were used to deliver auditory stimuli. Stimulus presentation was managed using MATLAB 2007b with the Psychophysics Toolbox (PTB3 extensions).

Participants, wearing headphones during the experiment, responded by pressing number keys on a keyboard. To calibrate sound levels and seating positions, foam was given, and detailed instructions were provided at the start of every session. Participants viewed these conversations of two persons representing speech and point-light display, and participants were asked to react to the respective emotional congruence by pressing the respective key on the keyboard as fast as possible. This setup further allowed the study to investigate different performances between the LAQ and the HAQ groups in perceiving emotional congruency and incongruency. In total, participants were presented with 64 trials, including 32 for the emotionally congruent conditions, and the remaining for incongruent conditions. The experiment lasted about 10 minutes recording the responses along with their reaction times. Presentation sequence was pseudo-randomized, with the instruction to the participants to decide whether the emotions expressed by speech prosody and gestures (Angry/Happy/Neutral) from two speakers were congruent or incongruent.

4.3.2.4 Data analysis

All statistical analyses were performed with R (R Development Core Team, 2008). In the research, demographic and cognitive measures such as age, gender, AQ, VIQ, PIQ, and FSIQ were compared between the HAQ and LAQ groups. First, the normality of continuous variables was tested by the Shapiro-Wilk test. Independent t-tests and/or Mann-Whitney U test was applied. Comparisons in the gender distribution in the groups were made by the Fisher's exact test.

This study, therefore, explored how the autistic traits would affect the perception of emotion in prosody and gesture in either a congruent or an incongruent condition. Descriptive statistics of each group were calculated (mean, SD, SE) for any combination of prosody and gestures. To explore the effects of prosody-gesture congruence and group on correct response rates across all tasks, we submit the data to a Mixed-Effects Beta Regression Model using the glmmTMB package in R. We used beta regression given that correct response rates are proportions between 0 and 1. The model is specified below, including fixed effects of prosody-gesture congruence and group, their interaction, and a random participant ID effect to control for within-subject differences.

The model was defined as: *Correct Response Rate ∼ Congruence × Group + (1 | Participant ID)*

To handle boundary issues in the beta regression model, response rates of 0 or 1 were adjusted by adding a small epsilon value. The data were then transformed into long format, treating congruence and group as categorical predictors. A logit link function was used in the model, and the summary output revealed significant effects of congruence, group, and their interaction on correct response rates. Individual differences between the different types of congruence and the different groups were investigated in post-hoc analyses using estimated marginal means by means of the emmeans package. The distributions of reaction times were compared using Wilcoxon rank-sum tests, comparing the LAQ and HAQ groups. This non-parametric test has been chosen because the distributions of the reaction time may not be normal.

To investigate the relationship between autistic traits and cognitive performance on emotional prosody perception, Spearman correlation analyses were conducted. These correlations examined the relationships between correct response rates for recognition of congruence, Autism Spectrum Quotient (AQ), reaction times, and intelligence measures, including Verbal IQ (VIQ), Performance IQ (PIQ), and Full-Scale IQ (FSIQ). Data from both the LAQ and HAQ groups were combined for these analyses. A significance level of $p = 0.005$ was applied to account for multiple comparisons and reduce the likelihood of Type I error.

4.3.3 Results

4.3.3.1 Correct response rate and reaction time

Congruency and incongruency of emotions between the speakers' speech prosody and gestures were measured by descriptive statistical procedure for both the HAQ and LAQ groups in terms of mean, SD and SE of correct response rates for each condition. As shown in Table 4.2, LAQ always outperformed HAQ in the correct response rates of both congruent and incongruent conditions. In congruent trials, the mean correct response rate for the HAQ group was 0.827, but that for the LAQ group was steadier and more reliable at 0.913. Under incongruent conditions, performance for both groups fell to mean correct response rates of 0.547 for the HAQ group and 0.557 for the LAQ group, reflecting difficulty in processing incongruent cues.

Statistical tests showed that the HAQ performed significantly better under the congruent condition ($p < 0.001$) but demonstrated a significant decrement in performance in the incongruent condition ($p < 0.001$). Similarly, the LAQ demonstrated a significant loss in performance from congruent to incongruent conditions ($p < 0.001$) but maintained an overall advantage over the HAQ (see Table 4.3). Post-hoc testing also showed that the LAQ group performed significantly better than the HAQ group in the congruent condition ($p < 0.0001$), pointing to a special enhancement in the processing of aligned emotional cues. The most prominent task performance difference was between the conditions HAQ-incongruent and LAQ-congruent for both groups, with p's < 0.0001, and points to the role of congruency in the subject performance. The incongruent condition yielded no significant main effect of group, $p = 0.9968$, indicating similar difficulties to be experienced in incongruent cue processing by the two groups.

This is further supported by reaction time analysis, which indicated that the median response time for the HAQ group was 3.80 seconds with an IQR of 0.698, suggesting moderate variability. On the other hand, the LAQ group responded slightly quicker and more consistently, with a median response time of 3.54 seconds, IQR = 0.347. The results showed a non-statistically significant difference between the two groups according to the Wilcoxon rank sum test, $p = 0.084$, but this did suggest a trend for faster and more consistent responses in the LAQ group.

Overall, these suggest that even though in incongruent conditions both groups showed reduced performance, correct response rates of LAQ were constantly higher when the emotional cues were congruent. This underlines the performance superiority of the LAQ group while pointing to the critical role of congruency in the outcome of the task.

Table 4.2 Means, standard deviations (SD), and standard errors (SE) assessing the recognition of emotional congruence between prosody and gestures in the LAQ and HAQ groups

Task	Condition	Group	Mean	SD	SE
Congruency recognition	Congruent emotions between prosody-gestures	LAQ	0.913	0.074	0.012
		HAQ	0.827	0.131	0.245
	Incongruent emotions between prosody-gestures	LAQ	0.557	0.161	0.026
		HAQ	0.547	0.172	0.033

Table 4.3 Summary of mixed-effects beta regression model: Fixed effects estimates, z values, and p-values for identifying emotional congruency between prosody and gestures on task performance

Task	Parameter	z value	Pr(>|z|)
Congruency recognition	Intercept (congruent HAQ)	9.598	$p<0.001^{***}$
	Condition (Incongruent vs. Congruent)	-6.569	$p<0.001^{***}$
	Group (LAQ vs. HAQ)	5.337	$p<0.001^{***}$
	Interaction (Incongruent x LAQ)	-4.090	$p<0.001^{***}$

(*p<.05, **p<.01, ***p<.001)

4.3.3.2 Correlation analysis

Correlations between correct response rates, response time, cognitive measures of AQ, VIQ, PIQ, and FSIQ, and demographic data of age and gender were analyzed. Distribution of data was tested with the Shapiro-Wilk test, and correlations for normally distributed variables were calculated by Pearson's method and for non-normally distributed variables by Spearman's method. Significant positive inter-correlations occurred among the intelligence measures. For example, there were very high correlations between VIQ and FSIQ ($r = 0.796$, $p < 0.001$), while PIQ and FSIQ were similarly highly related ($r = 0.791$, $p < 0.001$), indicating that the higher the performance IQ the greater overall cognitive ability will be. Correct response rates, reaction time, or other cognitive and demographic variables were not significantly correlated with r-value greater than 0.4. The strongest correlations confined to cognitive measures revealed an intrinsic connection between IQ domains. Reaction time also did not vary significantly with age or AQ scores, suggesting that these factors do not notably influence performance on the task.

4.4 Differences in perception of emotional congruence from audiovisual information: An fMRI Study

4.4.1 Research questions

This research examines the brain changes indicating the recognition of emotional congruence and incongruence between prosody and gestures in a social environment, comparing individuals with high autistic-traits to age- and IQ-matched controls with low-autistic traits. Of particular interest were the following:

1. How does the neural respond in incongruent and incongruent emotional situation, and do high-autistic traits groups present different neural responses? Furthermore, how does this variability depend on the level of autistic traits?
2. What are the differences in neural activity responses between adults with high and low autistic traits when processing conflicting emotional information presented simultaneously in social conversations emotional context?

4.4.2 Experimental methods

4.4.2.1 Participants

A total of 30 participants who had previously participated in the related behavioral study were included in the fMRI study. Because one HAQ participant's data was corrupted, 29 participants were included in the final analysis. Participants were native English speakers, aged between 18 and 40 years. They were divided into two groups depending on their scores on the Autism Spectrum Quotient AQ; Baron-Cohen et al., 2001, which scored low-autistic traits below 18, and HAQ, with high-autistic traits above 29. Edinburgh Handedness Inventory Oldfield, 1971 was used for assessment of preferred hand. Of the 29 participants, 16 (5 males, 11 females) fell within the low-autistic traits group, and 13 (5 males, 8 females) fell within the high autistic traits group. All participants also completed the Wechsler Abbreviated Scale of Intelligence (WASI) to assess cognitive function (see Table 4.4).

Table 4.4 Summary of demographic characteristics of the low and high AQ groups

	Low AQ group	**High AQ group**	**Group comparison**
Cut-off score (AQ)	Below 18	Above 29	-
Number	16 (M:5, F: 11)	13(M:5, F: 8)	p=0.714 (Fisher's exact test)
Age	23.3±5.6	24.2 ±7.3	p =0.706 (Mann-Whitney U)
Handedness	16 R	13 R	-
AQ	13.8±4.5	33.7±5.1	$p < 0.001^{***}$ (Mann-Whitney U)
VIQ	113.81±8.8	121.69±9.4	$p = 0.028^{**}$ (t-test)
PIQ	116.81±14.1	119.08±8.5	p =0.615 (t-test)
FSIQ	117.06±10.5	122.85±7.1	p =0.102 (t-test)

($^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$)

4.4.2.2 Stimuli

The stimulus set used in this study originally comes from Piwek, Pollick, and Petrini (2015). These stimuli were the same and displays from the stimuli set previously descried and in behavrioal experiment. For this experiment, sixty audio-visual dialogues were chosen from this set, all 3 seconds in length and of medium intensity.

4.4.2.3 Design

The two-run fMRI experiment with block-design was carried out to explore differences in brain activation between individuals with low and high autistic traits while presenting emotional audio-visual stimuli. During every run, blocks were presented in a pseudo-randomized manner. A total of 60 stimuli for each run could be shown for up to 3 seconds (3 emotions × 10 conversations × 2 conditions). The runs consisted of 410-sec experimental sessions, with each run containing 12 blocks. Each run began with a 10-sec black screen display before video trials and was followed by an end with a 20-sec black screen display. Each block contained five stimuli and was presented in 16-second blocks, including emotion-congruent displays (e.g., happy prosody - happy gesture) and emotion-incongruent displays (e.g., happy prosody - angry gesture). Again, the congruency condition changed between blocks.

4.4.2.4 Data acquisition

Participants visited the Centre for Cognitive Neuroimaging at the University of Glasgow, where MRI data were collected on a 3T Tim Trio MRI scanner (Siemens, Germany) with a 32-channel head coil. High-resolution T1-weighted anatomical whole-brain scans were acquired using a 3D magnetization-prepared rapid acquisition gradient echo (MP-RAGE) sequence lasting 5 minutes, capturing 192 contiguous 1 mm axial slices with dimensions of 256 mm × 256 mm (TR = 1900 ms, TE = 2.52 ms, inversion time = 900 ms, FA = 9°). Functional T2-weighted images were obtained using a T2*-weighted gradient echo pulse sequence (TR = 2000 ms, TE = 62 ms, FA = 9°), with 32 axial slices (3 mm thick with a 0.3 mm gap) acquired in an ascending interleaved sequence to ensure full brain coverage. Functional data were collected across two runs, each consisting of 205 volumes and lasting 6 minutes and 50 seconds. The first two volumes of each run were dummy volumes that were not analyzed and were excluded from the fMRI data collection. No stimuli were presented during these dummy volumes.

4.4.2.5 Procedure

Each participant was fully informed and given every opportunity to ask questions before signing the consent. After screening them for imaging contraindications, the task was briefly explained. The current experiment concerned whether emotional prosody and gesture of each speaker in the conversations was matching or mismatching. What follows is that participants listened to a series of dialogues-for example, Actor 1: "Where have you been?" Actor 2: "I've just met with John," and were asked to evaluate the degree of match between the emotional expressions of the speakers.

Each run consisted of audio-visually presenting two conditions and all the stimuli were presented on a black background. The participants decided on the emotional congruence of the two speakers by responding in a forced-choice manner by pressing one of two buttons on a response box. The stimuli were designed using Presentation 14.9 software (NeuroBehavioural Systems [NBS]) and presented via electrostatic earphones (NordicNeuroLab, Norway), with a sound pressure level of 80 dB. Then, unless the sound was comfortably heard by participants with respect to the standard noise presented by the scanner, the operator matched the sound before entering the scanning.

4.4.3 Analysis

4.4.3.1 fMRI pre-processing

All fMRI data were collected, pre-processed, and analyzed using BrainVoyager QX Version 2.8. The first two functional volumes were excluded to account for T1 stabilization. A standard pre-processing pipeline was applied to each participant's functional data (Goebel, Esposito, & Formisano, 2006). Slice timing correction was performed using sinc interpolation, and movement correction based on rigid body transformation was used to compensate for slight head movements. Estimated translations and rotations were within 3 mm or 3 degrees. Functional MR images underwent spatial smoothing with an isotropic Gaussian filter (6 mm FWHM) and were temporally filtered using a high-pass filter of three cycles. Data were registered to the AC-PC plane (anterior commissure-posterior commissure) and normalized to Talairach standard space (Talairach

& Tournoux, 1988). Each participant's anatomical data were co-registered with their functional data, producing normalized 4D volumetric time-course (VTC).

4.4.3.2 Data analysis

The identification of emotional congruence between prosody and gestures was analyzed using a second-level, multi-subject, random effects (RFX) general linear model (GLM). A 2 (Group: LAQ, HAQ) × 2 (Congruence: Congruent, Incongruent) repeated-measures ANOVA was conducted, with Group as the between-subject factor and Congruence as the within-subject factor. Significant brain activations were identified using one-sample t-tests within each group for both conditions (congruent, incongruent) in audio-visual information and their contrasts (congruent > incongruent; incongruent > congruent). Additionally, univariate ANOVA was conducted to explore group and condition effects on each contrast. To correct for multiple comparisons, a false discovery rate (FDR) correction was applied at $q = 0.05$. Small clusters were removed using a minimum cluster size ($p<0.05$) determined by 1,000 Monte Carlo simulations. All reported clusters met criteria for correction of multiple comparisons at the whole-brain level. Brain regions of interest were localized by using Talairach coordinates with the aid of the Talairach Client software (Lancaster et al., 2000) which allows for mappings of functional activation. Separate correlation analyses were performed for both the LAQ and HAQ groups using AQ and the subdomains of IQ: the Verbal IQ and Performance IQ. For each group, correlated brain regions were reported using an uncorrected threshold of $p = 0.001$.

4.4.4 Results

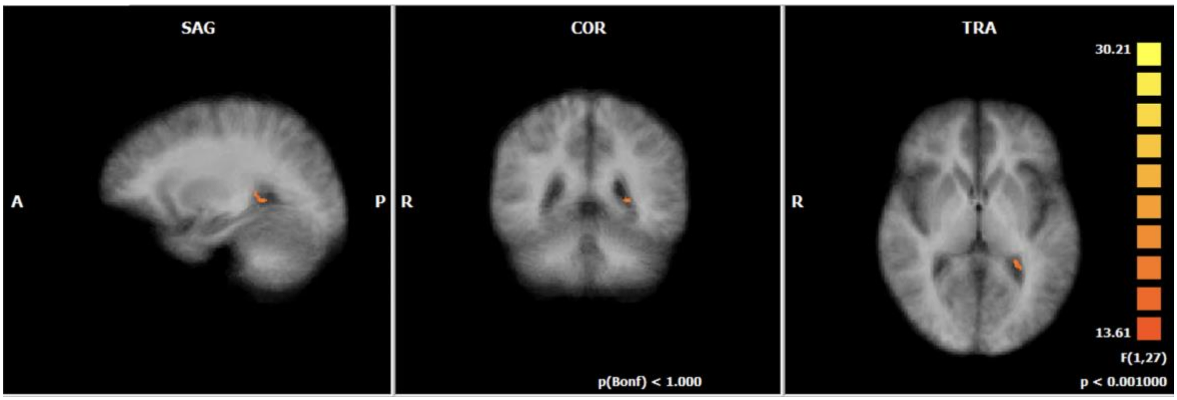
4.4.4.1 Main effect of group, congruence, and interaction between the factors

A 2 (Group: LAQ, HAQ) × 2 (Congruence: Congruent, Incongruent) repeated-measures ANOVA was performed to investigate differences in neural activity between groups and congruence conditions. The analysis reported here showed that the main effects for group and congruence were significant, but the interaction between them was not. The different levels of congruence caused activations in several areas of the brain. The main effect of group yielded significant activation in the left fusiform gyrus (FG), reflecting differential processing between LAQ and HAQ groups. Significant activations in several regions including right inferior frontal gyrus (IFG), right middle frontal gyrus (MFG), right insula, right superior frontal gyrus (SFG), left putamen, and left precentral gyrus (PreCG) were found for the factor of congruence. During the experiment, these regions showed distinctive activation, indicating that there was a significant difference in brain response between congruent and incongruent stimuli. These activations suggest that these regions differentially process the congruence of emotional prosody and gestures. (see Table 4.5, Figure 4.1).

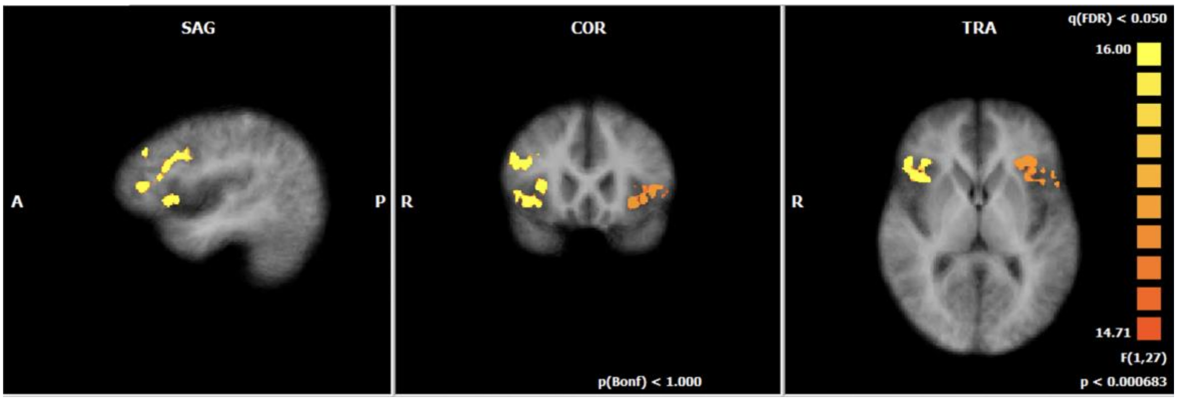
Table 4.5 The significant clusters from the results of a 2 x 2 ANOVA with group as a between-subjects factor and congruence as a within-subjects factor

Contrast	Region	Talairach coordinate of peak voxel x, y, z	L/R	F	p	Number of Voxels
Main effect of group	Fusiform Gyrus	-27,-43,1	L	29.22	0.00001	131
Main effect of congruence	Inferior Frontal Gyrus, pars opercularis	48,14,13	R	19.79	0.000134	147
	Middle Frontal Gyrus	33,5,28	R	46.60	<0.000001	2829
	Insula	36,26,4	R	45.14	<0.000001	2734
	Superior Frontal Gyrus	42,35,31	R	25.44	0.000027	240
	Putamen	-27,17,-2	L	59.84	<0.000001	2820
	Precentral Gyrus	-30,5,31	L	38.40	0.000001	1743
Interaction	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Significant brain area was activated in the main effect of group during the emotional congruency task



(b) Brain areas exhibiting significant activation due to the main effect of condition during the emotional congruency task

Figure 4.1 Brain regions in both groups exhibited significant (a) main effects of group and (b) condition during the task of recognizing emotional congruence and incongruence between prosody and gestures.

4.4.4.2 Individual contrast

No significant interactions were found; however, we conducted t-tests for each group in both audio-visual conditions and contrasts separately. The results were assessed in two conditions, and each condition's impact was analyzed within the groups before making comparisons between groups. The analyses included two congruence conditions (congruent and incongruent) and contrast comparisons (congruent > incongruent, incongruent > congruent).

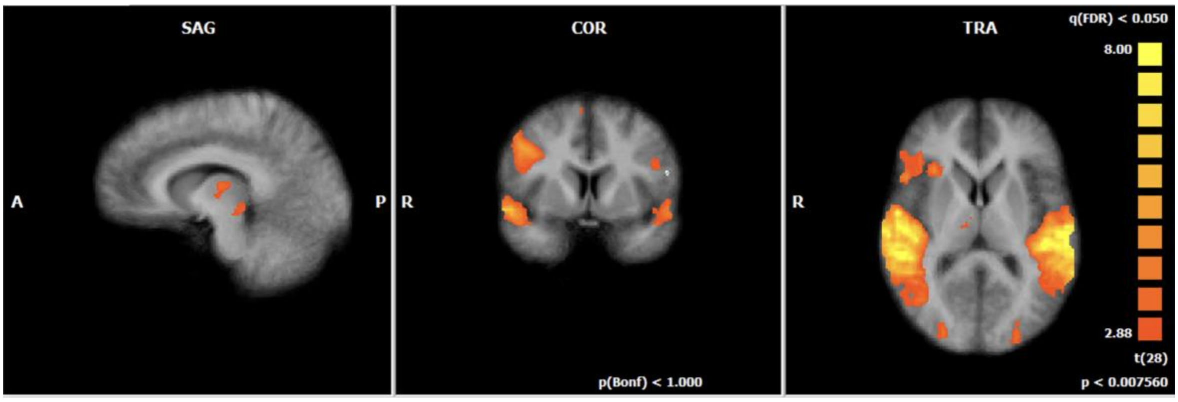
(1) Congruent condition

Table 4.6 shows the results of the congruent condition analysis by group. Both the LAQ and HAQ groups exhibited activation in the right superior temporal gyrus (STG) and brainstem. In the LAQ group, significant activations were observed in regions including the right superior temporal gyrus (STG), right precuneus, brainstem, right thalamus, right medial frontal cortex (MeFC), left inferior frontal gyrus (IFG), and left precentral gyrus (PreCG). In the HAQ group, significant activity was noted in the right middle temporal gyrus (MTG), right superior frontal gyrus (SFG), right supplementary motor cortex (SMC), brainstem, left superior temporal gyrus (STG), and left precuneus. No significant differences were found between the LAQ and HAQ groups in the congruent audio-visual condition in group comparisons (see Table 4.6, Figure 4.2).

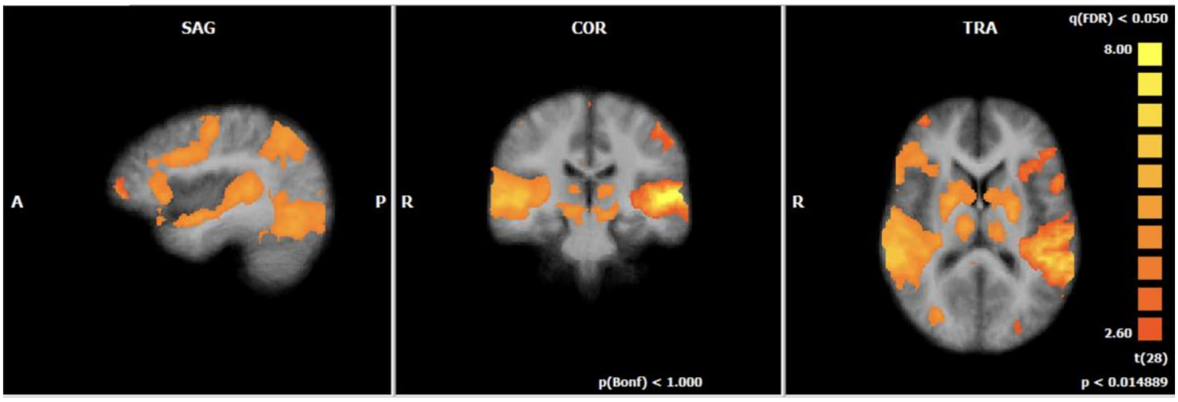
Table 4.6 Significant neural activation was observed in the LAQ group, the HAQ group, and in group comparisons during the processing of emotionally congruent prosody and gestures in conversations

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Condition: Congruent						
LAQ group	Superior Temporal Gyrus, posterior division	51,-19,4	R	12.41	<0.000001	59783
	Precuneus	30,-58,40	R	5.87	0.000003	4879
	Brainstem	6,-28,-5	R	6.61	<0.000001	596
	Thalamus	6,-16,13	R	3.92	0.000517	490
	Medial Frontal cortex	3,-4,64	R	4.46	0.000121	575
	Brainstem	-15,-22,-5	L	5.08	0.000022	431
	Superior Temporal Gyrus, posterior division	-51,-22,4	L	11.93	<0.000001	36156
	Precuneus	-30,-52,40	L	5.31	0.000012	1112
	Inferior Frontal Gyrus, pars opercularis	-48,17,19	L	4.09	0.000326	1023
	Precentral Gyrus	-42,-7,46	L	4.68	0.000067	701
HAQ group	Middle Temporal Gyrus	54,-34,10	R	12.02	<0.000001	112940
	Superior Frontal Gyrus	35,50,4	R	5.10	0.000021	730
	Supplementary Motor Cortex	6,8,55	R	4.74	0.000056	4520
	Brainstem	3,-43,16	R	4.37	0.000154	1093
	Superior Temporal Gyrus	-51,-22,4	L	11.69	<0.000001	65104
	Precuneus	-24,-70,25	L	5.81	0.000003	9704
LAQ > HAQ	n. s					
HAQ > LAQ	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Significant brain regions activated in the LAQ group during the processing of emotional congruence between prosody and gestures



(b) Significant brain regions were activated in the HAQ group while processing emotional congruence between prosody and gestures

Figure 4.2 Both the (a) LAQ and (b) HAQ groups showed significant brain activations while processing emotionally congruent audio-visual information, but significant differences between the groups were not identified, as indicated in Table 4.6.

(2) Incongruent condition

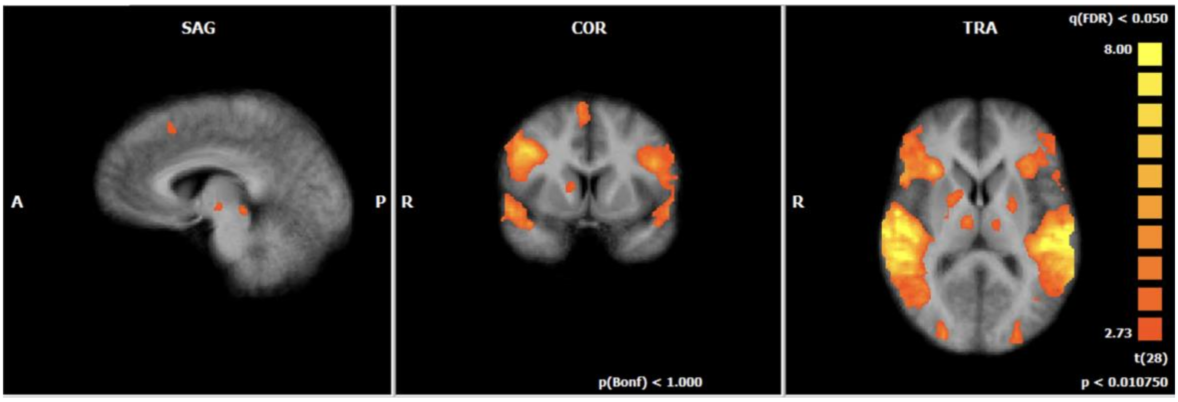
Details of the incongruent audio-visual condition analysis results within and between groups are shown in Table 4.7. Figure 4.2 display the regions activated in both the LAQ and HAQ groups, highlighting overlapping activation in the right middle temporal gyrus (MTG) and the cerebellum. The LAQ group showed neural activation in the right superior occipital gyrus (SOG), right caudate, brainstem, right medial frontal cortex (MeFC), left thalamus, left putamen, and bilateral precuneus.

By contrast, the HAQ group revealed significantly increased activations in the right middle temporal gyrus (MTG), right cerebellum, right supplementary motor cortex (SMC), left posterior cingulate gyrus (PCG), and left middle frontal gyrus (MFG). Group comparison analysis showed no significant differences between the LAQ and HAQ groups in the incongruent condition (see Table 4.7, Figure 4.3).

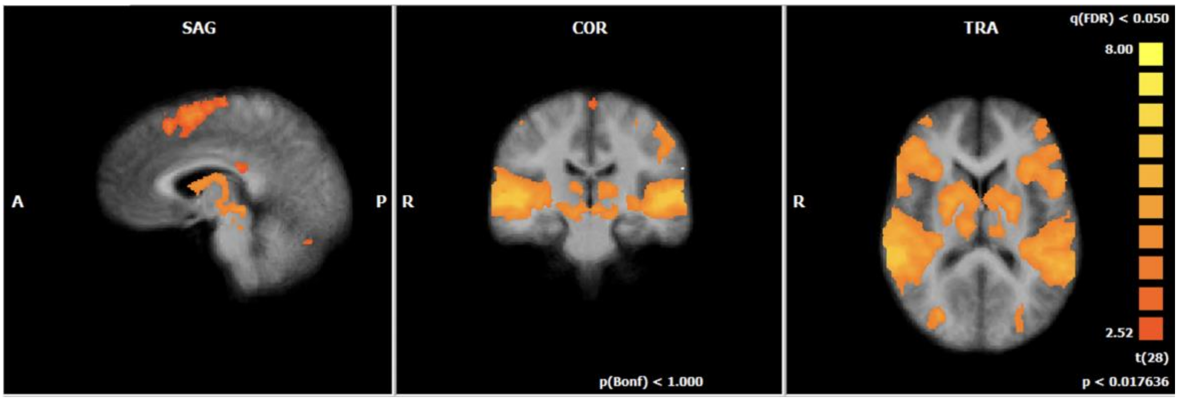
Table 4.7 Both the LAQ and HAQ groups, as well as their group comparisons, showed significant neural activation while processing emotionally incongruent prosody and gestures in conversations

Group	**Anatomical regions**	**Talairach coordinate of peak voxel (x, y, z)**	**L/R**	**t**	**p**	**Number of Voxels**
Condition: Incongruent						
LAQ group	Middel Temporal Gyrus	54,-34,10	R	12.50	<0.000001	79933
	Superior Occipital Gyrus	27,-80,28	R	6.20	0.000001	7568
	Cerebellum	12,-76,-23	R	4.16	0.000273	600
	Caudate	15,2,10	R	5.10	0.000021	1587
	Brainstem	6,-28,-5	R	5.51	0.000007	2770
	Meidal Frontal Cortex	3,-4,64	R	5.10	0.000021	4648
	Thalamus	-1,-13,1	L	4.12	0.000305	743
	Brainstem	-12,-25,-5	L	5.09	0.000022	740
	Sueprior Temporal Gyrus	-51,-22,4	L	12.00	<0.000001	55306
	Putamen	-21,-7,13	L	4.11	0.000316	566
	Precuneus	-24,-73,25	L	4.62	0.000078	532
	Precuneus	-30,-52,40	L	5.45	0.000008	3220
HAQ group	Middle Temporal Gyrus	54,-34,10	R	12.51	<0.000001	244594
	Cerebellum	21,-76,-26	R	5.04	0.000025	829
	Supplementary Motor Cortex	6,8,55	R	5.49	0.000007	9689
	Cingulate Gyrus, posterior division	0,-31,25	L	4.09	0.00033	873
	Middle Frontal Gyrus	-39,35,22	L	4.26	0.000208	636
LAQ > HAQ	n. s					
HAQ > LAQ	n. s					

(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) Significant brain regions were engaged in the LAQ group during the processing of emotional incongruence between prosody and gestures



(b) In the HAQ group, significant brain activations occurred during the processing of emotional incongruence between prosody and gestures

Figure 4.3 Both the (a) LAQ and (b) HAQ groups demonstrated significant brain activations while processing emotional incongruence between prosody and gestures in conversations; however, the comparison between the groups revealed no significant differences, as shown in Table 4.7.

(3) Congruence condition contrasts

There were no significant results in any of the contrasts comparing congruent > incongruent and incongruent > congruent conditions, either within groups or between groups.

4.4.4.3 Correlation analysis

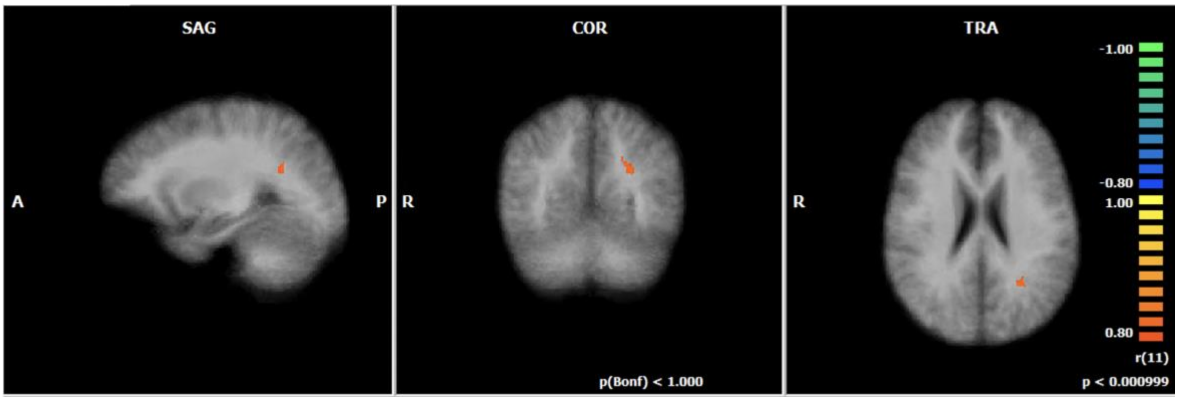
The results of the correlation analysis between the AQ scores and the emotionally congruent audio-visual information are presented in Table 4.8 and show a different pattern in the LAQ and HAQ groups. No significant correlations were found in the LAQ group for the congruent condition. In contrast, in the HAQ group, a strong positive correlation was present in the left precuneus ($r = 0.92$, $p = 0.000009$), with a very significant association of AQ scores with activity in this region (see Figure 4.4 (a)).

In the incongruent condition, the LAQ group once again failed to exhibit significant correlations where the HAQ group revealed strong positive correlations in the left caudate ($r = 0.90$, $p = 0.000026$) and the left precuneus ($r = 0.95$, $p = 0.000001$), indicating a robust correlation between higher AQ scores and neural responses during incongruent processing (see Figure 4.4 (b)). While comparing congruent with incongruent conditions, no significant correlations were shown in the LAQ group. The HAQ group had a significant negative correlation in the right middle temporal gyrus (MTG), suggesting a differential brain activity pattern that distinguishes these two conditions from within the HAQ group as shown in Figure 4.4 (c).

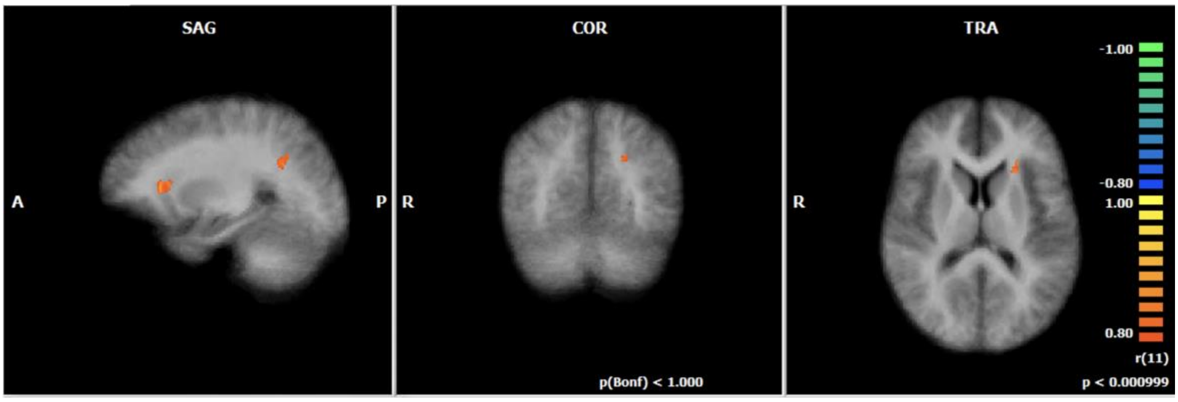
Table 4.8 Analysis of the correlation between the emotional congruence of audio-visual information during conversations and AQ scores

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	r	p	Number of Voxels
Condition: Congruent						
LAQ group	n. s					
HAQ group	Precuneus	-24,-55,25	L	0.92	0.000009	164
Condition: Incongruent						
LAQ group	n.s					
HAQ group	Caudate	-21,20,10	L	0.90	0.000026	141
	Precuneus	-21,-55,28	L	0.95	0.000001	305
Condition: Congruent > Incongruent						
LAQ group	n.s					
HAQ group	Middle Temporal Gyrus	57,-43,13	R	-0.89	0.000041	143

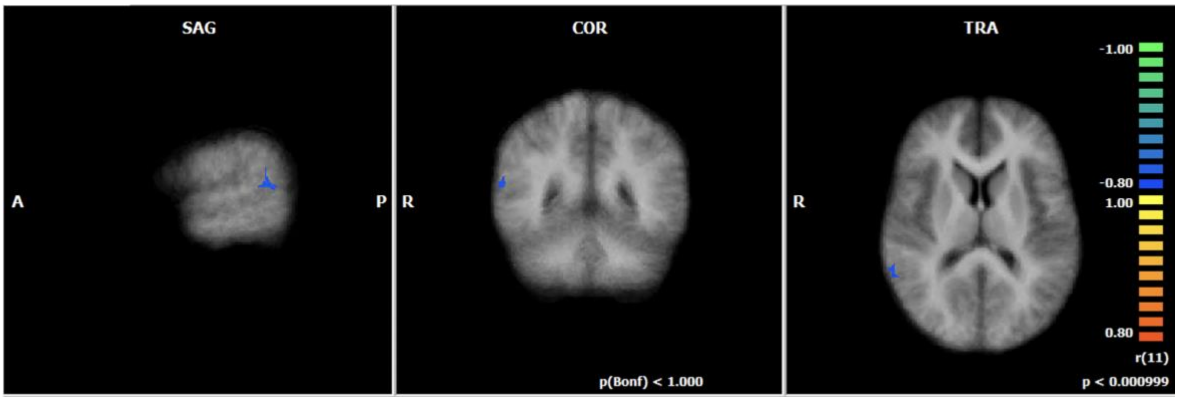
(x, y, z are stereotaxic coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at $p<0.001$ at the uncorrected level)



(a) Brain regions significantly correlated with AQ scores in the HAQ group when processing emotionally congruent audio-visual information



(b) Areas of the brain showing significant correlation with AQ scores in the HAQ group during emotionally incongruent audio-visual information



(c) Brain regions that exhibit significant negative correlation with AQ scores in the HAQ group when contrasting congruent and incongruent conditions (congruent > incongruent condition)

Figure 4.4 The figures illustrate the brain regions significantly associated with AQ scores in the HAQ group while processing emotionally congruent and incongruent audio-visual information

4.5 Summary and Discussion

The present research aimed to investigate how individuals with high- and low-autistic traits differ in behavioral and neural responses to emotional congruence and incongruence in audiovisual social contexts of prosody and gesture. These findings extend the knowledge about the specific neural and behavioral signatures associated with the processing of emotional information conveyed by individuals with high autistic traits. Consistent with previous research, the reuslts demonstrate that individuals with ASD as well as those with high-autistic traits show divergent performances regarding recognizing facial emotions, pointing to a difference in neural mechanisms between these processes (Baron-Cohen et al., 2019; Harms et al., 2010; Kliemann et al., 2010).

Behavioral findings showed that participants in the LAQ group outperformed those in the HAQ group in recognizing emotional congruence, particularly when cues were congruent. This suggests that individuals with low autistic traits may utilize multisensory cues more efficiently, enabling more automatic emotional interpretation. Conversely, the HAQ group exhibited lower accuracy even under emotionally congruent conditions, suggesting broader difficulties in multisensory integration. This finding is consistent with previous research reporting reduced integration of audiovisual stimuli in individuals with autistic traits (Cascio et al., 2012; Paton et al., 2012) and aligns with the Enhanced Perceptual Functioning (EPF) model, which posits a reduced reliance on integrative processing in autism (Mottron et al., 2006).

The LAQ group’s performance in congruent conditions supports the idea that they effectively use sensory information to decode emotional expressions. Conversely, the HAQ group’s difficulty in processing congruent cues points toward impairments in sensory integration (Robertson & Baron-Cohen, 2017; Noel et al., 2017). These challenges suggest that individuals with high autistic traits use compensatory strategies that are less effective than those employed by neurotypical individuals, highlighting a complex interplay of sensory processing deficits and cognitive compensation (Baum et al., 2015).

Both groups exhibited more pronounced difficulties under incongruent conditions, where emotional cues from prosody and gesture did not align. The HAQ group was significantly slower and less accurate in recognizing these incongruent emotional signals, consistent with findings that discordant sensory inputs require additional cognitive resources for resolution (Liu et al., 2021; Vasilevska Petrovska & Trajkovski, 2019). Results highlight the central role of sensory congruence in making accurate emotion perception possible and show that incongruent emotional cues place high cognitive demands on individuals with high autistic traits, who must work harder to resolve conflict between distinctive pieces of information coming from different sensory modalities.

Neuroimaging findings, however, did not reveal statistically significant group differences in whole-brain analyses between the HAQ and LAQ groups. While this limits the ability to draw definitive conclusions about neural divergence, qualitative observations of activation maps suggested distinct neural engagement strategies. For example, during congruent conditions, the LAQ group exhibited greater activation in sensory integration areas such as the superior temporal gyrus (STG) and fusiform gyrus (FG)—regions associated with the efficient processing of multisensory emotional information (Brown et al., 2022; Gao et al., 2020).

Conversely, the HAQ group showed more marked activation within brain structures implicated in cognitive control, mainly the left caudate and precuneus, during incongruent conditions. This pattern of activation suggests a compensatory response to the greater cognitive load imposed by incongruent stimuli, where individuals with high autistic traits tend to engage more cognitive resources to handle conflicting emotional cues (Dajani et al., 2015). This dependence on cognitive control regions suggests that individuals with high- autistic traits may employ more effortful and strategic modes to resolve emotional conflict, independent of direct emotional information provided by sensory integration (Keehn et al., 2016; Bird et al., 2016)

Further, higher AQ scores are associated with increased engagement of internal cognitive and self-referential networks, including the caudate and precuneus, particularly during incongruent emotional processing. This suggests that individuals with higher autistic traits may adopt compensatory strategies involving internally driven mechanisms when external emotional cues are ambiguous or conflicting (Bird et al., 2016; Lind et al., 2008).

While these neuroimaging findings should be interpreted cautiously given the lack of significant group-level contrasts, they nonetheless provide valuable qualitative insights into possible compensatory mechanisms and variability in neural engagement.

This study is not without limitations. The modest sample size may have reduced the power to detect significant neural differences. Future research should include a larger and more diverse participant pool, incorporate additional emotional categories (e.g., fear, sadness), and apply advanced analyses such as functional connectivity or multivariate approaches (Bzdok et al., 2018).

In summary, this study highlights distinct behavioral patterns and potential neural processing differences in individuals with high-autistic traits, particularly in response to emotional congruence and incongruence. While no significant neural group differences were found, qualitative patterns suggest differential recruitment of brain networks. These findings underscore the complexity of emotion perception and point to the importance of considering both behavioral and neurocognitive factors in understanding social-communication challenges associated with autistic traits. Further research is essential to refine our models and inform more tailored interventions for individuals with ASD or high-autistic traits.

5 Multisensory Integration of Emotional Audiovisual Stimuli in Adults with High-Autistic Traits

5.1 Abstract

The present research used fMRI to investigate the underlying brain mechanisms in the interpretation of emotional sounds and gestures in adults with different autistic traits. Integration of information across multiple senses plays an important role in understanding emotional expressions and social communication, and impaired integration of emotional audio-visual events stands out as a core feature of high-autistic traits. Subjects were divided into LAQ and HAQ groups based on their scores. The super-additive and max criteria were used to identify patterns of brain activation in tasks with angry or happy tones that had associated gestures. It was found that each group namely LAQ and HAQ have their distinct brain response patterns. There was notable left anterior cingulate cortex (ACC) activation for the LAQ group for combining an angry voice with angry gestures indicating heightened emotional valuation as well as allocation of cognitive resources. For the HAQ group however, they showed a more extensive activation in the right superior frontal gyrus (SFG) and bilateral anterior cingulate cortex (ACC), and left precuneus, suggesting more dependence on cognitive and visual processing networks. The max criteria did indicate some level of engagement in auditory and visual processing areas for the LAQ group in comparison to the HAQ group who recruited more motor and memory processing regions indicating compensatory integration strategies. As for the happy condition, super-additive criteria did not indicate any significant activations for the LAQ group but marked activation was seen in the frontal and occipital lobes among HAQ group. These findings indicate that in individuals with high autistic traits, neural networks involved in multisensory emotional processing are less specialized and more effortful; thus, they point to the necessity of more focused interventions with heightened emphasis on the improvement of social communication in this group.

5.2 Introduction

Multisensory integration-the process whereby the brain integrates information from multiple senses-is imperative to functional human contact and communication. The capacity to combine auditory and visual information, such as speech prosody and facial expression, is of primary importance in the accurate identification of emotions, specifically within complex social situations (Murray et al., 2012; Noel et al., 2017). In recent years, however, more emphasis has been given to how such integration processes are altered in individuals with ASD and high autistic traits, given their documented difficulties in social-emotional communication and emotion perception (Baum et al., 2015; Cascio et al., 2016: Robertson & Baron-Cohen, 2017).

In recent years, there has been a constant stream of evidence from functional magnetic Resonance Imaging (fMRI) studies highlighting significant disruptions in the neural mechanisms underlying multisensory processing among individuals with ASD, especially in several critical brain areas playing crucial roles in integrating auditory and visual emotional information, such as superior temporal gyrus (STG), fusiform gyrus (FG), and amygdala (Beauchamp et al., 2010; Maximo et al., 2014; Nomi et al., 2015; Zilbovicius et al., 2013). The superior temporal gyrus (STG) normally provides the critical coordination between facial expressions and tones of voice, it is usually under-activated and under-connected in individuals with ASD, impairing the smooth processing of audiovisual emotional signals. Despite these challenges, the superior temporal gyrus (STG) still activates robustly in response to auditory stimuli alone, highlighting its crucial role in emotional tone processing in voices.

Integration of emotional audiovisual stimuli-for example, facial expressions paired with prosodic cues-forms an integral part of social interaction. Typically developing individuals demonstrate robust neural responses within multisensory areas, while processing these combined stimuli. Those with high-autistic traits frequently demonstrate reduced or aberrant patterns of activation (Kleinhans et al., 2008; Nomi & Uddin, 2015). These neural abnormalities are further related to challenges in conducting tasks that call for processing of incongruent emotional information, for which there is a discrepancy between the facial expression and the tone of voice (Collignon et al., 2008). This results in individuals with ASD having to utilize compensatory neural strategies, such as increased cognitive control, more often than others (Lerner et al., 2013). This reliance reflects the extra effort required in by individuals with ASD while processing and integrating complex emotional cues that neurotypical individuals can interpret more automatically.

The recent research has pointed out the emphasis of autistic traits on the neural mechanism of emotional perception from audiovisual stimuli, especially those related to the fusiform (FG) gyrus and amygdala in terms of the recognition of combined facial and vocal stimuli. In this respect, altered activation and connectivity between such bilateral regions may yield fragmented emotional perception that makes it hard for people with ASD to interpret the emotional states of others (Kleinhans et al., 2008; Kana et al., 2009; Just et al., 2012). For example, functional connectivity disruptions between the fusiform gyrus (FG) and amygdala have been associated with impaired integration of audiovisual emotional information; such deficits are not localized but rather reflect more pervasive network-level disruptions that massively impede social and emotional perception (Rudie et al., 2013; Alaerts et al., 2014).

Conjunction analysis of sensory processing is a crucial tool for identifying overlapping neural activation patterns across various sensory modalities, helping to pinpoint essential multisensory processing regions such as the superior temporal gyrus (STG), fusiform gyrus (FG), and prefrontal cortex (PFC) (Gao et al., 2023; Beauchamp, 2005). Conjunction analyses in individuals with ASD commonly reveal reduced activation in key multisensory integration regions, with compensatory recruitment of alternative neural networks. This pattern suggests that integration deficits in ASD extend beyond low-level sensory processing and reflect broader disruptions in the neural systems responsible for social and emotional cognition (Martínez-Sanchis, 2014; Müller et al., 2011).

Three principal statistical methods have been used to identify brain regions where multisensory integration is taking place in our case audiovisual processing. These methods use the patterns of activation for unisensory and multisensory stimulation to determine whether multisensory processing is taking place and are known as the super-additive, max, and mean criteria:

Super-Additive Criteria This method assesses whether the combined neural response to multisensory stimuli exceeds the sum of individual responses to audio and visual stimuli, isolating unique brain regions involved in multisensory integration beyond mere sensory processing (Joassin et al., 2011). In ASD, the super-additive approach commonly shows less activation compared to neurotypical controls, suggesting a core deficit in the ability to effectively process multisensory emotional information (Stevenson et al., 2014).

Max Criteria The max criteria compare the neural response to multisensory stimuli with the largest response to any single sensory modality, measuring how integration reduces processing loads (Beauchamp, 2005). In individuals with ASD, emotional integration often involves increased recruitment of cognitive control regions—such as the dorsolateral prefrontal cortex (dlPFC), anterior cingulate cortex (ACC), and basal ganglia—suggesting a compensatory mechanism rather than automatic processing. This pattern has been observed in neuroimaging studies involving emotional conflict and decision-making tasks (Schmitz et al., 2006; Dichter et al., 2009).

Mean Criteria This approach compares the multisensory response to the average of unisensory responses, identifying regions where integration aligns with typical levels of sensory activation. In ASD research, this approach often shows less-than-optimal integration, demonstrating that while some multisensory emotional processing occurs, it is not to the extent seen in typically developing individuals, supporting the notion of suboptimal multisensory neural function in this population (Bolis et al., 2017; Courchesne et al., 2019).

Social communication relies heavily on multisensory integration, which combines auditory and visual emotionally relevant events in a dynamic process. However, individuals with high autistic traits often exhibit severe deficits in this integrative capacity, particularly when processing complex and real-world stimuli. Recent advances in fMRI, particularly the use of conjunction (max/mean) and super-additivity criteria, have clarified how multisensory integration deficits in ASD result from large-scale network disruptions and compensatory dynamics (Regener, 2015; Foss-Feig et al., 2016).

In this chapter, we explore the neural correlates of cross-modal integration of emotional prosody and gestures in individuals with high and low autistic traits. Using two statistical measures (super-additive and max criteria), this study characterizes neural responses to identify specific integration signatures that differentiate emotional information from other stimuli, emphasizing the locations and nature of discrepancies in emotional processing.

5.3 Differences in the multisensory integration processing of emotional prosody and gestures: An fMRI study

5.3.1 Research questions

This study aimed to identify differences in brain regions involved in the multisensory integration of emotional prosody and gestures between individuals with high and low autistic traits, using two statistical criteria: super-additive and max criteria.

The research questions examined were:

1. How do brain activation patterns differ between individuals with high- and low-autistic traits during the multisensory integration of emotional prosody and gestures?
2. Do the super-additive and max criteria statistical methods reveal regional differences in brain activation between groups during the combined processing of emotional prosody and gestures?

5.3.2 Experimental Methods

5.3.2.1 Participants

Thirty participants were initially recruited for this fMRI study. Due to data integrity issues, one participant from the high-autistic traits group (HAQ) was excluded, resulting in 29 participants for the final analysis (see Table 5.1). All participants were native English speakers aged 18 to 40. They were divided into low-autistic traits (LAQ) and high-autistic traits (HAQ) groups based on their Autism Spectrum Quotient (AQ) scores. Participants with scores above 29 were placed in the HAQ group, while those with scores below 18 were assigned to the LAQ group. Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Sixteen participants (5 males, 11 females) were assigned to the LAQ group, and thirteen participants (5 males, 8 females) were assigned to the HAQ group. Cognitive ability was measured using the Wechsler Abbreviated Scale of Intelligence (WASI).

Table 5.1 Summary of demographic information for the low and high AQ groups

	Low AQ group	High AQ group	Group comparison
Cut-off score (AQ)	Below 18	Above 29	-
Number	16 (M:5, F: 11)	13(M:5, F: 8)	p=0.714 (Fisher's exact test)
Age	23.3±5.6	24.2 ±7.3	p =0.706 (Mann-Whitney U)
Handedness	16 R	13 R	-
AQ	13.8±4.5	33.7±5.1	$p < 0.001^{***}$ (Mann-Whitney U)
VIQ	113.81±8.8	121.69±9.4	$p = 0.028^{**}$ (t-test)
PIQ	116.81±14.1	119.08±8.5	p =0.615 (t-test)
FSIQ	117.06±10.5	122.85±7.1	p =0.102 (t-test)

(*p<.05, **p<.01, ***p<.001)

5.3.2.2 Stimuli

This study used stimuli created by Piwek, Pollick, and Petrini (2015), which featured 20 male actors aged 17–43 years performing various emotional scenarios. The dataset contained 242 displays of actor pairs, showing emotions (angry or happy) at different intensity levels (low, medium, high), interactions involving different dialogue types (inquiry or deliberation), and a neutral state. The stimuli were recorded using a 12-camera Vicon MXF40 motion capture system at 120 fps. The stimuli were processed into three formats: Audio-Only, Visual-Only, and Audio-Visual. In the present study, a total of 60 stimuli were used, including 20 from each modality (Audio-Only [AO], Visual-Only [VO], and Audio-Visual [AV]), encompassing both emotion conditions (angry and happy). Each stimulus was 3 seconds in length with medium intensity.

5.3.2.3 Design

A two-run fMRI block-design experiment was employed to investigate differences in neural activation between individuals with low and high levels of autistic traits during the presentation of emotional stimuli. Sixty stimuli (2 emotions × 3 modalities × 10 conversations) were presented per run in a pseudo-random order, with each stimulus displayed for up to 3 seconds. Each 410-second run began with a 10-second black screen and ended with a 20-second black screen to allow for the loading of a new video clip. Each of the 12 blocks lasted 16 seconds and included five stimuli expressing the same emotion and modality, with conditions varying across blocks.

5.3.2.4 Data acquisition

Participants visited the Centre for Cognitive Neuroimaging at the University of Glasgow, where they underwent MRI scanning using a Siemens 3T Tim Trio MRI scanner equipped with a 32-channel head coil. The imaging protocol included a 5-minute structural T1-weighted scan using a 3D MP-RAGE sequence, capturing 192 contiguous 1 mm slices with a field of view of 256 mm × 256 mm. The scanning parameters were TR = 1900 ms, TE = 2.52 ms, inversion time (TI) = 900 ms, and flip angle = 9°. Functional T2*-weighted images were obtained using an echo-planar gradient-echo sequence with TR = 2000 ms, TE = 62 ms, and FA = 9°, capturing 32 axial slices (3 mm thick with a 0.3 mm gap) in an ascending interleaved sequence to ensure full brain coverage. Functional data were collected in two runs, each lasting 6 minutes and 50 seconds, with 205 volumes per run. The first two volumes were treated as dummy volumes and were excluded from the analysis.

5.3.2.5 Procedure

Participants were thoroughly briefed on the study and given the opportunity to ask questions before providing consent. A safety check was conducted to ensure their suitability for MRI scanning, followed by an explanation of the scanning procedure. The primary aim was to evaluate emotional recognition across audio-only, visual-only, and audio-visual modalities. Participants performed a forced-choice task to identify emotions expressed in the conversations, using a response box. Each block contained stimuli of the same modality type, and participants were requried to respond at the end of each block rather than after each individual stimuli. Stimuli were delivered through electrostatic earphones at 80 dB using Presentation 14.9 software, with adjustments made for comfort against scanner noise.

5.3.3 Analysis

5.3.3.1 fMRI pre-processing

All fMRI data were preprocessed and analyzed using BrainVoyager QX Version 2.8. The first two functional volumes were excluded to allow for signal stabilization. The standard preprocessing pipeline was applied (Goebel, Esposito, & Formisano, 2006), which included slice timing correction using sinc interpolation and 3D motion correction to compensate for small head movements through rigid-body transformations. Translation and rotation parameters were kept within 3 mm or 3 degrees. Functional images underwent high-pass filtering with three cycles and spatial smoothing using a 6 mm FWHM Gaussian kernel. The data were aligned in the AC–PC plane and transformed into Talairach space (Talairach and Tournoux, 1988). Each functional time series volume was co-registered with the corresponding anatomical volume and normalized into a 4D volume time course.

5.3.3.2 Data analysis

A second-level, multi-subject random-effects (RFX) general linear model (GLM) was used to compare emotion processing across three modalities. A 2 (Group: LAQ, HAQ) × 6 (2 Emotions × 3 Modalities: Angry_Audio-only, Happy_Audio-only, Angry_Visual-only, Happy_Visual-only, Angry_Audio-visual, Happy_Audio-visual) repeated-measures ANOVA was conducted, with group as the between-subjects factor and emotional modalities as the within-subjects factor.

To characterize brain activations specifically related to the multisensory integration of prosody and gesture, a subtraction based on the super-additive effect was employed. This effect stipulates that the summation of bimodal responses yields higher activity than the sum of unimodal responses when baseline levels are accounted for (Joassin et al., 2011). The difference between the bimodal condition (AV) and the unimodal conditions of prosody (A) and gestures (V) was calculated as AV - [A + V]. The max criterion was also applied to determine regions where the multisensory response was greater than any unisensory response using AV-max(A, V) (Beauchamp, 2005): $(AV > A) \cap (AV > V)$. Additionally, a univariate ANOVA was used to test the main effects of group (LAQ, HAQ) and modality conditions on brain activations that differed based on emotional or sensory functions associated with neural coding across groups.

False discovery rate (FDR) correction was applied for multiple comparisons at $q = 0.05$. Clusters were thresholded to remove small clusters ($p<0.05$) based on Monte Carlo simulations (1000 iterations; minimum cluster size).Only clusters surviving correction for multiple comparisons at the whole-brain level were reported. Activated voxels were identified using Talairach coordinates with the "Talairach Client" software (Lancaster et al., 2000), which aided in mapping functional brain regions of interest. Separate correlation analyses were performed for both the LAQ and HAQ groups using AQ and the subdomains of IQ: the Verbal IQ and Performance IQ. For each group, correlated brain regions were reported using an uncorrected threshold of $p = 0.001$.

5.3.4 Results

5.3.4.1 Main effect of group, emotional modality, and interaction between the factors

A 2 (Group: LAQ, HAQ) × 6 (2 Emotions x 3 Modalities, Emotional modality: Angry_Audio-only, Happy_Audio-only, Angry_Visual-only, Happy_Visual-only, Angry_Audio-visual, Happy_Audio-visual) repeated-measures ANOVA was conducted to examine neural activity differences across groups and emotional modalities. The analyses using the super-additive and max criteria methods did not reveal significant results, suggesting no substantial differences in neural activation based on group, emotional modality, or interactions between these factors.

5.3.4.2 Individual contrast

Since no significant main effects or interactions were observed, contrasts of audiovisual integration were conducted within each group and between groups using super-additive and max criteria. These contrasts specifically focused on Angry and Happy emotions to assess neural activation patterns related to multisensory integration.

1) Angry emotion

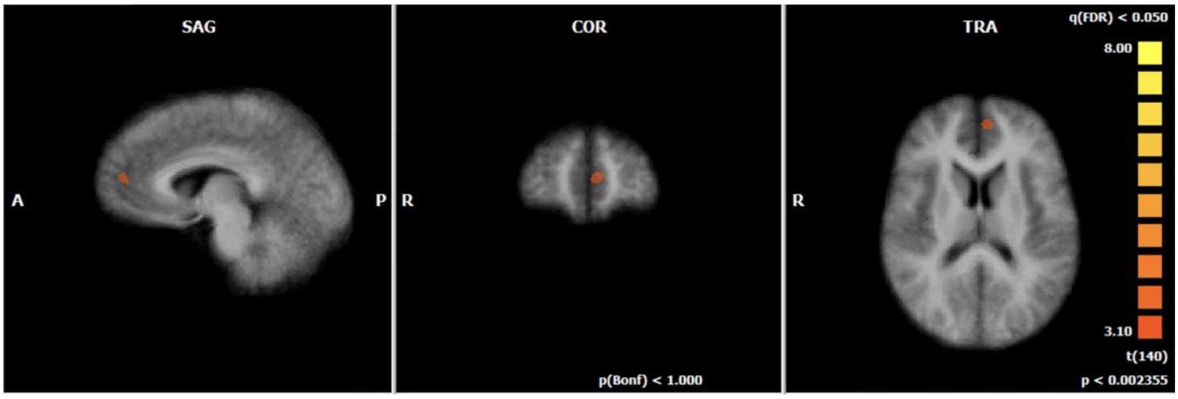
Table 5.2 presents the multisensory integration results for angry prosody and gestures. In the LAQ group, the super-additive method revealed significant activation in emotional and cognitive processing areas, particularly the left anterior cingulate cortex (ACC). In contrast, the HAQ group exhibited broader activation in regions such as the right superior frontal gyrus (SFG), bilateral anterior cingulate cortex (ACC), left precuneus, and the left posterior superior temproal gyrus (pSTG) suggesting more extensive involvement of cognitive and visual processing.

Using max criteria, the LAQ group displayed significant activations in the right inferior frontal gyrus (IFG), right middle occipital gyrus (MOG), and left superior temporal gyrus (STG), reflecting an emphasis on auditory and visual processing. The HAQ group also showed activation in motor and memory-related regions, such as the right precentral gyrus (PreCG) and right parahippocampal gyrus (PHG), indicating a more comprehensive neural response. No significant differences were observed in group comparisons.

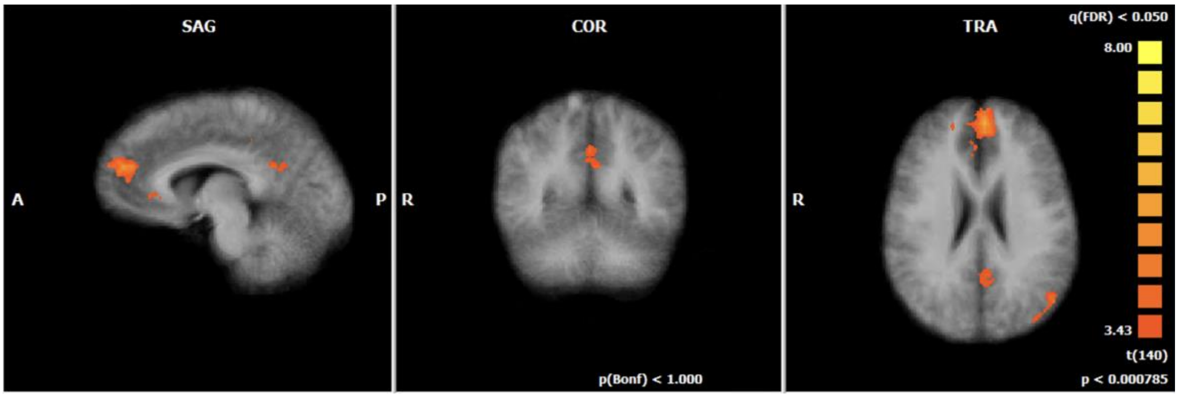
Table 5.2 Significant increases in neural activation were observed in both the LAQ and HAQ groups, as well as in group comparisons, during the multisensory integration of angry prosody and gestures in conversations. These results were derived using two distinct statistical criteria.

Group	**Anatomical regions**	**Talairach coordinate of peak voxel (x, y, z)**	**L/R**	**t**	**p**	**Number of Voxels**
Method: Super-additive (AV-[A+V])						
LAQ group	Anterior Cingulate Cortex	-6,50,16	L	4.42	0.00002	246
HAQ group	Superior Frontal Gyrus	18,47,25	R	5.06	0.000001	197
	Medial Frontal Gyrus	-3,50,22	L	7.00	<0.000001	3879
	Anterior Cingulate Gyrus	0,32,13	R	4.72	0.000006	297
	Precuneus	-3,-37,37	L	4.68	0.000007	345
	Cuneus	0,-49,31	R	4.41	0.000021	841
	Anterior Cingulate Gyrus	-9,38,4	L	4.42	0.00002	248
	Middle Frontal Gyrus	-27,44,16	L	4.42	0.000019	182
	Superior Temporal Gyrus (posterior)	-45,-64,19	L	4.93	0.000002	1361
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Method: Max criteria ((AV>A)∩(AV>V))						
LAQ group	Inferior Frontal Gyrus	54,-7,7	R	8.31	<0.000001	15060
	Middle Occipital Gyrus	42,-67,-5	R	4.01	0.000097	538
	Superior Temporal Gyrus	-54,-16,4	L	8.23	<0.000001	17588
HAQ group	Inferior Frontal Gyrus	48,-13,4	R	9.28	<0.000001	24181
	Ventrolateral Prefrontal Cortex	52,-7,46	R	4.07	0.000078	371
	Middle Occipital Gyrus	42,-67,-8	R	4.67	0.000007	1838
	Parahippocampal Gyrus	12,-22,-8	R	4.45	0.000017	329
	Brainsem	-9,-28,-5	L	4.51	0.000014	342
	Middle Frontal Gyrus	-27,44,16	L	4.70	0.000006	920
	Superior Temporal Gyrus (posterior)	-48,-22,1	L	10.14	<0.000001	27432
	Cerebellum	-39,-58,-17	L	3.72	0.000286	490
	Precuneus	-48,-64,29	L	4.39	0.000022	1060
LAQ > HAQ	n. s					
HAQ > LAQ	n.s					

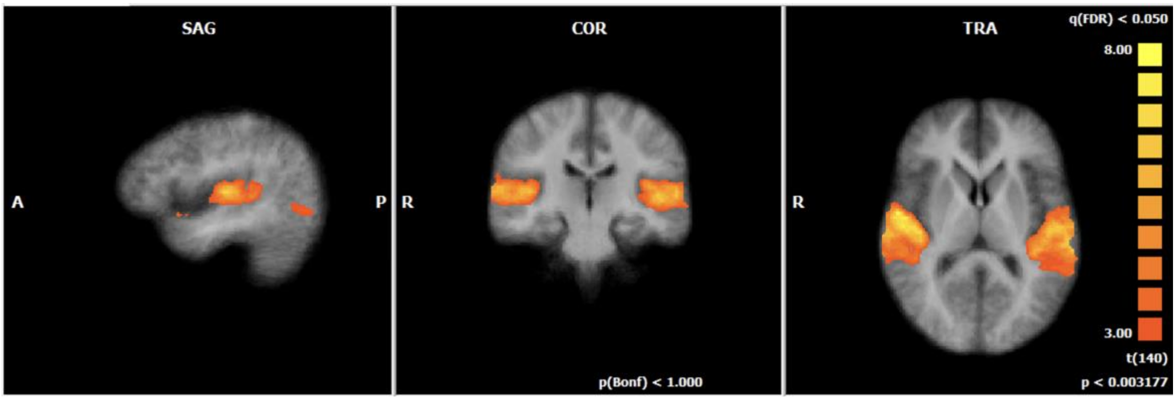
(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



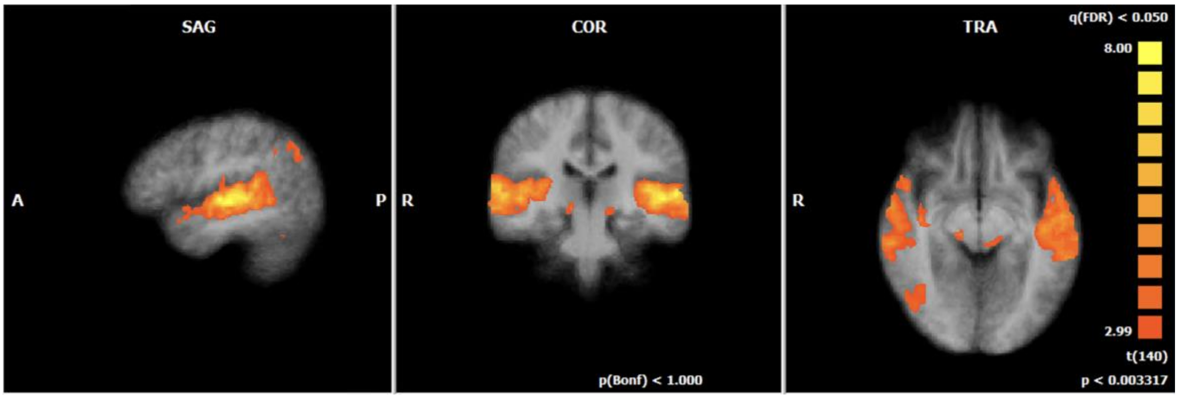
(a) Significant brain regions were activated in the LAQ group during the multisensory integration of angry prosody and gestures, as identified by the super-additive criteria



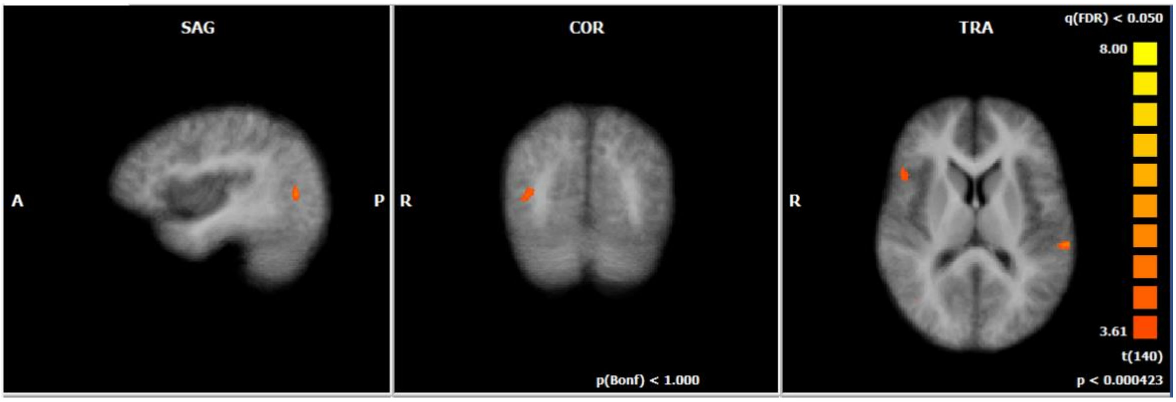
(b) The super-additive criteria revealed significant neural activation in the HAQ group during the multisensory integration of angry prosody and gestures in conversations



(c) Significantly increased neural activity was observed in the LAQ group in brain regions responding to multisensory integration of angry prosody and gestures, resulting from the max criteria



(d) The HAQ group exhibited significant brain activation during multisensory integration of angry prosody and gestures, as identified through max criteria



(e) The HAQ group showed significantly increased brain activation compared to the LAQ group during the multisensory integration of angry prosody and gestures, as identified by the max criteria

Figure 5.1 Results from both the LAQ and HAQ groups, as well as group comparisons, showed significant brain activations during the multisensory integration of angry prosody and gestures in conversations, identified using two statistical criteria.

2) Happy emotion

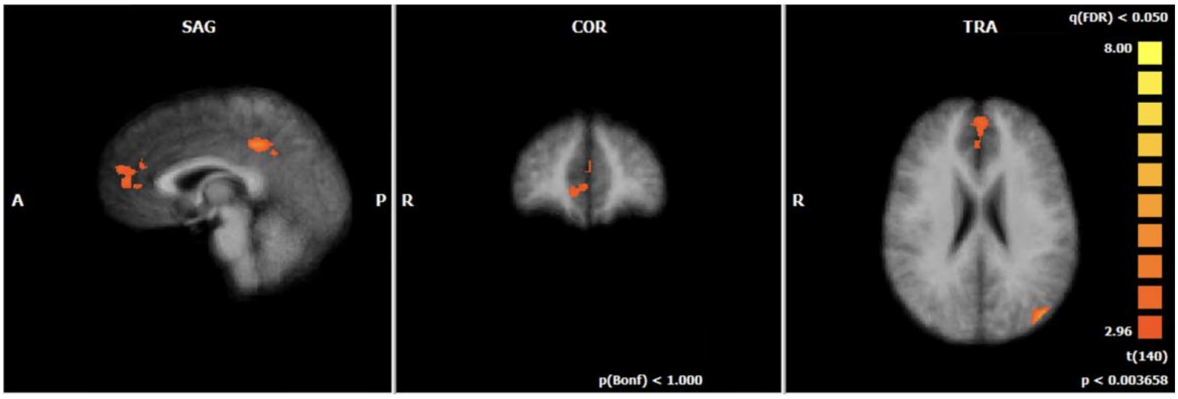
The findings from the multisensory integration analysis of happy prosody and gestures are summarized in Table 5.3. The super-additive approach did not reveal significant activations in the LAQ group; however, the HAQ group showed notable activations in the right superior frontal gyrus (SFG), left medial frontal gyrus (MeFG), and left superior occipital gyrus (SOG), suggesting enhanced cognitive and visual processing.

Using the max criteria, the LAQ group displayed significant activity in the right inferior frontal gyrus (IFG), right middle occipital gyrus (MOG), and left inferior frontal gyrus (IFG), indicating strong auditory and visual involvement. In contrast, the HAQ group showed broader activations, including the right ventrolateral prefrontal (vlPFC) and middle occipital gyrus (MOG), reflecting motor and visual processing engagement (see Figure 5.2). In group comparisons, the HAQ group exhibited greater activation than the LAQ group in regions including the right inferior frontal gyrus (IFG), right fusiform gyrus (FG), and left superior temporal gyrus (STG), highlighting enhanced engagement in multisensory integration. The super-additive method identified regions involved in emotional and cognitive integration, while the max criteria revealed broader neural responses, including areas associated with motor and sensory integration (see Table 5.3, Figure 5.2).

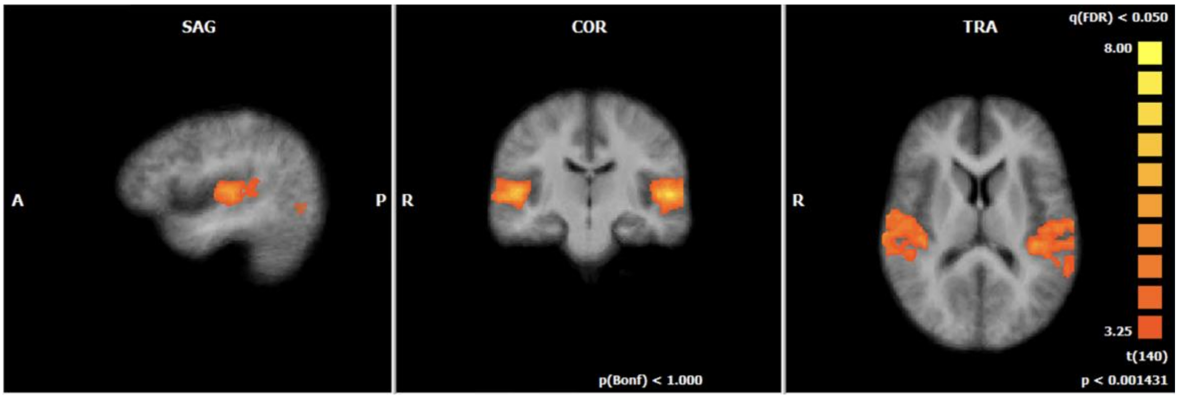
Table 5.3 The results showed significantly increased neural activation in both the LAQ and HAQ groups during the multisensory integration of happy prosody and gestures in conversations, based on analyses using two different statistical criteria

Group	Anatomical regions	Talairach coordinate of peak voxel (x, y, z)	L/R	t	p	Number of Voxels
Method: Super-additive (AV-[A+V])						
LAQ group	n.s					
HAQ group	Superior Frontal Gyrus	18,17,49	R	4.00	0.000102	407
	Medial Frontal Gyrus	-3,50,19	L	5.01	0.000002	2153
	Cuneus	0,-40,37	L	5.98	<0.000001	2324
	Superior Occipital Gyrus	-43,-73,22	L	4.83	0.000004	611
LAQ > HAQ	n.s					
HAQ > LAQ	n.s					
Method: Max criteria ((AV>A)∩(AV>V))						
LAQ group	Inferior Frontal Gyrus	48,-13,7	R	7.73	<0.000001	11589
	Middle Occipital Gyrus	42,-67,-5	R	4.10	0.000007	265
	Inferior Frontal Gyrus	-54,-16,4	L	7.96	<0.000001	12501
HAQ group	Ventrolateral Prefrontal Gyrus	60,-10,10	R	7.37	<0.000001	14809
	Precentral Gyrus	42,-64,25	R	4.04	0.000088	269
	Middle Occipital Gyrus	-51,-13,1	L	10.26	<0.000001	14871
LAQ > HAQ	n. s					
HAQ > LAQ	Inferior Frontal Gyrus	51,17,13	R	5.00	0.000002	176
	Fusiform Gyrus	39,-64,4	R	5.52	<0.000001	233
	Superior Temporal Gyrus	-60,-28,9	L	5.23	0.000001	484

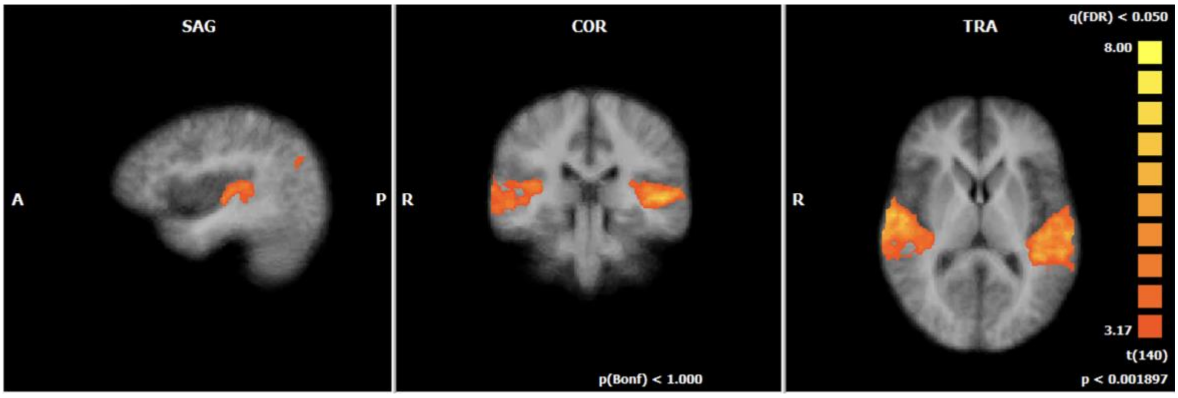
(x, y, z are Talairach coordinates of peak-voxels. L= Left Hemisphere, R= Right Hemisphere. All the reported regions were thresholded at q=0.05 at the corrected level)



(a) The super-additive criteria identified significant brain activation in the HAQ group during the multisensory integration processing of happy prosody and gestures in conversations



(b) Significant neural activations were detected in the LAQ group during the multisensory integration processing of happy prosody and gestures, as highlighted by the max criteria



(c) Using the max criteria, the HAQ group demonstrated notable brain activations during multisensory integration of happy prosody and gestures in conversations

Figure 5.2 Significant brain activations were observed in both the LAQ and HAQ groups during the multisensory integration of happy prosody and gestures in conversations, according to two different statistical criteria. However, no significant differences were found between the groups, as shown in Table 5.3.

5.3.4.3 Correlation analysis

A correlation analysis between AQ scores and neural activation results from the multisensory integration of different emotional conditions, using two distinct statistical criteria across the LAQ and HAQ groups, found no significant correlations. This suggests no substantial relationship between autistic traits and brain activation patterns during multisensory integration for each emotion.

5.4 Summary and Discussion

The present study explored differences in brain regions involved in the multisensory integration of emotional prosody and gestures between individuals with high and low autistic traits, employing both super-additive and max criteria methods. The full analysis did not show group differences, however separate analyses of the groups indicated distinct neural activation patterns between the two groups, highlighting the influence of autistic traits on the integration of emotional audiovisual stimuli.

The super-additive method revealed that during the integration of angry prosody and gestures, significant activation of the left anterior cingulate cortex (ACC) occurred in the LAQ group, supporting the anterior cingulate cortex's (ACC) role in emotional and cognitive processing (Joassin et al., 2011). In the HAQ group, more widespread activation was observed, including regions such as the right superior frontal gyrus (SFG), bilateral anterior cingulate cortex (ACC), ventrolateral prefrontal cortex (vlPFC), and posterior superior temporal gyrus (pSTG), suggesting increased reliance on cognitive control and visual processing areas (Beauchamp, 2005). The max criteria analysis indicated that the LAQ group primarily activated core sensory integration areas, while the HAQ group showed involvement of supplementary motor and memory-related regions, hinting at compensatory strategies (Whyatt & Craig, 2013)

For the happy emotion condition, the super-additive analysis showed no significant activation in the LAQ group, while the HAQ group activated regions such as the superior frontal gyrus (SFG), superior occipital gyrus (SOG), and posterior superior temporal gyrus (pSTG). These areas are associated with visual and social information processing (Liu, 2018). These areas are associated with visual and social information processing. The max criterion similarly showed broader activation in the HAQ group, again suggesting compensatory neural engagement (Bolis et al., 2017).

Although between-group contrasts did not reach statistical significance, qualitative comparisons suggested greater activation in areas such as the inferior frontal gyrus (IFG) and fusiform gyrus (FG) in the HAQ group. These patterns imply a more distributed and possibly less efficient integration network in individuals with high autistic traits (Chen et al., 2024; Kana et a., 2009; Wang et al., 2021). By contrast, the LAQ group appeared to rely on a more specialized network for sensory integration.

Atypical responses in key multisensory processing areas, such as the superior temporal gyrus (STG) and fusiform gyrus (FG), ventrolateral prefrontal cortex (vlPFC) and posterior superior temporal gyrus (pSTG)are crucial for integrating auditory and visual cues, which likely contribute to the social and emotional processing difficulties commonly observed in these populations (Chen et al., 2024; Feldman et al., 2018; Wang et al., 2021). Concurrent enhanced activation in the ventrolateral prefrontal cortex (vlPFC) and posterior superior temporal gyrus (pSTG)within the HAQ group suggests a compensatory strategy to deal with such complex integration of social contexts, along with increased cognitive and neural effort (Stevenson et al., 2014).

The super-additive and max criteria offer different perspectives on multisensory integration. While the super-additive method identifies regions specifically involved in integrating multimodal emotional content, the max criterion provides insight into broader recruitment patterns. The HAQ group’s engagement of regions such as the ventrolateral prefrontal cortex (vlPFC) and posterior superior temporal gyrus (pSTG) suggests greater reliance on compensatory strategies due to underactivity in core multisensory networks (Stevenson et al., 2014).

Although many fMRI studies in ASD report hypoactivation in the inferior frontal gyrus (IFG) and fusiform gyrus (FG) (Dapretto et al., 2006; Schultz et al., 2003), functional connectivity analyses (e.g., thalamus–FG, precentral–IFG) show increased coupling in individuals with higher autistic traits (Ayub et al., 2021). These broader patterns of neural engagement point to a reliance on higher-order cognitive processes rather than automatic sensory integration in individuals with high autistic traits. This observation aligns with Bolis & Schilbach (2017) showing executive control recruitment. Altered connectivity in regions such as the fusiform gyrus and amygdala may also contribute to atypical multisensory processing (Hadjikhani et al., 2004).

This study focused on angry and happy emotional stimuli but did not directly compare these conditions. A future comparison of positive and negative emotional valence could provide more precise insights into how emotion type influences multisensory integration strategies across trait levels. The current findings suggest that individuals with high autistic traits may depend more on cognitive control areas such as the ventrolateral prefrontal cortex (vlPFC), inferior frontal gyrus (IFG), and posterior superior temporal gyrus (pSTG) during emotional processing, contributing to increased cognitive load and potentially explaining social communication challenges.

These findings highlight potential targets for intervention, particularly in enhancing the efficiency of neural processes in regions such as the ventrolateral prefrontal cortex (vlPFC) and posterior superior temproal gyrus (pSTG). Strengthening connectivity in core sensory integration networks may reduce reliance on broader, compensatory networks, potentially improving social communication outcomes (Stevenson et al., 2014; Taylor et al., 2010).

Despite the promising observations, several limitations must be acknowledged. One major limitation is the relatively small sample size, which may affect the generalizability of the findings and limit the detection of more subtle effects. Additionally, the study examined only two emotional categories—anger and happiness—which restricts the range of emotional processing assessed. Emotional understanding in real-world situations involves a broader spectrum of affective states, many of which may be particularly challenging for individuals with autistic traits. Future studies should therefore explore a wider array of emotions and incorporate additional methodologies—such as eye-tracking, behavioral measures, or neurophysiological tools—to better capture the complexity of multisensory integration in autism spectrum conditions (Fridenson-Hayo et al., 2016; Siemann et al., 2020).

In conclusion, although the study did not yield statistically significant group-level differences, the observed activation patterns suggest the use of distinct neural strategies in individuals with high versus low autistic traits. These findings contribute to the growing literature on the neural basis of social communication challenges in ASD and highlight the value of examining individual variability in multisensory emotion processing. They also provide a foundation for future research aimed at developing more tailored interventions that take into account the diverse processing styles observed across individuals on the autism spectrum.

6 General Discussion

6.1 Overview of the research

6.1.1 Research Summary and Key findings

This thesis was focused on the neural and behavioral differences between adults with high autistic traits and those with low autistic traits in the light of emotional processing, using both behavioral experiments and functional Magnetic Resonance Imaging. The research aimed at explaining how these groups process emotional information conveyed through prosody, gestures, and audio-visual stimuli under both congruent and incongruent conditions. Focusing on the multisensory integration of emotional stimuli, this investigation was aimed at elucidating what divergence in neural pathways of processing contributes to a scenario of social and communication difficulties representative of individuals with high autistic traits.

6.1.1.1 Behavioral outcomes

These behavioral experiments were developed to gauge the participants' skills in the classification of emotions based on prosody, gestures, and audiovisual signals. Tasks were designed to assess participants' ability to identify emotional content through different sensory modalities, providing a robust framework for evaluating multisensory integration capabilities. The results revealed significant performance differences between HAQ and LAQ groups across all tasks, particularly highlighting difficulties experienced by individuals with high-autistic traits. In the prosody task, where participants identified emotions based solely on vocal tone, HAQ participants generally responded more slowly and less accurately than their LAQ counterparts. These findings suggest that individuals with high autistic traits may process prosodic information less efficiently, relying more heavily on cognitive resources to interpret vocal emotional cues.

The gesture processing task to identify emotions through body language and facial expressions, also underlined challenges in processing. The participants in the LAQ group were highly accurate and quick in their responses; they identified emotional gestures even in complex or ambiguous conditions. On the other hand, HAQ participants showed a much-reduced level of accuracy with significantly slower reaction times in conditions of incongruence, wherein emotional gestures were not matching other sensory inputs. That sustains the hypothesis of a more general problem in interpreting non-verbal social displays crucial for successful everyday interaction.

The most salient behavioral differences emerged in tasks with audiovisual integration, where participants were required to process the concurrent emotional cues from both auditory and visual sources. LAQ participants showed high ability to integrate these multisensory signals into an accurate response with fast response times in both congruent and incongruent conditions. In striking contrast, HAQ individuals showed marked impairments, especially under incongruent conditions wherein competing signals were given across emotional modalities—for example, a happy voice and a sad face. Slower reaction times and higher error rates by HAQ participants suggest a very basic impairment in the ability to resolve conflicting sensory input, reflecting broader challenges in multisensory integration.

6.1.1.2 Neural findings

The fMRI data collected during these experiments provided critical insight into the neural mechanisms underlying the behavioral differences observed between HAQ and LAQ participants. For the LAQ group, neural activation patterns across all emotional processing tasks suggested efficient and automatic sensory processing. They primarily engaged brain regions associated with sensory integration, such as the superior temporal gyrus (STG) and fusiform gyrus (FG), both of which are crucial for integrating auditory, visual, and contextual information during emotion recognition. This neural profile corresponds with the LAQ group's rapid and accurate behavioral responses, indicating a reliance on automatic, sensory-driven pathways to decode emotional signals with minimal cognitive load.

In contrast, HAQ individuals exhibited broader and less specialized neural activation patterns, particularly in tasks involving emotional prosody. Significant engagement of cognitive control regions such as the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) was observed, suggesting that HAQ participants relied on more effortful, compensatory processing mechanisms to interpret vocal emotional cues.

This finding implies a shift from automatic sensory-driven processes, typical in the LAQ group, to a more deliberate cognitive approach in the HAQ group.

During gesture processing, HAQ individuals showed increased activation in regions such as the medial prefrontal cortex (mPFC) and right superior frontal gyrus (SFG), both associated with self-referential thinking and evaluative processing. his extended neural engagement suggests a more analytical approach to interpreting gestures, aligning with their slower and less accurate behavioral performance. In contrast, LAQ participants showed strong activation in regions such as the occipital face area (OFA) and fusiform gyrus (FG), supporting the hypothesis of efficient decoding of facial and body movement cues that are important in social communication.

The audiovisual integration tasks revealed more pronounced neural differences between groups. LAQ participants exhibited efficient activation in key multisensory integration areas, including the superior temporal gyrus (STG) and posterior superior temporal gyrus (pSTG), which supported their rapid and accurate recognition of emotional cues. In contrast, HAQ individuals showed greater activation in cognitive control regions—particularly during incongruent trials—suggesting a heavier reliance on evaluative and top-down processing networks to resolve conflicting emotional inputs. This pattern may reflect a compensatory, effortful strategy that contributes to their slower and less accurate behavioral responses, as indicated by overactivation in regions associated with cognitive control and emotional evaluation.

6.1.1.3 Overview of findings

This research identified systematic behavioral and neural differences in emotion processing between individuals with high- versus low-autistic traits. Across prosody, gesture, and audiovisual integration tasks, participants with high-autistic traits (HAQ) consistently demonstrated slower response times and reduced accuracy, particularly under emotionally incongruent conditions. These behavioral patterns may reflect less efficient or less automatic processing of socio-emotional cues. Complementary neuroimaging findings indicated that participants with low-autistic traits (LAQ) primarily engaged core sensory integration regions, including the superior temporal gyrus (STG) and fusiform gyrus (FG), which are commonly implicated in rapid and intuitive emotional recognition. In contrast, the HAQ group showed more widespread activation, including areas associated with executive function and internally oriented processing, such as the dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), and precuneus.

These patterns may suggest a reliance on alternative or compensatory neural strategies among individuals with high-autistic traits when processing emotional stimuli, particularly in complex or ambiguous contexts. Rather than relying on streamlined, bottom-up sensory integration, these individuals may recruit top-down regulatory networks, potentially resulting in increased cognitive load and reduced processing efficiency. The divergence was most pronounced during audiovisual integration tasks, underscoring the additional challenges associated with interpreting dynamic, multimodal social information. While the current findings do not allow for causal conclusions, they align with theoretical frameworks suggesting that increased cognitive effort may underlie the socio-communicative difficulties often reported in autism spectrum conditions. These results underscore the importance of further investigating the neural underpinnings of emotion processing and the potential for targeted interventions aimed at enhancing multisensory integration and reducing compensatory processing demands in individuals with elevated autistic traits.

6.2 Interpretation of Results and comparisons with existing literature

The results of this thesis contribute to the existing literature on the neural and behavioral mechanisms of emotional processing in individuals with high autistic traits. In line with a growing body of evidence, the findings suggest that individuals with high AQ scores (HAQ) engage broader and less specialized neural networks during emotional processing. This pattern likely reflects compensatory reliance on cognitive control regions to offset reduced efficiency in automatic sensory integration (Stefanou et al., 2020; Duville et al., 2023). This engagement, notably in areas such as the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC), is indicative of increased cognitive load during emotional recognition tasks. These findings support the notion that emotional processing may be more effortful and cognitively mediated in HAQ individuals than in their low-AQ (LAQ) counterparts.

6.2.1 Cognitive Control and Compensatory Neural Strategies

A key observation in this research was the consistent engagement of cognitive control regions, notably the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC), during emotional prosody and gesture processing in individuals with high-autistic traits (HAQ). These brain areas are traditionally associated with executive functions, including conflict monitoring, working memory, decision-making, and higher-order evaluative processes (Just et al., 2007; Dichter et al., 2012). Their activation in the context of emotion recognition tasks suggests that HAQ individuals may rely on more effortful, cognitively mediated strategies to interpret emotional signals that are typically processed more automatically in individuals with low-autistic traits.

Rather than engaging fast, intuitive pathways for decoding social cues, HAQ participants appear to recruit regions associated with sustained attention and self-regulation. This aligns with previous neuroimaging findings showing atypical patterns of activation in frontal regions during emotional and social cognitive tasks among individuals with elevated autistic traits (Just et al., 2007). Such activation may reflect a compensatory mechanism that enables these individuals to perform adequately despite difficulties in automatic processing. The reliance on these networks likely contributes to the increased response latencies and decreased accuracy observed behaviorally, especially under more cognitively taxing conditions such as incongruent audiovisual stimuli.

Moreover, the recruitment of cognitive control regions may reflect the need to resolve conflicting or ambiguous input when processing complex emotional signals. In situations where facial expressions, gestures, or prosody do not align, HAQ individuals may engage the anterior cingulate cortex (ACC) to monitor conflict and the dorsolateral prefrontal cortex (DLPFC) to regulate responses, indicating a heavier cognitive load. These findings are consistent with broader patterns reported in ASD populations, where similar compensatory activation in prefrontal regions has been interpreted as an adaptive but resource-intensive mechanism to support performance (Dichter et al., 2012). The findings from the present research therefore add to this literature by suggesting that even in non-diagnosed individuals with high-autistic traits, the neural systems underlying emotion recognition may differ substantially from typical patterns, reflecting distinct cognitive-affective processing routes that may have both functional and developmental implications.

6.2.2 Difficulties in Sensory Integration

The research also confirmed that sensory integration, particularly under emotionally incongruent conditions, poses significant challenges for individuals with high-autistic traits (HAQ). Behavioral data revealed that HAQ participants experienced greater interference when exposed to conflicting emotional cues—such as angry prosody paired with a happy gesture—resulting in significantly slower and less accurate responses. This finding aligns with prior literature indicating that individuals with ASD or elevated autistic traits often demonstrate impairments in integrating cross-modal emotional signals, particularly when the signals are ambiguous or mismatched (Stevenson et al., 2014). The difficulty in resolving these conflicts likely stems from disruptions in the ability to form coherent percepts from competing auditory and visual information, a key component of efficient social communication.

These multisensory processing challenges have important implications, especially considering that real-world social interactions frequently involve dynamic, multimodal emotional signals. The observed delays and increased error rates among HAQ individuals may reflect underlying limitations in their ability to rapidly synthesize diverse sensory inputs, particularly under cognitively demanding circumstances. When emotional information from prosody and gesture does not align, as is often the case in nuanced social exchanges, HAQ individuals may experience a higher degree of cognitive strain. This increased effort can lead to slower reactions, more frequent misinterpretations, and ultimately contribute to the broader social-communicative difficulties that are often observed in individuals with high-autistic traits. Such limitations may manifest as reduced social fluency, heightened anxiety in interpersonal contexts, or difficulty in navigating subtle emotional dynamics.

These behavioral findings are supported by the neuroimaging data, which revealed increased activation in brain regions associated with evaluative and higher-order cognitive processes. Specifically, HAQ participants showed heightened engagement of the superior frontal gyrus (SFG) and posterior cingulate cortex (PCC) during emotionally incongruent trials. These regions are known to contribute to internally directed cognition and sustained evaluative processing, implying that HAQ individuals rely more heavily on effortful cognitive strategies to manage conflicting emotional information. Interestingly, while previous research has emphasized the role of the anterior cingulate cortex (ACC) and right insula in conflict detection and salience monitoring (Botvinick et al., 2001; Menon & Uddin, 2010), these regions were not prominently activated in the HAQ group in this research. This absence may reflect the engagement of alternative, possibly less efficient compensatory pathways that differ from the typical salience network response observed in neurotypical individuals.

In contrast, LAQ participants exhibited neural patterns indicative of more efficient and automatic emotional processing. Stronger activation was observed in the superior temporal gyrus (STG) and fusiform gyrus (FG), regions that are central to the integration of auditory and visual emotional cues. These findings suggest that individuals with low autistic traits possess more streamlined neural systems for decoding complex emotional information, allowing them to engage with social stimuli more rapidly and with less cognitive effort. The contrast between HAQ and LAQ activation patterns reinforces the idea that atypical sensory integration in individuals with high-autistic traits reflects a broader reorganization of the neural systems involved in social-affective perception.

6.2.3 Comparisons with neurotypical population

The divergence in neural activation patterns between individuals with high-autistic traits (HAQ) and those with low-autistic traits (LAQ) underscores fundamental differences in how emotional information is processed across the autistic trait continuum. For LAQ individuals, emotion recognition appears to be supported predominantly by bottom-up sensory integration processes, enabling rapid, efficient, and intuitive responses to emotional stimuli. This neural profile is characterized by selective activation of regions such as the superior temporal gyrus (STG) and fusiform gyrus (FG), which are involved in decoding auditory and visual emotional signals. Such patterns are in line with those typically observed in neurotypical populations, where emotion processing tends to occur automatically and with minimal reliance on higher-order cognitive resources. These individuals are often able to quickly interpret emotionally salient cues—such as facial expressions or tone of voice—without needing to engage in deliberative evaluation or conscious inference. As Stevenson et al. (2014) highlight, efficient multisensory integration is a hallmark of neurotypical emotional processing, and it facilitates fluid and adaptive social behavior in everyday contexts.

In contrast, HAQ participants exhibited a markedly different neural strategy, relying on a broader and more top-down network of brain regions to interpret emotional information. This included heightened activation in areas associated with executive functions, such as the dorsolateral prefrontal cortex (DLPFC), anterior cingulate cortex (ACC), and medial prefrontal regions. These regions are typically involved in processes such as conflict resolution, sustained attention, and evaluative reasoning, suggesting that HAQ individuals approach emotion recognition as a more cognitively demanding task. Rather than relying on fast and automatic processing, these individuals appear to engage in more effortful, strategic analysis of emotional cues, possibly as a compensatory response to less efficient sensory integration mechanisms. This heightened cognitive engagement may slow down emotional decoding and increase the likelihood of misinterpretation, especially in socially ambiguous or emotionally incongruent situations.

Importantly, these findings provide further support for the notion that individuals with high-autistic traits may be neurologically predisposed to experience greater social fatigue and cognitive load during interpersonal interactions. The need to continually engage executive networks for tasks that are typically automatic in neurotypical individuals may contribute to the social and emotional exhaustion often reported by this group. This could, in turn, lead to heightened levels of anxiety, increased avoidance of emotionally intense or unpredictable social situations, and a tendency to prefer structured or less emotionally demanding environments. By highlighting these differences, the present research adds to a growing body of literature emphasizing the importance of accounting for individual differences in emotional processing strategies when developing support systems or interventions for individuals across the autism spectrum.

6.2.4 Implication for interventions and clinical practice

Although the findings are largely descriptive and correlational, they nonetheless point toward promising directions for future therapeutic interventions. Given the heightened cognitive demands involved in emotional processing among individuals with high-autistic traits (HAQ), multisensory integration training has emerged as a particularly compelling approach. A randomized controlled trial in autistic youth, for instance, demonstrated that computer-based audiovisual perceptual training can modify the dynamics of the temporal binding window, with individual outcomes moderated by cognitive factors such as IQ and language profile (Feldman et al., 2023).

Computerized emotion recognition programs—particularly non-VR formats—have demonstrated moderate improvements in recognition accuracy (Grynszpan et al., 2014). Additionally, neurofeedback training has shown preliminary success in normalizing behavioral and electrophysiological markers in autistic individuals (Pineda et al., 2014). Emerging tools such as mobile apps and vibrotactile feedback systems further show promise, although continued empirical validation is required before clinical application.

In addition to enhancing emotion recognition through direct training, defining specific neural activation profiles in individuals with high-autistic traits could advance the development of personalized intervention strategies. Neuroimaging assessments may uncover distinct patterns of neural strengths and vulnerabilities, offering clinicians objective biomarkers for tailoring therapies and monitoring progress. This approach resonates with the broader framework of precision medicine, which prioritizes individual variability in cognitive, neural, and genetic domains when designing treatment plans (Ecker et al., 2015). Integrating neurobiological findings with behavioral data could help ensure that interventions are both context-sensitive and scientifically robust.

Finally, the present findings emphasize the necessity of multi-method assessment frameworks that integrate both behavioral observations and neural metrics when designing diagnostic and therapeutic approaches for individuals with high-autistic traits. Sole reliance on behavioral data may overlook critical aspects of the neural mechanisms underlying emotion recognition difficulties. Incorporating neuroimaging and other physiological measures can offer a more comprehensive view of these challenges, thereby enhancing diagnostic accuracy, personalizing intervention strategies, and improving overall treatment efficacy. Moreover, such integrated approaches may enable earlier identification of individuals at risk and promote proactive, developmentally informed support for social communication and emotional functioning.

6.2.5 Broader Context and Future Directions

This study contributes to the growing literature on the neural mechanisms underpinning social communication difficulties in individuals with high autistic traits. The findings support dominant ASD theories on sensory integration deficits and compensatory cognitive strategies while adding new knowledge about specific neural mechanisms involved. Future research should continue exploring the dynamic interplay between sensory integration, cognitive control, and emotional recognition in this population. Longitudinal studies capturing neural activation changes in response to specific interventions can provide insights into enhancing emotional processing and reducing cognitive load. The study underscores the need for interventions addressing sensory integration deficits and cognitive load in individuals with high autistic traits, forming a basis for more targeted therapeutic approaches aimed at improving social communication and quality of life.

6.3 Theoretical and practical implications

These findings carry important theoretical and practical implications for understanding the neural mechanisms underlying social communication difficulties in individuals with high autistic traits. Theoretically, this study contributes to the literature by elucidating how deficits in sensory processing and compensatory cognitive strategies interact to shape emotional processing in ASD. The dependence on cognitive control regions in HAQ individuals indicates a core dissimilarity in the processing of emotional information compared with neurotypical individuals. This underlines the need to consider revising conventional models of emotional recognition and social communication in ASD from a purely behavioral framework to one that incorporates neural mechanisms as well (Dichter et al., 2012; Just et al., 2007).

6.3.1 Theoretical implications

A key theoretical contribution of this study is its detailed characterization of compensatory neural strategies among individuals with high autistic traits (HAQ) during emotional processing. These strategies prominently involve cognitive control regions such as the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC), which are generally associated with executive functioning, including decision-making, monitoring, and evaluative processing (Schmitz et al., 2006)). Their sustained involvement implies that emotional recognition in HAQ individuals is effortful, contrasting with more automatic pathways used by low autistic trait (LAQ) individuals.

This insight challenges dominant theoretical models of emotional recognition as a highly automated process for typically developing individuals. By showing that HAQ individuals rely on broader and more effortful neural networks, this study highlights the importance of integrating cognitive control and sensory processing models when conceptualizing emotional recognition in ASD. This shift in perspective not only broadens the theoretical landscape but also lays the foundation for new hypotheses regarding the nature of social communication difficulties in ASD, such as how these compensatory strategies evolve over time and their consequences for daily functioning (Wallace & Stevenson, 2014)

In addition, these findings align with the framework of Milton’s Double Empathy Theory (Milton, 2012), which posits that communication difficulties between autistic and non-autistic individuals arise not from a unidirectional social deficit but from a mutual lack of understanding and mismatched perspectives. From this viewpoint, the observed differences in neural processing in the HAQ group may not reflect impairments per se, but rather divergent modes of perception and interpretation. The reliance on alternative neural circuits could be seen as an adaptation to this divergence rather than a deficit to be corrected. Incorporating this perspective underscores the importance of reciprocal models of social cognition, which consider both parties' roles in communication challenges, and moves away from pathologizing neurodivergent processing styles.

Furthermore, the findings lend support to the hypothesis of neural plasticity in HAQ individuals, suggesting that they develop alternative neural routes to maintain function in the face of processing inefficiencies. Rather than viewing these mechanisms as purely maladaptive, this study frames them as essential adaptations. This perspective invites further research into how compensatory strategies are shaped and how they might be optimized through training or therapeutic input.

6.3.2 Practical implications for intervention and therapy

The current findings hold several important practical implications for intervention design and therapeutic application, particularly for individuals exhibiting high levels of autistic traits (HAQ). One of the central observations from this research is that HAQ individuals demonstrate increased cognitive effort and difficulty in integrating emotional cues across sensory modalities. These challenges were particularly apparent in tasks involving audiovisual incongruence, where the ability to resolve conflicting emotional information was markedly reduced. As such, intervention strategies may benefit from placing greater emphasis on enhancing multisensory emotional integration. Rather than focusing solely on single-channel (e.g., facial or vocal) emotion recognition, therapeutic programs could be developed to train individuals in processing emotionally congruent and incongruent cues in real-time, thereby fostering more automatic and efficient interpretation.

Although still in early stages of development, structured multisensory training programs represent a promising direction in this regard. Such approaches offer repeated, controlled exposure to emotional stimuli across multiple modalities—typically through audiovisual pairings—in order to support the development of more robust integration strategies. Initial evidence suggests that these interventions may facilitate improvements in emotion recognition accuracy and speed. For instance, Isaksson et al. (2019) found preliminary support for multisensory training in individuals with ASD, showing modest gains in behavioral performance. However, these findings remain tentative, and further research employing more rigorous methodologies and larger sample sizes is required to substantiate the efficacy and generalizability of such programs.

Another area of growing interest involves the use of neurofeedback as a method for promoting adaptive neural activation patterns. Neurofeedback involves real-time monitoring and modulation of brain activity, enabling individuals to learn how to regulate neural responses in a targeted manner. Friedrich et al. (2015) have demonstrated that such approaches may be capable of influencing the neural underpinnings of social and cognitive function in ASD populations. Nonetheless, the direct application of neurofeedback for improving emotion recognition remains underexplored. At this stage, claims regarding its potential to reduce cognitive load or enhance multisensory integration should be approached with caution and must be supported by robust empirical validation, including randomized controlled trials with well-defined outcome measures.

In parallel, the personalization of interventions based on individual neural and behavioral profiles represents a promising and forward-looking therapeutic direction. Instead of implementing uniform social skills training across diverse populations, tailoring interventions to the unique sensory, cognitive, and neural characteristics of each individual may lead to more precise and effective outcomes. This approach is in line with recent advances in precision medicine and neurodevelopmental research. However, realizing such individualized strategies will require the development of accessible and cost-effective neuroimaging assessment tools, alongside validated protocols for translating neural profiles into intervention targets. Furthermore, longitudinal studies will be essential to determine the sustainability of treatment effects and their broader impact on real-life social communication outcomes.

6.3.3 Education implications

Beyond clinical interventions, the findings of this research also carry important implications for educational contexts, particularly in designing supportive learning environments for students exhibiting high levels of autistic traits (HAQ). One of the key insights from this study is the increased cognitive load that HAQ individuals experience when processing emotional information—particularly under conditions requiring integration of multiple sensory cues. In classroom settings, where students are often required to interpret verbal instructions, visual materials, and social cues simultaneously, this heightened cognitive burden can interfere not only with social functioning but also with academic performance. Accordingly, educational strategies that reduce sensory ambiguity and promote structured, predictable multisensory input may help mitigate some of these challenges.

One promising avenue involves the use of multisensory learning strategies, which aim to support information processing by reinforcing content across multiple sensory channels. For example, combining visual aids with auditory instruction has been shown to enhance learning outcomes in individuals with sensory processing differences (Shams & Seitz, 2008). Although such strategies have not been specifically validated for populations with high autistic traits, their theoretical relevance is supported by research demonstrating that multimodal teaching methods can compensate for deficits in unisensory processing. Furthermore, previous work has highlighted the importance of sensory-sensitive classroom design—such as minimizing background noise or adjusting lighting—to better accommodate students with atypical sensory profiles (Baranek, 2002; Ashburner et al., 2008). These environmental adjustments, while relatively simple to implement, may reduce cognitive fatigue and allow students with high autistic traits to better focus on learning tasks.

In addition to environmental modifications, integrating social-emotional learning (SEL) into educational programs may offer benefits for students with high autistic traits. Structured SEL curricula—delivered in a scaffolded, predictable, and low-pressure format—can provide repeated opportunities to practice interpreting facial expressions, gestures, and vocal tone within a safe context. Over time, this may foster more intuitive emotion recognition and reduce social anxiety. Meta-analytic evidence supports the effectiveness of social skills training, including computerized and behavioral interventions, in improving social competence among autistic youth (Gates et al., 2017). Similarly, facial emotion recognition training has been shown to enhance emotional understanding, although further research is needed to establish long-term effects and real-world generalization (Zhang et al., 2021a). Crucially, such programs must be tailored to the sensory sensitivities and cognitive profiles of the target group to prevent overstimulation or the reinforcement of negative associations with social interaction.

Technology-based interventions also offer a potentially powerful tool for supporting emotional learning in educational settings, but their implementation requires careful consideration. Interactive platforms, including gamified software and virtual reality environments, have been explored as methods for teaching social skills to neurodiverse students. However, findings have been mixed, and the success of these tools appears to hinge on how well they are tailored to the individual's needs and preferences (Parsons et al., 2015). For students with high autistic traits, overly complex or stimulating digital environments may inadvertently increase cognitive load rather than reduce it. Therefore, future research must identify best practices for adapting educational technologies to align with neurodivergent sensory and cognitive profiles, as well as evaluate their long-term impact on both academic and social-emotional development.

In sum, by acknowledging the neurocognitive differences associated with high autistic traits, educators can move toward more inclusive practices that not only support academic achievement but also promote emotional resilience and social integration. These efforts, when grounded in empirical evidence and tailored to individual needs, may ultimately contribute to more equitable and supportive learning environments for all students.

6.3.4 Broader implications for diagnostics and clinical practice

This research underscores the potential value of incorporating neural markers into diagnostic and intervention frameworks for individuals with high autistic traits. Traditional diagnostic systems, which often rely primarily on behavioral observations and self-reports, may not fully capture the underlying neurobiological processes contributing to social-communicative difficulties. In particular, individuals who exhibit atypical patterns of neural engagement—such as heightened reliance on cognitive control regions during emotion processing—may present with subtle challenges not readily observable through conventional diagnostic tools. Including neuroimaging and cognitive profiling in select contexts could facilitate earlier identification of these individuals and inform the development of more individualized and potentially effective interventions.

Despite this potential, the routine application of neuroimaging in clinical practice remains limited. Practical constraints such as high costs, limited accessibility, and the need for specialized expertise in data interpretation pose significant barriers to widespread clinical use. Moreover, the clinical utility of neural markers remains an area of ongoing research, and their predictive validity for individual outcomes has yet to be conclusively demonstrated. Therefore, neuroimaging should be conceptualized not as a replacement for current diagnostic practices, but rather as a complementary tool that can enhance assessment precision in research or in specialized clinical settings where resources permit.

The therapeutic strategies suggested by the current findings—such as multisensory integration training, neurofeedback, and structured social cognition exercises—would benefit from further empirical support. While preliminary studies have shown promise in these areas, more robust and longitudinal research is needed to evaluate the effectiveness and scalability of such approaches. Importantly, these interventions must be grounded in evidence regarding their feasibility, cultural acceptability, and adaptability to diverse real-world environments, such as schools, community mental health centers, and outpatient clinics.

This perspective aligns with emerging principles of precision medicine, which advocate for tailoring health interventions to individual profiles based on biological, cognitive, and behavioral variability (Insel, 2014). While group-level neural activation trends provide valuable insight, future investigations should focus on determining the reliability and sensitivity of such measures at the individual level, particularly in the context of clinical decision-making. Bridging the gap between neuroscientific discovery and practical implementation will require thoughtful integration of technology, multidisciplinary collaboration, and a commitment to equity and accessibility. Ultimately, enhancing diagnostic precision and personalizing interventions for individuals with high autistic traits represents a promising, though still evolving, direction for clinical science.

6.4 General issues identified in the research

This research brings to light several overarching issues concerning emotional processing in individuals with high-autistic traits (HAQ). A central observation is the heightened cognitive load associated with emotional recognition tasks in this group, as evidenced by increased activation in cognitive control regions, including the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) (Just et al., 2007). These neural findings suggest that HAQ individuals may experience emotional perception as a more effortful and analytically mediated process, particularly when presented with emotionally incongruent or ambiguous stimuli. This interpretation aligns with behavioral data showing longer reaction times and reduced accuracy in tasks requiring emotional discrimination. However, it is important to note that the extent to which these neural differences reflect a stable trait or context-dependent state remains to be clarified.

Such increased cognitive effort may introduce variability in how emotional cues are perceived and interpreted, possibly resulting in inconsistent social responses or delays in real-time interpersonal exchanges. The performance discrepancies observed between congruent and incongruent emotional cue conditions provide further evidence of difficulties in sensory integration, which may have implications beyond controlled experimental settings. In everyday social contexts, where rapid and often implicit processing of multimodal emotional information is required, these challenges may manifest as difficulties in maintaining fluid social interactions or accurately interpreting others' emotional intent.

In addition, the findings prompt deeper consideration of the developmental and adaptive nature of the observed compensatory strategies. A key question concerns whether these patterns of neural engagement represent long-standing neurocognitive adaptations or whether they reflect flexible, potentially modifiable processing strategies. While research on individuals with ASD has demonstrated some degree of neuroplasticity following targeted cognitive and perceptual training (Tseng et al., 2023), it remains an open question whether similar plastic changes can be reliably elicited in individuals with high—but subclinical—levels of autistic traits. Longitudinal and intervention-based studies may be required to examine how stable these neural patterns are over time and whether they are amenable to change through structured support or training.

Overall, these general observations emphasize the importance of evaluating not just the outcomes of emotion recognition tasks but also the underlying cognitive and neural costs associated with those outcomes. For individuals with high autistic traits, even when performance appears comparable to that of neurotypical individuals under certain conditions, the route to achieving those outcomes may be more resource-intensive. This has implications for understanding the subjective experience of emotional processing in HAQ populations and may inform the development of more supportive environments—

socially, educationally, and clinically—where such cognitive demands are acknowledged and, where possible, reduced.

6.5 Limitations and future research directions

While this research offers meaningful insights into the neural and behavioral mechanisms of emotional processing across levels of autistic traits, several important limitations must be acknowledged. Foremost among these is the relatively small sample size, which inevitably constrains the statistical power of the analyses and the generalizability of the findings (Button et al., 2013; Marek et al., 2022; Lombardo et al., 2019). Although the observed patterns are suggestive, caution must be exercised in extending these results to broader populations. Future studies would benefit from recruiting larger and more demographically diverse samples, which would not only improve statistical robustness but also facilitate the examination of individual variability and subgroup differences across Autism Spectrum Disorder (ASD)

Another limitation concerns the sample selection method. Although two participants in this research had received a formal clinical diagnosis of Autism Spectrum Disorder (ASD), the majority of the sample had not been diagnosed and were instead categorized based on self-reported scores on the Autism Spectrum Quotient (AQ).This dimensional approach allows for the investigation of autistic traits across a broader range of the population and may help capture subclinical variations in social-cognitive processing. However, it may also overlook important clinical features typically observed in formally diagnosed individuals, including sensory sensitivities, comorbidities, or developmental trajectories. Moreover, reliance on self-report questionnaires introduces the possibility of bias due to individual differences in self-awareness, interpretation of questions, or response tendencies (Baron-Cohen et al., 2001; Ruzich et al., 2015; Lai et al., 2015). Future research may benefit from combining trait-based assessments with clinical evaluations or structured interviews to capture a more comprehensive profile.

The interpretation of fMRI data presents inherent challenges. Although fMRI offers valuable insight into neural activation, it remains an indirect measure influenced by individual differences in vascular, anatomical, and attentional factors (Logothetis, 2008;

Linden, 2012; Uddin, 2015). These variables may have contributed to both the significant and non-significant results observed in this research, underscoring the complexity of drawing firm conclusions from isolated imaging findings. To address these limitations, future studies could incorporate multimodal methods such as EEG, MEG, or resting-state connectivity to capture more precise and dynamic aspects of neural activity. Longitudinal or interventional designs may also help determine hether these neural differences reflect stable traits or are modifiable through experience and training, particularly in individuals with high-autistic traits.

Finally, it is important to reflect on the methodological rigor of the research. During earlier stages of this study, some theoretical claims were supported by references that did not align precisely with the content they were intended to substantiate. These inconsistencies have since been addressed, with unsupported citations either removed or replaced with more appropriate sources. Nonetheless, this highlights the need for continued attention to the validity and accuracy of scholarly referencing. Future studies should maintain a commitment to transparency and empirical precision by ensuring that claims are consistently grounded in directly relevant evidence (Ioannidis, 2005; Munafò et al., 2017; Open Science Collaboration, 2015). Emphasizing these standards will support both the credibility of research outputs and the reproducibility of findings in this evolving area of study.

6.6 Conclusion

This thesis provides further insights into the neural and behavioral mechanisms at the heart of multisensory emotional processing in individuals with high autistic traits. By comparing adults with high and low autistic traits in a combination of behavioral experiments and functional Magnetic Resonance Imaging, the study allows new insights into how these groups process emotional information conveyed through prosody, gestures, and audiovisual stimuli. Overall, the results indicate stable patterns of neural activation and strategies of compensation in HAQ participants, engaging wider cognitive control networks to increase a cognitive burden in emotional recognition tasks.

Thus, a key interpretation of results using this paradigm is that a neural strategy for processing emotional cues is more effortful and less specialized in HAQ individuals, often recruiting regions associated with cognitive control and conflict resolution, including dorsolateral preforntal cortex (DLPFC) and anterior cingulate cortex (ACC). This reliance on higher-order cognitive resources contrasts with the more efficient, automatic processing of individuals with LAQ, whose neural activation is confined mostly to the primary sensory integration areas such as the superior temporal sulcus and fusiform gyrus. The difference in neural activation may point to a difference in the difficulties with social communication—that for individuals with HAQ, processing emotional information is slower, more cognitively effortful, and less automatic than among people with low-autistic traits.

The findings highlight the integral role of sensory integration in allowing efficient emotional recognition, since incongruities during this process give rise to an increase in cognitive interference in HAQ individuals while incongruent emotional signals are being processed. Difficulties also appear in natural social interactions, with quick and correct decoding of emotional expressions being a prerequisite for sound communication. Individuals with HAQ may use compensatory strategies to maintain performance, but these come at the cost of increased cognitive load, leading to social fatigue and eventually breakdown in communication.

Such findings also extend the understanding of how high autistic traits manifest at the neural level and point toward compensatory mechanisms in the processing of emotional tasks. While enabling HAQ individuals to reach performance levels comparable to those in LAQ, these strategies do so via less efficient neural routes and with substantially larger cognitive resources. The key issue, in this respect, is that the double effort that HAQ individuals have to make—to interpret the emotional displays, but also to engage more mental resources for what others may perform in a very automatic way—is crucially deep.

The neural patterns also provide a clue that interventions reducing these sensory integration deficits may decrease the cognitive burden in HAQ individuals while processing emotions. Neurofeedback techniques, involving real-time feedback about one's brain activity (Pineda et al., 2014), or multisensory integration training aimed to recalibrate the sensory paths involved in emotional recognition, might shift HAQ individuals toward more efficient processing strategies (Stevenson et al., 2014). Such interventions may enhance the degree of automaticity in emotional recognition, by encouraging lesser engagement of cognitive control areas and greater reliance on primary sensory regions, leading to improved social communication skills and quality of life.

This is further supported by the use of the AQ as a selection criterion for including participants in the present research,highlighting the greater spectrum of autistic traits within the general population. Although this approach offers much insight into how autistic traits influence emotional processing beyond those formally diagnosed with ASD, it also opens up several limitations that are necessary to consider for further investigation. In particular, notably, inclusion of the clinically diagnosed ASD individuals in similar studies would help validate these findings and might explore whether the observed neural and behavioral pattern extends to the clinical population. This would provide a much better sense of how these compensatory strategies and sensory integration difficulties manifest across the spectrum of autistic traits.

This work further underlines the variability within the population with ASD and contests the notion of a single profile in the processing of emotions in individuals with autistic traits. This would further support that the manifestation of autistic traits is highly variable, and not wholly represented through current diagnostic measures. The identification of specific neural activation profiles has as its clinical corollary the implementation of more personalized therapeutic strategies directed at specific sensory integrative deficits with associated cognitive impairments. This personalized approach parallels larger trends in precision medicine that seek to provide medical treatment which is more tailored to individual variability with respect to genetics, environment, and behavior.

The findings also carry important implications for educational and clinical practices. The insights provided by this study may thus be used in educational settings to create an enabling environment that meets the special sensory integration challenges of HAQ individuals. For example, accommodations in the classroom that minimize sensory overload, incorporate multisensory teaching, and provide opportunities for students to practice emotional recognition in a secure environment can better align the cognitive demands with learning outcomes.

It is here, with an understanding of the heightened cognitive burden based on the emotional processing of information, that educators may also take further steps in designing interventions that would result in positive academic achievements while nurturing social communication skills. From a clinical standpoint, the diagnostic and treatment implications hold far greater promise, as neuroimaging data inform clinicians more fully about both the sensory and cognitive perturbations that individuals with HAQ experience. Further details on the specific neural pathways that are involved in the process of emotional recognition might help in the development. of more selective therapies aimed at reducing cognitive expenditure and strengthening sensory integration.

Such a relational approach extends the traditional behavior-focused intervention to represent a more holistic treatment model for the neural and behavioral components of the communication difficulties considered to be social. It also underlines the critical role of sensory integration in social communication and hints that interventions focusing on these processes may have far-reaching positive consequences beyond emotional recognition. That would mean persons with high autistic traits, through improvement in the integration of multisensory information in the brain, would have wider benefits in the realm of social interactions: better understanding of social hints, reduced anxiety in social situations, and greater confidence in dealing with complex emotional situations.

Each of these features would lead to an overall improvement in quality of life for persons exhibiting high autistic traits and grant an individual better means with which to compete more effectively in social environments. Consequently, this thesis contributes significantly to the newly emerging field of social neuroscience with complex neural and behavioral dynamics of emotional processing in individuals with high autistic traits. The research gives an in-depth account of the compensatory strategies driving the unique approach to the recognition of emotions in HAQ people and focuses on the necessity of differential interventions which address the problems of sensory integration deficits and cognitive load.

Setting these findings in the wider context of prior literature, the research emphasizes how personally tailored treatment is imperative, with regard to both neural and behavioral dimensions of social contact. Future studies should further investigate the dynamic interplay that exists between sensory processing, cognitive control, and emotional recognition in individuals with high-autistic traits. Longitudinal designs that explore changes in such neural patterns following specific interventions will be especially instructive in teasing out the most reinforcing strategies notably enhancing sensory integration and reducing cognitive load.

Further research examining a broader range of emotions—beyond basic affective states such as happiness and anger—and incorporating more ecologically valid, naturalistic social scenarios will be essential to deepening our understanding of emotional processing in individuals with high autistic traits. Real-world social interactions involve dynamic, multimodal cues embedded within complex contexts, and current experimental paradigms may not fully capture this complexity. Investigating emotion recognition in more realistic settings could uncover subtle deficits or compensatory mechanisms that remain hidden in controlled laboratory tasks. Such research would not only contribute to theoretical models of social cognition and sensory integration but also play a critical role in informing clinical practice. In particular, insights gained from naturalistic studies may help refine or consolidate intervention strategies that are more aligned with the actual challenges faced by this population in their everyday social lives.

This research contributes to a growing body of evidence suggesting that individuals with high autistic traits rely on alternative, and often more cognitively demanding, neural mechanisms to interpret emotional information. By identifying the specific neural and behavioral features that differentiate HAQ individuals from their neurotypical counterparts, this thesis lays the groundwork for developing targeted, personalized interventions. Such approaches may ultimately enhance social communication skills and improve overall quality of life. However, it is crucial that future work continues to integrate behavioral, neurobiological, and contextual factors to ensure a holistic understanding of emotion processing. With sustained research and careful translation into practice, it is hoped that individuals with high autistic traits will be better supported in navigating the intricacies of social interaction—developing greater confidence and competence in responding to the emotional signals that structure human relationships.

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