Psychopathic and autistic traits influence neural activation for voice processing

Christine Skjegstad

Cognitive Neuroscience

Master Thesis

University of Oslo

Faculty of Social Sciences

Department of Psychology

Autumn 2021

Psychopathic and autistic traits influence neural activation for voice processing

Christine Skjegstad (UiO), Sascha Frühholz (UiO, UZH)

Abstract

Introduction: Personality traits influence brain activity related to perception and social cognition while social cognition further influences the expression of such traits in social interactions. The voice is the most primal social signals involved in verbal and nonverbal communication that is encoded by a core network of specialized voice-sensitive brain regions in the "temporal voice areas" (TVAs) of the superior temporal cortex (STC) and then forwarded to the extended network for higher-order cognitive processes. The current study analyzes how subclinical primary psychopathic (F1), secondary psychopathic (F2) and autistic (AQ) traits influence voice processing and how such neural activity may relate to social interactions.

Methods: A community sample of 113 participants (66 females) from ages 18 to 40 years (*M* = 25.59, *SD* = 4.797) completed several self-report trait assessments (Big Five Inventory [BFI], Levenson Self-Report Psychopathy Scale [LSRP], Autism-Spectrum Quotient [AQ]) and passively listened to auditory stimuli during an fMRI voice localizer scan. The functional brain images from the vocal and non-vocal sound trials were contrasted and analyzed with the LSRP and AQ assessment scores using multiple linear regression while including gender, age, and BFI scores as covariates. The study uses existing data that was collected as part of a larger project at the Cognitive and Affective Neuroscience Lab at the University of Zürich.

Results: The LSRP Total scores correlated with hypoactivity in right posterior STC, right ventromedial prefrontal cortex (vmPFC), left inferior frontal gyrus (IFG), left inferior parietal lobule (IPL), left fusiform gyrus, bilateral precentral gyri, and bilateral planum temporale. The F1 scores correlated with widespread hypoactivity in areas including the left anterior STC, limbic, paralimbic, striatal and frontal regions. The F2 scores correlated with hyperactivity in the substantia nigra and calcarine sulcus, and with hypoactivity in the left middle temporal cortex (MTC). AQ scores correlated with hypoactivity in left IFG, left inferior temporal sulcus (ITS), areas of white matter in the cingulum bundle and near the right MTC.

Conclusion: Those with overall psychopathic traits may not automatically perceive a voice sound as a salient or socially relevant signal, and therefore may not pay attention to it. They also seem to lack automatic imitation, making it difficult to bond with others. Those with primary psychopathic traits may not recognize voice stimuli as a relevant signal in pursuing their goals and they may not be motivated to listen to or engage with vocal stimuli, which may influence bottom-up sound perception. Those with secondary psychopathic traits may associate voices with the possibility of reward. They also seem to be sensitive to sound location and may be more inclined to direct their attention toward the speaker. Autistic traits were related to white matter hypoactivity that may reflect insufficient cortical connections leading to social impairment. Hypoactivity of the left IFG may reflect some dysfunction in the speech information pathway, neural mirroring, and empathic processes.

Keywords: social cognition, voice processing, voice localizer, passive listening, individual differences, personality, psychopathic traits, autistic traits, LSRP, AQ50

Table of Contents

1. Introduction

The voice is our most primary means of expression that we instinctively and immediately use upon birth, through crying. Throughout development, we learn to use our own voice and to interpret the voices of others as social signals that convey meaningful information. Though voices are often used in social interactions to carry semantic information with language through speech, nonverbal vocal expressions such as crying, sighing, or laughter also hold important communicative and emotional information. The perception of voices occurs because the brain is in constant anticipation of sensory input from its surrounding environment and thus translates and integrates these sound vibrations over time into a useable neural code that creates a mental representation of the signal (Siegel et al., 2018). Following this, not only do we hear a sound, but we also know that we specifically hear a voice, regardless of if we can understand what the voice may be conveying semantically. The Temporal Voice Areas (TVAs) of the superior temporal gyrus (STG) and sulcus (STS) are voice-sensitive brain regions specialized for voice processing. Personality traits modulate the processing of social signals (Fox & Zougkou, 2011) and voice processing may also be modulated by personality traits. This study investigated whether self-reported psychopathic and autistic traits influence voice processing in the core and extended networks.

1.1 Social cognition

Humans are emotional and social creatures that depend on social skills to effectively share the world with others. We rely on social cognition to understand others and to intelligently manage social interactions such as communication, cooperation, manipulation, and competition. To understand others, we must be able to interpret their mental state through social signals. We perceive social information from different modalities and social cognition can be engaged in many ways, most of which often require communication. Voices are used as social signals to convey communicative information, mainly with speech to carry semantic meaning through language, and with nonverbal vocalizations that may hold emotional meaning (Belin, 2018). “The social brain” supports our ability to cognitively process the social world by mediating perception and processing through interconnected brain networks, including areas of the brain specialized for processing the voice. These voice areas encode and store the sounds of these voices throughout many different experiences, and these regions also become active again when retrieving a specific memory involving a voice (Banich & Compton, 2018).

1.1.1 Voice sensitive brain areas

Regions of the human superior temporal sulcus/gyrus (STS/STG) of the superior temporal cortex (STC) are both sensitive and strongly selective to human as well as chimpanzee vocalizations (Belin, 2018; Belin et al., 2000; Ceravolo et al., 2020). These voice-selective regions that have been termed “temporal voice areas” (TVA) are more precisely located bilaterally in the posterior (TVAp/pSTC), middle (TVAm/mSTC), and anterior (TVAa/aSTC) STC (Pernet et al., 2015) and typically emerge in early infancy between 4 and 7 months of age (Grossmann et al., 2010). This core network engages in voice structural encoding by first detecting the incoming sound as a human voice through extracting the voice acoustics and matching them with an internal acoustic voice template in the TVAm (Belin, 2018; Bestelmeyer et al., 2011; Young et al., 2020). Next, the acoustical differences between voices and individual voices are represented by the TVAa, which is involved in voice identity recognition (Belin, 2018; Belin & Zatorre, 2003; Schelinski et al., 2016; Schirmer, 2018). Finally, higher-level social stimuli (such as complex voice features) are represented in the TVAp, which is sensitive to unfamiliar voices, voice prosody, and face information in the right hemisphere (Belin, 2018; Jiahui et al., 2017; Kreifelts et al., 2009; Schelinski et al., 2016; Young et al., 2020). The pSTC and left STG are further involved in the integration of audiovisual social signals and emotion perception and are part of a larger network of higher-order social cognition processing (Young et al., 2020).

After the voice structural encoding stage, the acoustical voice information is further processed by the extended voice network that involves subcortical areas (such as the amygdala) and several areas of the prefrontal cortex (such as the inferior prefrontal cortex) according to the task demands (Belin, 2018; Pernet et al., 2015). The extended network is involved in higher-level goal-related processing of the voice signal in three organized and interactive processing pathways that are each involved in extracting one of the three main specialized types of vocal information (Belin, 2018). Firstly, a speech information pathway involves predominantly left hemispherical anterior and posterior STS, inferior prefrontal areas such as pars opercularis (IFGoper / BA 44) and pars triangularis (IFGtri / BA 45), and premotor cortex. Secondly, a vocal affective information pathway involves predominantly right hemispherical temporo-medial regions such as anterior insula (AIC) and amygdala, and inferior prefrontal regions such as the inferior frontal gyrus (IFG) and orbitofrontal cortex (OFC; Belin, 2018; Rolls, Cheng, et al., 2020). Finally, a vocal identity pathway involves “voice recognition units” that activate by hearing the voice of a known person and contributes to a supramodal stage of person recognition (Belin, 2018). Voice recognition abilities are correlated with the functional connectivity between right frontal and right TVAs (Aglieri et al., 2018; Schelinski et al., 2016).

Each of the pathways are dissociable, though they interact and are each important in social cognition. For example, vocal identification is not necessary in understanding speech or affective information, nor is vocal affective information necessary in speech processing (Young et al., 2020). However, vocal affective information may be necessary to accurately interpret the intended meaning behind speech information. Women are more perceptive to emotion in voice than men and may get more information from vocal affective processing (Belin, 2018). Women also recruit the middle part of the middle temporal gyrus (MTG) in voice processing while men do not (Ahrens et al., 2014). Through the extended network it is possible to attribute personality traits to the voices, though this judgment may yet be inaccurate (McAleer & Belin, 2018).

1.2 Individual differences in social cognition

To understand social cognition, we must consider its underlying mechanisms and how these mechanisms work. Though we may hear and understand what another person is saying through their verbal statements, an accurate interpretation could require more than taking the statement literally if it is intended to be ironic, playful, or even deceptive. Each person is guided by their own goals, feelings, beliefs, and knowledge that influence their manner of social interactions. In social interactions, we automatically attribute mental states to others such as emotions, intentions, or goals to understand their behaviors so that we can predict their future actions while making sense of their previous actions. To understand another person's mind and infer their mental or emotional state requires neural mirroring and mentalization.

Neural mirroring may also be referred to as simulation, imitation, or mimicry, which means to act like, or imitate another person such that an observer's brain activity reflects the mental state of the one being observed, creating experience sharing and somato-sensorimotor resonance between the self and the other (van Dongen, 2020). Mirror neurons of the sensory, emotional, and error-monitoring systems are activated by vicarious observations and automatically imitate a variety of emotional, automatic, and voluntary actions (Baird et al., 2011; Froese & González-Grandón, 2020) to transform the observation into knowledge of mental states or goals. The mirror neuron system is useful in recognizing what action is being done and interpreting the intentions behind why the action is being done for better prediction and anticipation of future actions (Acharya & Shukla, 2012; Rajmohan & Mohandas, 2007).

Mirror neurons are rich in the STS, IFG, precentral gyrus (PreC), inferior parietal lobule (IPL), superior frontal gyrus (SFG) and supramarginal gyrus with somatotopic representations in the frontal and parietal regions that suggest a homunculus of action mapping (Buccino et al., 2004; Rajmohan & Mohandas, 2007; Sommer et al., 2010). The IPL is known to be an association area that integrates sensory information, and its mirror neurons are "action-constrained" providing information not only about the action itself but also why it is done in the given context to understand the intentions behind the action and code for the next possible action (Acharya & Shukla, 2012).

Mentalizing, or Theory of Mind (ToM), is the ability to cognitively represent and reason about the cognitive or affective mental state of oneself or others, while also understanding that another person's mind is different from one's own (Beaudoin et al., 2020; Rajmohan & Mohandas, 2007). Mentalizing is the ability to explain actions in terms of emotions, beliefs, knowledge, goals and intentions while affective ToM is to infer another's feelings by interpreting social cues such as facial expression, tone of voice, and non-verbal communication (Rajmohan & Mohandas, 2007; van Dongen, 2020). This information may be further integrated with situational context to determine the "true" meaning of a mental state beyond a straight-forward or literal interpretation (Chong et al., 2008). Mentalizing depends on executive functions such as attention, working memory, and self-regulation (van Dongen, 2020) while its use in social interactions depends on many factors such as life experiences, emotions, social values, and personality traits (Beaudoin et al., 2020). Self-mentalizing involves ventromedial prefrontal cortex (vmPFC), ventrolateral PFC (vlPFC), and insula while other-mentalizing involves dorsomedial PFC (dmPFC), temporoparietal junction (TPJ), and precuneus (Denny et al., 2012).

Empathy may be defined as sharing, understanding, and responding to another's emotional experience by cognitively processing social cues (Smith et al., 2015; van Dongen, 2020), which depends on both neural mirroring and mentalizing. Empathy involves self-agency and self-regulation, influences prosocial behavior, inhibits aggressive behavior, and develops moral behavior (Rajmohan & Mohandas, 2007; van Dongen, 2020). Affective empathy means to feel as and with another person in an emotional, sensorimotor, and visceral response to the other's affective state (Yu & Chou, 2018). It involves affective sharing or emotional contagion, which results from bottom-up neural mirroring and emotion perception with an understanding that the affective state corresponds to that which is experienced by the other (Rajmohan & Mohandas, 2007; van Dongen, 2020). Cognitive empathy involves understanding the emotional perspective of others through cognitive perspective-taking while maintaining a distinction between one's own and another's experience (Rajmohan & Mohandas, 2007; Smith et al., 2015; van Dongen, 2020). Both affective and cognitive empathy are supported by processing in the AIC, IFG, midcingulate (MCC) and anterior cingulate cortex (ACC; Seara-Cardoso & Viding, 2015; Smith et al., 2015). The ACC and AIC are involved in processing the affective value of somatosensory stimuli (van Dongen, 2020) where the ACC is further involved in avoiding social conflict (Braem et al., 2017) and the AIC is necessary for emotional awareness (Gu et al., 2013; Terasawa et al., 2015).

Additionally, affective empathy is mediated by the core mirror neuron system along with subcortical structures from the limbic system (amygdala), while cognitive empathy is mediated by regions associated with other-mentalization such as mPFC, TPJ, and precuneus (Smith et al., 2015; van Dongen, 2020). The OFC is also involved in simultaneous affective and cognitive empathy in emotional experience sharing during cognitive mentalizing (Cerniglia et al., 2019). People who are more empathetic tend to show stronger activations in the mirror neuron system (Acharya & Shukla, 2012), while those with greater empathic accuracy tend to show greater activity in only certain areas associated with mirroring and mentalizing, such as IPL and mPFC (Zaki et al., 2009). Preexisting relationships also influence the neural mechanisms of empathy (Meyer et al., 2013).

Cognition and emotion bias social perception in a top-down manner (Siegel et al., 2018), while executive functions such as emotion regulation and inhibitory control further influence social interactions (van Dongen, 2020). Blunted or dysfunctional emotional processing affects perceptions and thought processes in such a way that influences empathic responding. At the extreme end, such responses may lead to flawed reasoning or moral judgment, leading to immoral action with lack of remorse (Sonne & Gash, 2018).

1.2.1 Personality traits

Personality is typically defined as a coherent set of characteristics leading to a consistent, automatic pattern of feelings, thoughts, and behaviors that distinguish each person individually (Ellingsen, 2020; Keller & Allemand, 2020; Revelle, 2007). Personality shapes how an individual experiences their surroundings and plays a significant role in all aspects of social relationships while perhaps even being transformed by these relationships (Doroszuk et al., 2020; Katsumi et al., 2020; Lukewich & El-Baba, 2020). Personality traits that describe these habitual behavioral, cognitive, and affective patterns help us to recognize, understand and describe others as these traits have a top-down influence on perception, memories, and how people interact with their surroundings (Revelle, 2007). Though the "Big Five"

(Goldberg, 1993) traits of the five-factor model (FFM; Digman, 1990) are estimated to be about 50% heritable, a person's trait levels can change over long periods of time, which means that a person's environment, experiences, motivation, and genetic interactions may influence trait levels (Chmielewski & Morgan, 2013; McCrae & Costa Jr, 2008; Roberts & DelVecchio, 2000).

Neuroticism, or negative affectivity, is the tendency to be chronically prone to experiencing psychological distress, emotional instability, negative thoughts and pessimistic attitudes (Chmielewski & Morgan, 2013; John & Srivastava, 1999; McCrae & Costa Jr, 2008). People high in Neuroticism have an attention bias towards potential threats and adverse stimuli with a low threshold for reacting to stimuli while feeling negative emotions regularly and intensively (Denollet, 2013; Lyons, 2019; Malouff et al., 2005; Niven, 2013; Sharma, 2013; Watson & Pennebaker, 1989). Further, they have a high inclination to worry and experience somatic symptoms. High levels of Neuroticism are linked to negative life outcomes such as low quality of life, psychological disorders, substance abuse, social conflicts, medical illness, and mortality (Chmielewski & Morgan, 2013; Lahey, 2009; Sharma, 2013). On the opposite end, people low in Neuroticism are Emotionally Stable, calm, secure, confident, and not easily worried (Cribbet & Williams, 2013; Lyons, 2019). Emotional Stability is related to predictable and consistent emotional reactions without rapid mood changes (John & Srivastava, 1999, p. 199).

Extraversion, or positive affectivity, is characterized by a driven interest towards people and things in the outer world rather than an inward focus on the subjective experience of the inner world (John & Srivastava, 1999; Lucas & Fujita, 2000). Those high in Extraversion are often warm, outgoing, sociable, energetic and optimistic (Chmielewski & Morgan, 2013; John et al., 2008; McCrae & Costa Jr, 2008). Extraverts thrive in social settings as they enjoy being in the company of others. Although Neuroticism and Extraversion are independent, Extraversion is a protective factor against the negative life outcomes linked with Neuroticism, with reduced morbidity and risk of illness (Chmielewski & Morgan, 2013; Cohen et al., 2003; Fortenberry et al., 2013). They experience less pain, fewer symptoms, higher cognitive flexibility, and better overall health (Fortenberry et al., 2013; Lyons, 2019). At the opposite end, Introversion is characterized as being more solitary and reserved with more of an interest on the subjective experience of the inner world (John et al., 1991, 2008). Introverts enjoy their own company, can be shy in social settings, and may report feeling less energetic after being in a highly social situation (Lyons, 2019).

Openness to experience is the tendency to be open to new ideas, values, aesthetic, and fantasy (John et al., 2008; John & Srivastava, 1999). Those high in Openness tend to be intellectually curious, imaginative, and inventive with wide interests, unconventional values and nondogmatic attitudes (Chmielewski & Morgan, 2013; John et al., 2008; John & Srivastava, 1999; McCrae & Costa Jr, 2008). Those high in Openness tend to enjoy new experiences and adventures (Chmielewski & Morgan, 2013; Lyons, 2019). Higher positive affect allows for more flexibility, creativity, and exploration which may broaden a person's attention such that their Openness may increase (Fortenberry et al., 2013; Fredrickson & Cohn, 2008; Vittersø, 2014). On the opposite end, individuals who are more Closed to experience are without concern for a broadening of horizons, but instead more consistent, cautious, and conventional with a preference for routine (John et al., 2008; Lyons, 2019).

Agreeableness is the tendency to get along with others by behaving cooperatively and unselfishly (Chmielewski & Morgan, 2013; John & Srivastava, 1999; McCrae & Costa Jr, 2008). Those high in Agreeableness are friendly, helpful, modest, compassionate, straightforward, altruistic, warm, trusting, and sympathetic (Chmielewski & Morgan, 2013; John & Srivastava, 1999; Lyons, 2019; McCrae & Costa Jr, 2008). Agreeableness is related with positive social experiences with family, friends, and colleagues (Chmielewski & Morgan, 2013). Low Agreeableness means to be Antagonistic by behaving in an unhelpful, analytical, and detached manner towards others (John & Srivastava, 1999; Lyons, 2019). Antagonism is associated with higher rates of criminality, imprisonment and psychopathy (John et al., 1991, 2008; Widiger & Lynam, 1998).

Finally, Conscientiousness, is the tendency to be hardworking, responsible, dependable, self-disciplined, and organized (Chmielewski & Morgan, 2013; John et al., 2008; John & Srivastava, 1999). Those high in Conscientiousness tend to strictly adhere to their principles, behave carefully, deliberately, and aim to work efficiently while striving after achievement (Chmielewski & Morgan, 2013; John et al., 2008; John & Srivastava, 1999). Low Conscientiousness is related to having a lack of direction, being easy-going, impulsive, careless, and lazy (John & Srivastava, 1999; Lyons, 2019). Those low in Conscientiousness are less likely to strive towards goals or to be organized, disciplined and reliable (Lyons, 2019).

Personality traits may influence neural reactivity to stimuli, even when not consciously perceived (Fox & Zougkou, 2011). Neuroticism is related to a resting state functional connectivity with brain areas involving in self-evaluation and fear while Extraversion is related to a resting state functional connectivity with brain areas involving reward and motivation (Adelstein et al., 2011). In processing vocal affective information, those high in Neuroticism show hemodynamic responses in the right amygdala, the left postcentral gyrus, and the right ACC (Brück et al., 2011). Though no relationship has been found between Big Five traits and vocal emotion recognition accuracy or recognition speed (Furnes et al., 2019). Those with high emotional intelligence show increased voice-sensitivity and gray matter volume of the insula with enhanced connectivity between the insula and the TVA, indicating increased salience of voices (Karle et al., 2018). However, high emotional intelligence also correlates with decreased face-sensitivity and gray matter volume of the fusiform face area, indicating a reduced visual bias in voice and face processing that potentially underlies emotional intelligence (Karle et al., 2018). In response to neutral voice and face stimuli, social anxiety is positively correlated with increased responses between sensory and emotion processing areas such as the voice-sensitive left TVA and left amygdala, with similar responses to faces as well (Kreifelts et al., 2019).

Women consistently rate higher in Neuroticism and Agreeableness than men, while men are often higher in Extraversion and Conscientiousness than women (McCrae & Costa Jr, 2008). Agreeableness and Conscientiousness are known to increase with age while both Neuroticism and Openness tend to decrease with age (McCrae & Costa Jr, 2008; Roberts & DelVecchio, 2000). It has been argued by some that the five traits could be narrowed down to three factors of Neuroticism, Extraversion, and Psychoticism, which is characterized by low Agreeableness and low Conscientiousness (Cribbet & Williams, 2013).

1.2.2 Psychopathic traits: primary and secondary

Psychopathy is a group of personality disordered traits related to a lack of ability to feel what others feel (affective empathy) and a general disregard for others, which sometimes manifests as interpersonal problems and criminal behavior (Lyons, 2019). Psychopathic individuals tend to respond abnormally to emotionally charged communication (Williamson et al., 1991), exhibit emotional voice recognition deficits (Bagley et al., 2009), and may feel emotions differently from most others (Lyons & Brockman, 2017). Actually, psychopaths may be incapable of love due to dysfunctional limbic, paralimbic and mesolimbic systems (Johanson et al., 2020). Though they lack spontaneous affective empathy due to a hypoactive the mirror neuron system (Mier et al., 2014), vicarious representations may be controlled top-down (Meffert et al., 2013). Further, psychopaths are capable of cognitive empathy as they must understand other's emotions in order to successfully manipulate or deceive others (Lyons, 2019; Wai & Tiliopoulos, 2012). However, the psychopath's cognitive perspective-taking may also not be an automatic response as their mentalizing processes are more engaged when they are intentionally controlled (Drayton et al., 2018).

During mentalizing and attribution of emotional states, psychopaths show increased activation in brain regions associated with more rational, outcome monitoring and attention related processes (i.e., OFC, mPFC, temporo-parietal areas) rather than the mirror neuron system (i.e., bilateral supramarginal gyrus and SFG; Sommer et al., 2010). Nonetheless, psychopaths may have an advantage in identifying negative emotional states (Demetrioff, Porter, and Baker, 2017), especially fear (Gillen et al., 2018). On the other hand, psychopaths may fail to self-mentalize as they exhibit Alexithymia, or the inability to understand or describe one's own emotions (Cairncross et al., 2013). Instead of self-mentalizing, those with psychopathic traits may avoid thinking about their own emotions and may have more externally oriented thinking rather than an internal focus (Jonason & Krause, 2013).

There are two psychopathic subtypes, as first differentiated by Karpman (1948). Primary or "true" psychopathy is related to low-anxious affective-interpersonal traits. Such interpersonal characteristics include being massively selfish, manipulative, pathologically untruthful, with superficial charm, grandiose sense of self-worth, and glibness. Affective characteristics include shallow affect, callousness, expressing superficial emotions, with a lack of empathy, anxiety and guilt or remorse (Harpur et al., 1989; Levenson et al., 1995; Lynam et al., 1999; Seara-Cardoso & Viding, 2015). A lack of empathic response is reflected by reduced amygdala activation in response to the distress of others (Blair, 2013). Primary psychopathy is positively associated with better recognition of fearful faces (Gillen et al., 2018) and ventral striatum activity when imagining others in pain (Decety et al., 2013), which may indicate pleasure of others' pain (Johanson et al., 2020). Primary psychopathy has also been named as "successful" psychopathy as the low-anxious affective-interpersonal facets associated with this subtype could be used as tools for achieving power in society while remaining unnoticed within a community and evading clinical or forensic diagnoses (Lyons, 2019; Seara-Cardoso & Viding, 2015).

Secondary or neurotic psychopathy, on the other hand, is related to high-anxious impulsive-antisocial traits with destructive behaviors manifesting under the influence of emotional distress that does not affect pure primary types (Harpur et al., 1989; Levenson et al., 1995; Lynam et al., 1999). Lifestyle characteristics include irresponsibility, lack of long-term goals, a parasitic lifestyle, and constant need for stimulation (Seara-Cardoso & Viding, 2015). Antisocial behaviors associated with secondary psychopathy include poor behavioral controls, a lack of emotional control, increased reactivity, impulsivity, destructiveness and criminal versatility (Levenson et al., 1995; Seara-Cardoso & Viding, 2015). Those with secondary psychopathy tend to experience intense emotional arousal, have a short temper, be prone to guilt, and may suffer from psychological ailments while also being prone to drug abuse, suicide, and aggression (Karpman, 1941; Levenson et al., 1995). Secondary psychopathic traits are also associated with reduced emotional intelligence (Gillen et al., 2018). Deficits in decision making and reinforcement learning are reflected by a dysfunction in the ventromedial prefrontal cortex (vmPFC) and striatum (Blair, 2013). Secondary psychopathy is considered the “unsuccessful” subtype because, in its nature, its lifestyle-antisocial presentation is more related to behaviors or crimes that raise attention from mental health professionals and authorities, with a higher potential of institutionalization (Levenson et al., 1995; Lyons, 2019).

Psychopathic personality is a continuous dimension that accounts for about 1% of the general population where it may go unnoticed, but is also occurring in about 20-30% of the prison population (Brinkley et al., 2001; Cleckley, 1976; Levenson et al., 1995; van Dongen, 2020). Primary psychopathy is characterized by a negative association with Agreeableness, and insignificant relations to low Neuroticism. Secondary psychopathy is characterized by negative associations with Agreeableness and Conscientiousness (high impulsivity) and positive associations with high Neuroticism and high levels of negative affect (Harpur et al., 2002; Levenson et al., 1995; Lynam et al., 1999; Weiss et al., 2016). Secondary psychopaths may be “unsuccessful” due to low Conscientiousness as Conscientiousness is important in achieving success (Lyons, 2019). Low Agreeableness (Antagonism) of both subtypes reflects that individuals with high levels of psychopathic traits have low aversiveness to negative, unpleasant, social interactions (Seara-Cardoso & Viding, 2015).

Primary psychopathy may result from a genetic predisposition whereas secondary psychopathy may develop as a result as an adaptation from environmental adversity and a history of maltreatment (Sethi et al., 2018). While primary psychopathy is negatively associated with emotional reactivity, fearfulness, and empathic concern, secondary psychopathy is positively associated with these variables and also with weak inhibitory control systems (Seara-Cardoso et al., 2015; Seara-Cardoso & Viding, 2015). Though limbic and paralimbic dysfunction are commonly seen in psychopathy (Johanson et al., 2020), there is evidence of dissociable neural substrates underlying these two subtypes as they each are associated with different patterns of neural activity (Del Casale et al., 2015; Seara-Cardoso & Viding, 2015). For example, Primary psychopathy is associated with decreased efficacy in neural communication between local and distal brain regions while secondary psychopathy is associated with increased efficacy in neural communication between local and distal brain regions (Tillem et al., 2018). The cingulo-opercular network (ACC-insula), related to salience detection, cognitive control and empathy, is correlated with reduced connectivity with primary psychopathy and increased connectivity with secondary psychopathy (Del Casale et al., 2015; Philippi et al., 2015). Likewise, in response to imagining others in pain, secondary psychopathic traits positively correlate with activity in the bilateral AIC, IFG, and dorsal anterior cingulate cortex (dACC) while primary psychopathic traits negatively correlate with activity in these regions (Seara-Cardoso et al., 2015).

Primary psychopathy, with low-anxious and affective-interpersonal facets, is related to attenuated reactivity to various emotional stimuli, with neural activations indicating disturbed affective processing with hypoactivity in affect-processing areas (amygdala and insula) in response to emotional stimuli such as viewing others' stress or fear, and imagining others in pain (Del Casale et al., 2015; Sadeh et al., 2013; Seara-Cardoso & Viding, 2015; Sethi et al., 2018). This reduced reactivity to others' distress may explain why those with primary psychopathic traits do not find issue with behaving manipulatively towards others without empathy (Sethi et al., 2018). Those with primary psychopathic traits also have decreased functional connectivity and dysfunction with deactivating the subregion mPFC of the Default Mode Network (DMN), which is related to internally directed attention, and could relate to deficits in attention processes, self-awareness and emotion reflection leading to increased self-focus, reduced empathy and reduced moral judgment (Del Casale et al., 2015; Freeman et al., 2015; Johanson et al., 2020; Philippi et al., 2015).

Secondary psychopathy, with high-anxious and lifestyle-antisocial facets, is positively associated with activity in emotion-processing areas (amygdala and AIC) and reactivity to others' pain (Del Casale et al., 2015; Seara-Cardoso et al., 2015). Secondary psychopathy related to exaggerated reactivity to reward, with increased neural response in regions typically associated with reward processing and cognitive control (ventral striatum and dlPFC) in tasks involving moral processing, decision making, and reward (Geurts et al., 2016; Seara-Cardoso & Viding, 2015). However, those with secondary psychopathic traits show reduced activity in reward-related areas in response to viewing others' distress, suggesting abnormal fear conditioning that could result from environmental trauma (Sethi et al., 2018). Those with secondary psychopathic traits also show dysfunctional activity in the frontoparietal network, which is related to externally directed attention, and may be strongly linked to their impulsive actions (Del Casale et al., 2015; Juárez et al., 2013; Philippi et al., 2015).

1.2.3 *Autism and autistic traits*

Autism and autism spectrum disorder (ASD) is a neurodevelopmental condition that is firstly characterized by persistent impairment in social interactions, including deficits in social communication and language (American Psychiatric Association, 2013). This social-cognitive deficit may present as an avoidance of eye contact, lack of facial expression, lack of social interaction and little interest in others (Hyman et al., 2020). Females with autism are significantly better at social interaction and communication than males, which may explain why females remain underdiagnosed (Wood-Downie et al., 2021). Secondly, autism is characterized by restricted, repetitive patterns of activities, behavior, or interests from a hyper- or hyposensitivity to sensory information (American Psychiatric Association, 2013). This sensorimotor deficit may present as repetition of words or phrases, focus on specific parts of objects, and unusual reactions to how things sound, smell, taste, look, or feel (Hyman et al., 2020). Specific types of repetitive behaviors and interests also present differently between females and males (Antezana et al., 2019; Knutsen et al., 2019). Autism affects about 1.8% of the population (Chiarotti & Venerosi, 2020) and symptoms are present in early development, sometimes by 9 months of age (American Psychiatric Association, 2013; Hyman et al., 2020). Sensory symptoms occur in about 90% of autistic individuals across each of the modalities and serve as a useful early diagnostic marker (Robertson & Baron-Cohen, 2017). Perceptual differences from sensory symptoms further predict the severity of higher-order social-cognitive deficits in adults (Robertson & Baron-Cohen, 2017). The Broader Autism Phenotype indicates individuals that also experience and exhibit autistic traits to a lesser degree that would not meet diagnostic standard (Gerdts & Bernier, 2011).

Opposite of psychopathy, people with autism can feel affective empathy when they understand or are made aware of the others' emotions, but struggle with cognitive empathy (Blair, 2005; Yu & Chou, 2018). For example, people with high autistic traits do exhibit contagious itching, but do not contagiously yawn due to a lack of eye gaze (Helt et al., 2021). Deficits in eye contact and gaze following associated with ASD also mean a failure to coordinate social information from the eyes (Chong et al., 2008). Individuals with ASD further show deficits in emotion perception, processing, and mentalization (Philip et al., 2010; Velikonja et al., 2019) with abnormal recognition and identification of facial expressions (Gervais et al., 2004). During face processing, adults with autism show weaker activity in the fusiform gyrus (Pierce, 2001) and greater activity inferior temporal gyrus, indicating they may process faces similarly to objects (Schultz et al., 2000). Children with autism show a lack of mirror neuron activity in the IFGoper during observation and imitation of emotional expression that is proportional to symptom severity (Dapretto et al., 2006). When making mentalistic inferences from the eyes, adults with high functioning autism activate fronto-temporo OFC and STG regions, but lack amygdala activity (Baron-Cohen et al., 1999). Individuals with ASD show hypoconnectivity between amygdala and prefrontal cortex, which may explain emotion attribution deficits (Chan & Han, 2020). Neural mirroring and mentalizing abnormalities in ASD leads to lack of imitation, problems with understanding intention and language difficulties (Acharya & Shukla, 2012; Baird et al., 2011; Dapretto et al., 2006).

Language comprehension difficulties are one of the first signs of autism in children and remains a core feature throughout the lifespan as adults with ASD continue to show deficits in verbal learning and memory (Velikonja et al., 2019). Children with ASD show a preference for non-speech signals (Kuhl et al., 2005) and are known to tune out voices in their environment, not even preferring their mother's voice (Abrams et al., 2019). Abnormal voice processing and reduced audiovisual binding underlie social and communication difficulties in autism (Gervais et al., 2004; Robertson & Baron-Cohen, 2017; Shultz et al., 2012). Typically developing children maintain left-lateralized STC activation in response to hearing speech and activation responses continue to increase with age (Eyler et al., 2012). However, at-risk toddlers and 2-3 year-olds diagnosed with autism already show greater abnormal right-lateralized STC activation in response hearing language, with worsening defects over time that become the most severe at 3-4 years old (Eyler et al., 2012). 7 to 19-year-olds diagnosed with autism show a different growth trajectory of the left STC and language development than neurotypicals, suggesting continued failure of left STC lateralization for speech throughout development (Bigler et al., 2007). When listening to voice, children with autism show weak connectivity between the TVA (pSTC) and brain structures involving reward and emotions (i.e., nucleus accumbens, OFC and amygdala; Abrams et al., 2013). The degree of underconnectivity also relates to communication deficit severity, which may impair the ability for children with autism to experience speech as pleasurable, impacting their motivation for social development (Abrams et al., 2013). Greater left angular gyrus activity of youth with ASD relates with higher social motivation to understand a conversation in noise (Hernandez et al., 2020).

While children with ASD may initially struggle with verbal fluency, this impairment seems to become less pronounced in adulthood and eventually catches up with typical development (Velikonja et al., 2019). While adults with high-functioning ASD may show typical TVA responses (Schelinski et al., 2016), those with more severe symptoms lack significant TVA activation in response to voice sounds and show selective impairment attending to vocal-speech sounds (Gervais et al., 2004). However, those with ASD process non-voice sound similarly to neurotypicals (Gervais et al., 2004) and show stronger responses to meaningless sentences than meaningful speech sentences in the left language regions (Alho et al., 2021). The severity of ASD symptoms is associated with temporal responses to speech, while stronger attention to meaningless speech is associated with parietal responses (Alho et al., 2021). Further, adults diagnosed with ASD show reduced connectivity between the left TVA, SFG, and mPFC that correlate with severity of social impairment (Hoffmann et al., 2016).

Studies on vocal affect processing in autism have yielded inconsistent results, though vocal emotion perception and recognition abilities seem to depend on the severity of symptoms in ASD (Schelinski & von Kriegstein, 2019). While some children with high functioning autism may struggle with accurately perceiving happy prosody (J.-E. Wang & Tsao, 2015), they are mostly similar to neurotypicals in identifying affective prosody, yet show reduced production of prosody compared with neurotypicals (Grossman et al., 2010). Adults with ASD show mostly typical brain activation in response to affective prosody, but also show increased caudate activity and rate emotional intensity lower than neurotypicals (Gebauer et al., 2014). When listening to emotional voices, adults with high functioning autism show greater variability in TVA activity and functional connectivity than neurotypicals and further showed greater disagreement than neurotypicals in judging the appropriateness of emotional vocal reactions in different social contexts (Pegado et al., 2020). ASD is associated with impaired face and voice recognition (Schelinski et al., 2014), which is reflected by lesser activation of the pSTC (Schelinski et al., 2016). Activity of the right TVAa correlates with voice identity recognition performance of neurotypicals, but is dysfunctional in those with high-functioning autism, possibly providing an explanation for such voice recognition impairments (Schelinski et al., 2016).

A meta-analysis found that ASD is positively associated with Neuroticism and negatively associated with Openness, Conscientiousness, Extraversion, and Agreeableness (Lodi-Smith et al., 2019). However, the authors note that the Big Five personality traits are statistically independent from ASD characteristics and that there is no equivalence between ASD and the Big Five traits in either clinical or non-clinical samples. Interestingly, in comparison to neurotypical individuals, those with ASD characteristics show higher variance in relation to the Big Five traits (Lodi-Smith et al., 2019). Autism is a heterogeneous disorder and likely results from a complex of underlying causes leading to similar clinical features that affect individuals differently in various domains (Philip et al., 2012; Velikonja et al., 2019).

1.3 Research question

Personality is expressed in social cognition and neuroimaging with fMRI helps us to understand in what way certain traits may influence such processes by analyzing brain activity of individuals with varying levels of difference factors (Cribbet & Williams, 2013). Studying lower-level perceptual processes, such as voice, further refines our understanding and allows for more confident claims of how these different personality traits influence brain activity during the processing of social information (Cribbet & Williams, 2013; Niedenthal & Wood, 2019). It has been found that personality traits modulate neural activation during the processing of facial expression (Fox & Zougkou, 2011) and voice stimuli (Brück et al., 2011). Furthermore, individuals diagnosed with ASD show abnormal voice processing that correlates to trait severity (Abrams et al., 2013; Alho et al., 2021; Hernandez et al., 2020; Hoffmann et al., 2016). Therefore, it may be assumed that subclinical psychopathic and autistic traits also modulate neural activation when passively listening to voice sounds in contrast to non-voice sounds. Investigating voice processing in relation to psychopathic and autistic traits is important as individual differences may reveal certain brain effects contributing to subsequent higher-level social cognition.

The main questions to be addressed in the current study are twofold. Firstly, how does psychopathy and autism influence brain activation when passively listening to voice sounds? Secondly, what is the impact of trait psychopathy and autism on brain activation? Because personality traits are continuous, using a non-clinical community sample may inform of the brain effects related to the lower end of the psychopathic and autistic spectrums, potentially aiding target interventions for treatment outcomes. Rather than clinical diagnoses, the Levenson Self-Report Psychopathy Scale (LSRP; Levenson et al., 1995) will be used to identify psychopathic traits while the Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001) will be used to identify autistic traits. These self-report scales quantify the trait differences in community samples that may identify subclinical psychopathy and autism. Because voice processing involves networks across many brain regions, there will not be a stringent focus only on specific regions, but rather a mix of exploration of the whole brain and certain regions of interest. Concentration on single brain regions alone does not consider how distributed networks may influence brain activity (Philip et al., 2012).

Neural mechanisms of those with primary and secondary psychopathic traits may differ due to their different etiologies and presentations. Psychopathic traits are on a continuous dimension rather than occurring discretely, and there also seems to be a continuity of neural mechanisms underlying such traits across the general population (Seara-Cardoso et al., 2015). Therefore, we may expect similar observations of psychopathic traits in a non-clinical community sample as we would in clinical or prison populations. In relation to primary psychopathy, we may except effects of blunted attentional, emotional, mirror neuron and empathetic processing, with reduced activity in frontal areas along with limbic, paralimbic, and mesolimbic systems. With secondary psychopathy, there may be enhanced activity in emotion-processing and reward processing areas such as amygdala, insula and ventral striatum (Del Casale et al., 2015; Seara-Cardoso et al., 2015). Focusing on a non-clinical community sample further helps with our understanding of the etiology of psychopathy that may eventually guide personalized treatment interventions (Johanson et al., 2020; van Dongen, 2020).

Because none of the participants are diagnosed with ASD in this community sample, and temporal responses to voice stimuli are associated with ASD severity (Alho et al., 2021), we may not see such a significant lack of TVA activation in the current study (Gervais et al., 2004; Schelinski et al., 2016). However, for those with higher autistic traits, we should still expect to see greater variability of neural activity in response to hearing voice stimuli than would be seen of a neurotypical response (Pegado et al., 2020; van Laarhoven et al., 2019). Autism is characterized by a range of higher-order cognitive deficits, including deficits in processing speech and emotion, that affects individuals differently (Velikonja et al., 2019). Therefore, we may expect to see effects in regions of the extended voice processing networks such as those involved in higher-order speech processing. We may also expect to see an effect in regions involved in the mirror neuron system.

2. Methods

2.1 Participants

The study includes 113 participants from the Swiss population. Age ranged from 18 to 40 years (*M* = 25.59, *SD* = 4.79), with 41.6% males (47) and 58.4% females (66). 62 participants spoke German (54.9%) while 51 spoke English (45.1%). Participants were recruited to the lab through public announcements distributed at the University of Zürich and posted onto online job boards. Participation was incentivized with a reward of 25 Swiss francs per hour at an average of two hours for completion. The participants were given a written explanation of the experiment and consent forms upon arrival. Participants were included if they were a right-handed male or female between the ages of 18 to 40. All participants included in the independent sample had normal hearing and normal or corrected-to-normal vision. Exclusion criteria were having hearing impairments, psychiatric or neurological disorders in life history including epilepsy. None of the participants presented a history of neurological or psychiatric disorders.

Each participant gave informed and written consent for their participation following the ethical and data security guidelines of the University of Zürich. Participant identities remain anonymous, and their data corresponds to a coded identifier. Before data collection, the experiment was approved by the cantonal ethics committee of the Swiss canton Zürich. The study is part of a larger project at the Cognitive and Affective Neuroscience Lab at the University of Zürich. The sample size was chosen due to resource constraints as this was the maximum amount of data collected thus far from the ongoing project. Data from participants were included if they completed TVA localization and self-report assessments, and if the fMRI data was sufficient. Originally 123 people participated in the study, though 10 were excluded due to data collection or preprocessing errors.

2.2 Trait assessments

On the day of the experiment, each participant completed several self-report assessments online (https://www.soscisurvey.de/caneuro/) in either English or German. These assessments included Big Five Inventory (BFI; John et al., 1991; Rammstedt & Danner, 2016), Levenson Self-Report Psychopathy Scale (LSRP; Levenson et al., 1995), and the Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001; Deutsche Übersetzung von G. Dammann, 2002). Each participant's raw scores were recorded then final scores were calculated according to their relevant standards as described in the following sections.

An “affect balance score” of the participant’s affective state was also obtained using the Positive and Negative Affect Schedule (PANAS; Breyer & Bluemke, 2016; Watson et al., 1988) by subtracting the Negative Affect (NA) score from the Positive Affect (PA) score (PA – NA; Koydemir & Schütz, 2012), with higher affect balance scores resulting from higher PA and lower PA (Yamasaki & Uchida, 2016). Because the current study is analyzing traits rather than states, the PANAS scores were not included in the fMRI analysis. Though the affect balance score was compared with trait scores to indicate how each trait was related to affective well-being at the time of the data collection.

2.2.1 Big Five Inventory (BFI)

The Big Five Inventory (BFI) assesses the five trait domains of the five-factor model (Big Five dimensions of personality) with a 44-item inventory of short phrases that uses a five-point Likert rating scale for responses (John et al., 1991). The items consist of characteristics that may or may not apply to the participants. Participants were asked to indicate to which extent they agreed or disagreed that each given characteristic applied to them with statements having been rated from 1 “disagree strongly”, 2 “disagree a little”, 3 “neither agree nor disagree”, 4 “agree a little”, 5 “agree strongly”. The English and German version of the assessment are shown in Appendices A and B.

The trait domains include Extraversion vs. Introversion (8 items; e.g., “I see myself as someone who is talkative”), Agreeableness vs. Antagonism (9 items; e.g., “I see myself as someone who is considerate and kind to almost everyone”), Conscientiousness vs. Lack of direction (9 items; e.g., “I see myself as someone who does things efficiently”), Neuroticism vs. Emotional stability (8 items; e.g., “I see myself as someone who can be tense”), and Openness vs. Closedness to experience (10 items; e.g., “I see myself as someone who is curious about many different things”). Certain items are recoded by reverse scoring before obtaining scale scores (Extraversion, 3 items; Agreeableness, 4 items; Conscientiousness, 4 items; Neuroticism, 3 items; Openness, 2 items). Finally, scale scores are obtained by averaging the item scores belonging to each domain. Higher scores indicate greater levels of that specific personality domain.

The BFI dimensions have high internal consistency (John et al., 1991) and are robust cross-culturally across major world regions in 56 nations with translations into 28 languages (Schmitt et al., 2007). The assessment of domain dysfunction in a large clinical sample has also proved the convergent and discriminant validity of the dimensions (Hopwood et al., 2009). Studies comparing the consensus structures of personality disorders and the Big Five have also shown high congruence (O'Connor, 2005). However, the phrasing of the questions may influence results as the dimensions have failed to reproduce in certain cultures of less developed, small-scale societies and amongst individuals who think predominantly in everyday concepts (Allik & Realo, 2015; Gurven et al., 2013; Toomela, 2003). The Big Five has been criticized for neglecting other context-dependent personality domains such as interpersonal relatedness (Cheung et al., 2001), dark triad, risk-taking, egotism, honesty, and religiosity (Allik & Realo, 2015). Factor analyses have found supporting evidence of two meta-factors (Stability and Plasticity) and an overall General Factor of Personality from the Big Five (Musek, 2007; van der Linden et al., 2010). Though there has been some argument about the "true" number of personality factors or other specifics, the FFM has proven to be powerful and robust as it consistently replicates across studies in different age, sex, race, and language groups (Costa & McCrae, 1992; Widiger, 2016).

2.2.2 Levenson Self-Report Psychopathy Scale (LSRP)

The LSRP is a 26-item questionnaire that assesses primary psychopathic (16 items) and secondary psychopathic (10 items) traits in non-institutionalized populations (Levenson et al., 1995). The assessment items were designed in similarity to the Hare Psychopathy Checklist (PCL-R, pp. 220-222; (Hare, 1991), which clinically identifies psychopaths by interview and review of official records. Primary psychopathy scale (F1) items assess traits such as selfishness, callousness, manipulativeness, tendencies to lie, and an uncaring orientation towards others. Secondary psychopathy scale (F2) items assess traits such as impulsivity, reactivity, poor behavioral controls, and self-destructive lifestyle choices (Lynam et al., 1999; Ronan et al., 2013). The Assessment is shown in Appendix C.

F1 includes items such as "For me, what's right is whatever I can get away with" and "I enjoy manipulating other people's feelings" while F2 includes items such as "I find myself in the same kinds of trouble, time after time" and "I don't plan anything very far in advance". The LSRP was designed such that each of the statements are to be rated on an ordinal four-point Likert scale with options being "disagree strongly", "disagree somewhat", agree somewhat", and "agree strongly" (Levenson et al., 1995). However, the current study included a fifth, neutral point being "neither agree nor disagree". Five items under F1 and two items under F2 are reverse scored to control for social desirability and response bias (Gummelt et al., 2012). A total psychopathy score is obtained by summing all 26 items, while F1 and F2 scores are obtained by summing their respective 16 and 10 items. The total sum score ranges from 26 to 130, the primary psychopathy score ranges from 16 to 80, and the secondary psychopathy score ranges from 10 to 50. LSRP Total cut-off scores established by (Brinkley et al., 2001) are commonly used, but neglect the F1 and F2 subscales such high scores in either subscale might not reach the Total cut-off score threshold.

The LSRP is internally consistent and its total and two-factor (F1, F2) scores correlate significantly with Hare's Psychopathy Checklist Revised (PCL-R, pp. 220-222; (Hare, 1991) scores and corresponding PCL-R factor scores, indicating good construct and concurrent validity (Brinkley et al., 2001). The subscales have convergent validity as higher scores are prototypical for psychopathy ratings (Miller et al., 2008). While F1 was related to an antagonistic interpersonal style (with low Agreeableness and high narcissistic personality disorder), F2 was related to high Neuroticism (negative emotionality), low Conscientiousness (disinhibition) and other personality disorder symptoms (Miller et al., 2008). However, when studying female inmates, the two-factor structure was not found and instead a three-factor structure was better supported (i.e., Egocentricity, Antisociality, and Callousness; (Brinkley et al., 2008). Cross-cultural studies replicating the three-factor structure has further supported the egocentric, antisocial, and callous factors (Garofalo et al., 2019; Psederska et al., 2020; M.-C. Wang et al., 2018). However, the three factors do not show improved reliability or validity, share associations with one another, are theoretical and need improvements (Brinkley et al., 2008; Garofalo et al., 2019; Psederska et al., 2020; Salekin et al., 2014). Because the two-factor model is adequate, established and shows convergent and discriminant validity with other variables, it may still be the best use of the LSRP (Salekin et al., 2014).

2.2.3 Autism-Spectrum Quotient (AQ)

The AQ is a 50-item questionnaire that quantitively measures the extent and degree to which an adult with normal intelligence may have traits associated with the autism spectrum (Baron-Cohen et al., 2001). The AQ assesses 5 different domains, each with 10 items per domain. These domains include: social skill ("I find social situations easy"), attention switching ("I frequently get strongly absorbed in one thing"), attention to detail ("I am fascinated by numbers"), communication ("I enjoy social chit-chat"), imagination ("Trying to imagine something, I find it easy to create a picture in my mind"; Baron-Cohen et al., 2001). Participants are asked to rate how much they agree with each of the statements on a four-point rating scale with the given options "definitely agree", "slightly agree", "slightly disagree", and "definitely disagree". The English and German versions of the assessment are shown in Appendices D and E.

The AQ was designed to score items with 1 point if the respondent selects an "agree" option on 24 of the items that indicate traits associated with autism and with 1 point if the respondent selects a "disagree" option on 26 of the items that indicate traits associated with typical development. The scores are then summed with final scores thus ranging from 0 to 50 with lower scores being at the lower end of the autistic trait continuum and higher scores at the higher end of the autistic trait continuum. Traits associated with autistic-like behavior are poor social and communication skills, poor imagination, exceptional attention to detail, and poor attention-switching / strong focus of attention (Baron-Cohen et al., 2001). The "screening" cut-off point of ≥ 26 has been determined to correctly identify 83% of clinical diagnoses (sensitivity 95%, specificity 52%) and performs significantly better than chance while the proposed "clinical" threshold of ≥ 32 has been found to only correctly identified 76% of clinical diagnoses (sensitivity 77%, specificity 74%) and does not perform better than chance (Ashwood et al., 2016; Woodbury-Smith et al., 2005). Though the test is not meant for making a diagnosis, it could be useful in screening for making referrals for a diagnostic assessment (Baron-Cohen et al., 2001).

Item 21 ("I don't particularly enjoy reading fiction") in the *Imagination* domain and items 9 ("I am fascinated by dates"), 29 ("I am not very good at remembering phone numbers"), 30 ("I don't usually notice small changes in a situation, or a person's appearance"), and 49 ("I am not very good at remembering people's date of birth") in the *Attention to detail* domain do not fit the expected model and need revision (Lundqvist & Lindner, 2017). Though it was assumed those on the Autistic Spectrum would agree with items 9 and 21, and disagree with items 29, 30, and 49, this has not proven to be true. A Factor Analysis revealed the AQ could be reduced to 12 items with little loss of explanatory power (Lundqvist & Lindner, 2017) while another found that a three-factor structure improved internal consistency (Hurst et al., 2007). Further, some studies found the AQ to lack significant correlation with other measures of autism (Bishop & Seltzer, 2012) and it has been argued to lack sufficient validity to reliably predict a diagnosis in outpatient settings (Sizoo et al., 2015). Nonetheless, the AQ is proven to have adequate construct validity, convergent validity with related measures and can differentiate people with and without autistic traits (Armstrong & Iarocci, 2013; Broadbent et al., 2013; Lundqvist & Lindner, 2017). Therefore, the AQ is reliable in investigating autistic traits.

2.3 Voice localizer

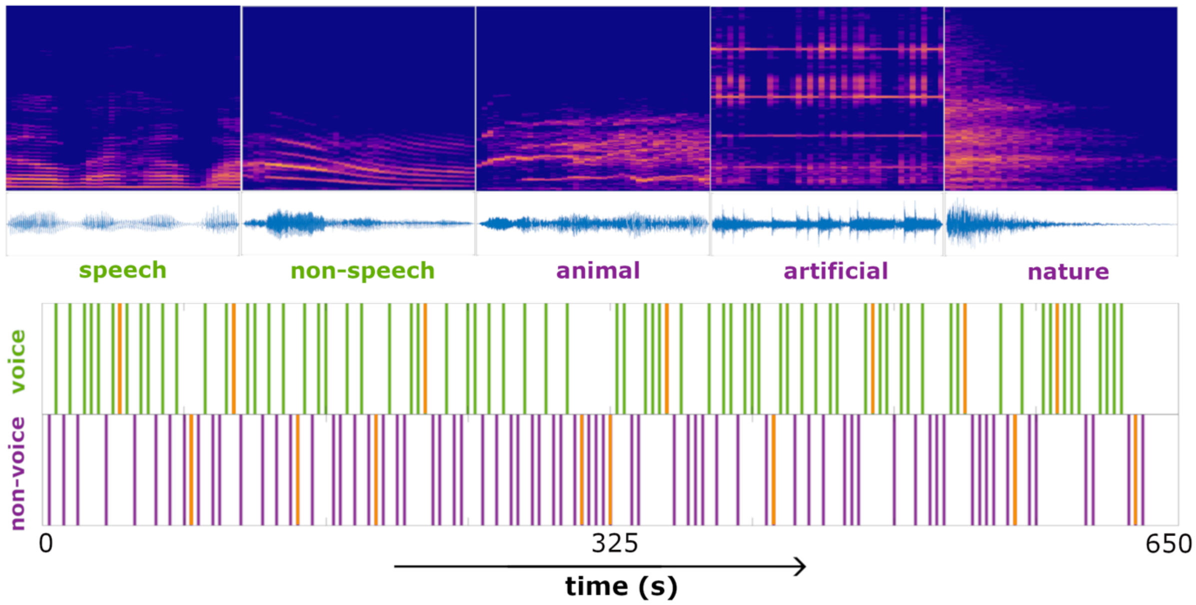
A set of 500ms natural sound recordings consisting of 70 human speech and non-speech vocalizations and of 70 non-human sounds (animal vocalizations, artificial sounds, natural sounds) were presented to each participant. Vocal recordings included speech (non-word) or non-speech (laughs, sighs, etc.) sounds from 47 speakers (Belin et al., 2000). Non-human recordings included sounds from animals (cries, gallops), the artificial human environment (cars, telephones, planes), and nature (wind, streams). All sounds were normalized to the root mean square (RMS) and were presented at 70dB sound pressure level (SPL) during the experiment. See Table 1 for more details on stimuli characteristics. Sounds may also be found here:
https://osf.io/tp937/?view_only=0d02e71c182c43f3a512ed34670cca12

The five voice and non-voice sound conditions were presented in an alternating 800 ms trial sequence with an inter-stimulus interval between 3 and 5 s. Each of the 140 sound recordings were played at least once with randomly chosen repetitions in about 10 percent of trials with a total of ~12 to 15 repetitions. To attenuate attentional load, the participants performed a one-back task and were instructed to press a button to indicate when a sound was repeated from the previous step while listening to the ~155 trials. The TVA localizer consisted of 407 total scans at 1.6 s each (block duration, 651 s; see Figure 1). Repeated sounds were excluded from fMRI analyses. Finally, TVA localization was performed with a univariate analysis contrasting vocal against non-vocal sound stimulation, with each condition accounting for ~50% of all trials.

Table 1. *Stimuli characteristics.* The durations in milliseconds and number of sound recordings (Nb) for each condition are shown. The amplitude range (dB) corresponds to the lowest and highest peaks in the time domain. The frequency peak (Hz) range indicates the frequency corresponding to maximum power spectrum.

Contrast	Condition	Durations	Nb	Amplitude (dB)	Frequency peak (Hz)
Voice	Speech	[501 502]	27	[-17.1 -5.7]	[148.1 901]
	Non-Speech	[501 502]	43	[-17.2 -2.9]	[80.8 2638]
Non-voice	Animal	[501 502]	18	[-14.9 -5.6]	[75.4 4854]
	Artificial	[501 502]	28	[-19.5 -2.5]	[96.9 7918]
	Nature	[501 502]	24	[-14.7 -1.2]	[45.8 2388]

Figure 1. *Voice localizer stimuli and block design.* Spectrograms (upper part, y-axis: frequency) and waveforms (just below, y-axis: amplitude) of the stimuli are shown above the randomized block design (voice in green, non-voice in purple and repetitions in orange).



2.4 fMRI acquisition

Structural and functional brain data were recorded in a 3T-Philips Ingenia by using a standard 32-channel head coil. High-resolution structural MRI was acquired by using T1-weighted scans (301 contiguous 1.2mm slices, repetition time [TR]/echo time [TE] = 1.96s/3.71ms, field of view [FOV] = 256mm, in-plane resolution 1 x 1mm^2). In each session, 407 functional whole-brain images were recorded by using a T2*-weighted echo-planar pulse imaging (EPI) sequence (TR 1.6s, TE 30ms, flip angle [FA] 82; in-plane resolution 220 × 114.2mm, voxel size 2.75 × 2.75 × 3.5mm^3; slice gap 0.6 mm) covering the whole brain. For each participant, a whole-brain magnetic field mapping sequence (TR 30ms, TEs 0.01/3.57ms, FA 60°, voxel size 2.7 × 2.7 × 4mm^3) was recorded to reduce image distortions from inhomogeneities in the magnetic field. Subjects were scanned while keeping their eyes closed and listening passively to the stimuli.

2.5 Preprocessing of fMRI data

Preprocessing and statistical analyses of functional images were performed using Statistical Parametric Mapping software (SPM12, Department of Cognitive Neurology, London; http://www.fil.ion.ucl.ac.uk/spm). Functional data were first manually realigned to the AC-PC axis and functional images were then motion corrected using a 6 parameter affine transformation with realignment to the mean image. Slice time correction (sinc interpolation – reference slice 12, i.e. middle of the TR). Each participant's structural T1 image was co-registered to the mean functional EPI image and then segmented for estimating the normalization parameters. The anatomical and functional images are then normalized to the Montreal Neurological Institute (MNI) stereotactic space (http://www.mrc-cbu.cam.ac.uk/Imaging/mnispace.html). Functional images were then re-sampled into 2 mm^3 voxels. Bilinear interpolation was applied for normalization. All functional images were spatially smoothed at 8 mm full width half maximum (FWHM) isotropic Gaussian kernel.

2.6 Single-subject and group analysis

For the fixed-effects single-subject analysis, a design matrix containing separate regressors for each condition was used and all trials were modeled with a stick function aligned to the onset of each stimulus, which was then convolved with a standard hemodynamic response function. The design included 6 motion correction parameters as regressors of no interest to account for signal changes not related to the conditions of interest. For the voice localizer scan, trials were modeled with vocal and non-vocal sounds separately in one general linear model (GLM). Each voxel across the whole-brain underwent a one-sample t-test that assessed the likelihood that vocal > non-vocal contrast values were significantly different from 0 across the group.

Contrast images from each participant for the voice localizer scan (vocal against non-vocal trials) were taken to separate random-effects group-level analyses by using a threshold of $p < 0.005$ (uncorrected) and a cluster extent corresponding to the specific analyses (see following). A factorial analysis was first completed with results thresholded at a combined voxel threshold of $p < 0.005$ and a minimum cluster level of $k = 49$. Separate analyses were then performed to compare voice processing with trait assessment scores. Separate multiple regressions used the LSRP (Total, F1, F2) and AQ scores with age, gender, and BFI scores included as covariates. Language was not included as a covariate because the sounds used in the voice localizer did not have linguistic meaning. Results for the multiple regressions were thresholded at a combined voxel threshold of $p < 0.005$ and a minimum cluster level of $k = 55$ for LSRP Total, $k = 30$ for LSRP F1 and F2, and $k = 13$ for AQ. These combined voxel and cluster threshold corresponds to $p = 0.05$ corrected at the cluster level and was determined by the 3DClustSim algorithm implemented in the AFNI software (https://afni.nimh.nih.gov/afni; version AFNI v21.1.20) including the recent extension to estimate the (spatial) autocorrelation function according to the median estimated smoothness of the residual images.

Functional activations were anatomically labelled according to the probabilistic cytoarchitectonic maps implemented in the SPM Anatomy Toolbox (version 2.2c, (Eickhoff et al., 2005, 2007) and the Harvard-Oxford Cortical Atlas (Desikan et al., 2006) implemented in FSLeyes (https://zenodo.org/record/3937147#.X7ZPUy2ZOuU). MNI coordinates from significant functional peaks and subpeaks were cross-referenced with the Automated Anatomical Labelling atlas (AAL; (Rolls, Huang, et al., 2020) and JHU White Matter Labels 1mm (https://neurovault.org/images/1401/) on MRIcroGL (https://www.nitrc.org/projects/mricrogl) and also with NeuroSynth (https://www.neurosynth.org/) to confirm location names.

Regions of interest (ROIs) of significant clusters resulting from the factorial analysis were then compared with LSRP total, F1, F2 and AQ scores using a partial correlation that controlled for age, gender, and BFI scores. ROIs included a 5 mm radius extending from the peak maxima MNI coordinates of the bilateral Inferior Frontal Gyrus pars opercularis (IFGoper; left: -50, 16, 18; right: 50, 18, 20), Precentral Gyrus (PreC; left: -52, -8, 46; right: 56, 0, 42), left Superior Temporal Gyrus (STG; (-62, -16, -2), and right Middle Temporal Gyrus (MTG; 62, -6, -6);).

3. Results

3.1 Assessments

Each self-report trait scale minimum (min) and maximum (max) scores as well as the means (M), standard deviations (SD), skewness, kurtosis, and Cronbach's alphas (α) are shown in Table 2. Please note that the LSRP Total, F1 and F2 scores result from the 5-point Likert scale used and are not according to the 4-point scale typically used (Levenson et al., 1995). The highest 25% of LSRP scores were ≥ 71 for Total, ≥ 43 for F1, and ≥ 26 for F2. On the AQ, 14 (12.39%) of the participants scored ≥ 26, potentially meeting criteria for diagnostic screening for autism.

Using low (1-2.33), mid (2.34-3.66) and high (3.67-5) cut-off scores for the BFI, 60 participants scored high in Openness, 50 scored high in Agreeableness, 42 scored high in Conscientiousness, 42 scored high in Extraversion, and 10 scored high in Neuroticism. 35 participants scored low in Neuroticism (high emotional stability), 9 scored low in Extraversion (introversion), 8 scored low in Conscientiousness (spontaneousness), 5 scored low in Openness (closedness), and 4 scored low in Agreeableness (antagonism). Besides Openness, more than half of the participants scored in the mid-range of the Big Five traits.

Table 2. *Descriptive statistics*

Trait	Min	Max	M	SD	Skewness	Kurtosis	α
LSRP Total	32	90	59.2	13.32	0.2	-0.64	0.84
LSRP F1	16	66	36.96	10.08	0.37	-0.16	0.84
LSRP F2	11	37	22.23	5.89	0.43	-0.3	0.7
AQ	6	39	18.34	6.52	0.81	0.82	0.78
Extraversion	1.38	4.88	3.36	0.73	-0.07	-0.46	0.81
Agreeableness	2.11	5	3.63	0.62	0.03	0.09	0.74
Conscientiousness	1.78	4.78	3.48	0.65	-0.58	0.05	0.77
Neuroticism	1	4.5	2.71	0.71	0.13	-0.42	0.78
Openness	1.7	4.8	3.68	0.62	-0.66	0.38	0.77
Positive Affect	12	49	31.99	7.45	-0.32	-0.06	0.87
Negative Affect	10	47	14.59	6	2.37	7.7	0.88
Affect Balance	-25	34	17.4	9.85	-1.46	3.85	-

N = 113

Point Biserial correlation coefficients were computed using a two-tailed t-distribution to assess the relationships between language, gender, age, and the assessment scores. English speakers tended to be older than German speakers $t(111) = .2$, $p = 0.03$. English speakers were also found to be more Agreeable than German speakers $t(111) = .2$, $p = .03$, and to have higher Positive Affect scores than German speakers $t(111) = .24$, $p = .01$. A positive association was seen between Males and AQ scores $r_{pb}(111) = .31$, $p = .001$. A positive association was seen between Females and Extraversion $r_{pb}(111) = .31$, $p = .001$.

Bivariate Pearson correlation coefficients were also computed using a two-tailed t-distribution to assess the relationships between each of the traits measured from the self-report assessments (see Table 3).

Table 3. *Pairwise Pearson correlation statistics for the assessment scores*

Trait	1	2	3	4	5	6	7	8	9
1. LSRP Total									
2. LSRP F1	.910**								
3. LSRP F2	.705**	.348**							
4. AQ	.297**	.190*	.348**						
5. Extraversion	-.188*	-0.081	-.288**	-.455**					
6. Agreeableness	-.443**	-.374**	-.361**	-.383**	.359**				
7. Conscientious	-0.114	0.083	-.399**	-0.121	.200*	.215*			
8. Neuroticism	0.131	0.001	.293**	.332**	-.219*	-.334**	-.252**		
9. Openness	-.299**	-.314**	-0.14	-.237*	.280**	.358**	0.171	-0.102	
10. Affect Balance	-.261**	-0.176	-.291**	-0.045	.195*	.256**	.330**	-.386**	0.18

** p < 0.01 (2-tailed); * p < 0.05; N = 113

LSRP Total was more correlated with F1 $r(111) = .91$, $p < .001$ than with F2 $r(111) = .71$, $p < .001$. F1 and F2 were even less correlated with one another $r(111) = .35$, $p < .001$. AQ was correlated with LSRP Total $r(111) = .3$, $p = .001$ but was more greatly associated with F2 $r(111) = .35$, $p < .001$ than with F1 $r(111) = .19$, $p = .04$.

Extraversion was negatively correlated with F2 $r(111) = -.29$, $p = .002$. F2 has previously been associated with small amounts of high Extraversion (Lynam et al., 1999), so this result is different from previous observations. Extraversion was also negatively correlated with AQ $r(111) = -.46$, $p < .001$.

Agreeableness was negatively correlated with AQ $r(111) = -.38$, $p < .001$, Neuroticism $r(111) = -.33$, $p < .001$, and all three LSRP scores: Total $r(111) = -.44$, $p < .001$, F1 $r(111) = -.37$, $p < .001$, F2 $r(111) = -.36$, $p < .001$. F1 and F2 are known to be related with low Agreeableness (Lynam et al., 1999; Miller et al., 2008).

Conscientiousness was negatively correlated F2 $r(111) = -.40$, $p < .001$, as commonly reported (Lynam et al., 1999; Miller et al., 2008).

Neuroticism was positively correlated with F2 $r(111) = .29$, $p = .002$ and AQ $r(111) = .33$, $p < .001$.

Openness was negatively correlated with F1 $r(111) = -.31$, $p = .001$ and AQ $r(111) = -.24$, $p = .001$.

Affect Balance negatively correlated with F2 $r(111) = -.29$, $p = .002$.

AQ correlation results are similar to a previous meta-analysis that found autism to be positively associated with Neuroticism and negatively associated with the remaining Big Five traits (Lodi-Smith et al., 2019).

3.2 Single-subject analysis

Each of the participants' significant cluster results from contrasting vocal against non-vocal trials were individually observed and categorically coded for activation cluster location and significance. Single-subject adaptive thresholding showed TVA activations in 97.3% of participants. Of the 113 participants, only 3 showed no significant clusters at $p \leq 0.001$ uncorrected. 60 participants (53.1%) showed predominate left hemispheric activations while only 39 participants (34.5%) showed predominate right hemispheric activations. 11 participants (9.7%) showed activations about equally in both hemispheres.

Bivariate Point Biserial correlation coefficients were computed using a two-tailed t-distribution to assess the relationships between observed cluster locations and assessment scores. Positive associations were found between significant activity in regions outside the TVA with English speakers $r_{pb}(111) = .22$, $p = .02$, and with Males $r_{pb}(111) = .19$, $p = .049$. Males also showed a positive association with predominant left hemispheric TVA activity $r_{pb}(111) = .24$, $p = .01$. No significant associations between Age and activity location were found.

Lateralized left TVA activity was positively associated with Extraversion $r_{pb}(111) = .2$, $p = .03$. Lateralized right TVA activity was positively associated with AQ $r_{pb}(111) = .2$, $p = .03$. Further, Lateralized right TVA activity was negatively associated with Conscientiousness $r_{pb}(111) = -.22$, $p = .02$.

Activity in other regions was negatively associated with LSRP Total $r_{pb}(111) = -.26$, $p = .005$ and F1 scores $r_{pb}(111) = -.28$, $p = .003$ but was positively associated with Agreeableness $r_{pb}(111) = .26$, $p = .006$. Higher significance clusters (where $p[FWE] \leq 0.001$) were also positively associated with Agreeableness $r_{pb}(111) = .2$, $p = .036$. Finally, more varied activation patterns were negatively associated with LSRP Total $r_{pb}(111) = -.21$, $p = .029$ and F2 $r_{pb}(111) = -.19$, $p = .044$.

3.3 Group-level analysis

3.3.1 Factorial design

Activation hemodynamic response function (HRF) clusters resulting from the factorial analysis of contrasted vocal versus non-vocal sound trials were similar to previous studies analyzing the voice localizer (Pernet et al., 2015). Thus, the current study has again replicated these findings of voice-sensitive regions. See Table 4 and Figure 2 for more details.

Table 4. *Peak coordinates for the factorial analysis functional contrasts*

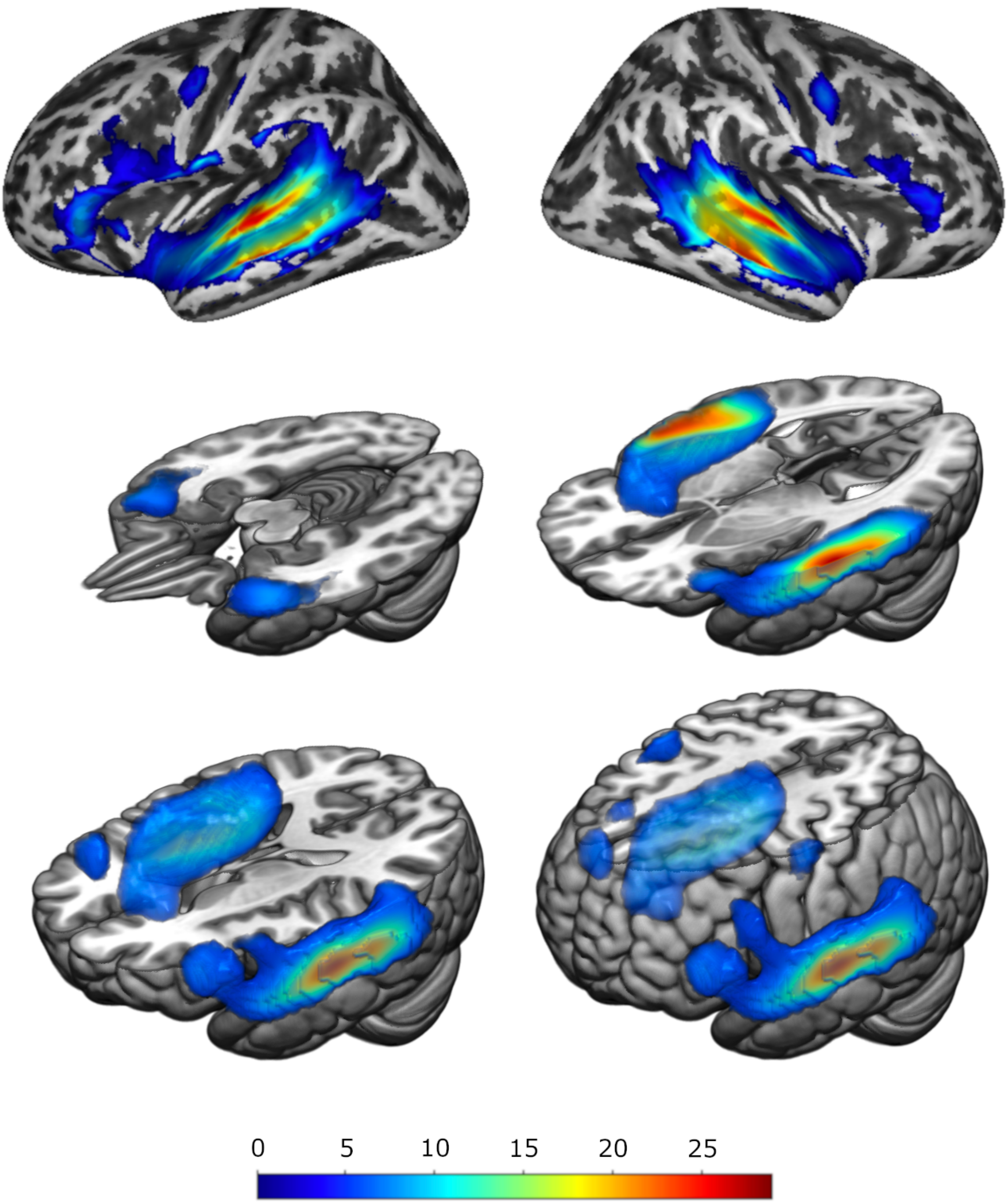
The table includes peak activations for contrasting vocal with non-vocal sound trials. Functional activations are thresholded at voxel level p = .005 (uncorrected) and cluster level k = 49, resulting in a combined p = .05 corrected at the cluster level.

			MNI Coordinates		
Region	**Cluster size (k_E)**	**Z value (Z_E)**	**x**	**y**	**z**
L Superior Temporal Gyrus	5404	Inf	-62	-16	-2
L Orbital Frontal Cortex		Inf	-40	30	-2
L Superior Temporal Pole		6.95	-44	2	-20
L Inferior Frontal Gyrus, pars opercularis		4.03	-50	16	18
		3.5	-52	10	10
R Middle Temporal Gyrus	3688	Inf	62	-6	-6
R Planum Polare		5.6	44	4	-22
R Precentral Gyrus	163	7.11	56	0	42
L Precentral Gyrus	77	6.05	-52	-8	46
R Inferior Frontal Gyrus, pars triangularis	227	5.41	52	28	4
R Inferior Frontal Gyrus, pars opercularis	55	3.18	50	18	20

Abbreviations: L, Left; R, Right; MNI, Montreal Neurological Institute;

Figure 2. *Neural activation for passive vocal-sound processing*

Random effects factorial analysis in 113 participants. The voice-sensitive area (TVA) revealed by the contrast vocal versus non-vocal sound trials. Whole-brain level analysis of voxels at which a t-test of the vocal vs. non-vocal difference in BOLD parameter estimates across n = 113 subjects yields significant values. Data are projected (i) on inflated cortical mesh surfaces created using Freesurfer version 40.1 available in SPM and (ii) on slices of the 152 MNI templates.



3.4 Multiple regression

Areas of the temporal lobe were hypoactive in relation to each of the assessment scores. The left anterior Superior Temporal Sulcus (aSTS; TVAa) was hypoactive with LSRP total and F1. The right posterior STS (pSTS; TVAp) also was hypoactive with LSRP total. The bilateral Planum Temporale (PT) were also hypoactive with LSRP total. The left Middle Temporal Cortex (MTC) was hypoactive with LSRP total (gyrus), F2 (sulcus and gyrus), and AQ (gyrus). The right MTC was also hypoactive with LSRP Total (sulcus) and AQ (surrounding white matter). The Left Inferior Temporal Cortex (ITC) was hypoactive with F1 (gyrus) and AQ (sulcus).

3.4.1 LSRP Total multiple regression

Only negative associations were found between HRF and LSRP Total scores. Clusters negatively associated with LSRP total were most similar to those seen for F1. Besides L anterior STS hypoactivation, similarities between LSRP total and F1 also include hypoactivity in the following areas: R dorsomedial Prefrontal Cortex (dmPFC), L Orbitofrontal Cortex (OFC), R Inferior Frontal Gyrus pars orbitalis (IFGorb), L Precentral Gyrus (PreC), bilateral Insula, bilateral Parahippocampal Gyri, L Superior Parietal Lobule, L Middle Occipital Gyrus, bilateral Amygdala, bilateral Hippocampus, bilateral Olfactory Gyri, R Basal Forebrain, R Caudate, bilateral Putamen, L Globus Pallidus, L Thalamus, R Hypothalamus and L Cerebellum.

The LSRP total score differed from F1 in its lateralized hypoactivity of certain regions. These include: L Inferior Frontal Gyrus pars orbitalis (IFGorb; bilateral total), R Precentral Gyrus (bilateral total), R posterior STS, L Angular Gyrus (right F1), L Caudate (bilateral total), R Globus Pallidus (bilateral total) and R Cerebellum (bilateral total)

Finally, some regions were only associated with LSRP total (mostly in frontal and basal ganglia). Hypoactive locations only associated with LSRP total and no other assessment scores were: R ventromedial Prefrontal Cortex (vmPFC), L Inferior Frontal Gyrus pars opercularis (IFGoper), bilateral Planum Tempolare, L Fusiform, and L Inferior Parietal Lobule.

See Table 5 and Figure 3 for more details.

Table 5. *Peak coordinates for the LSRP Total multiple regression analysis*

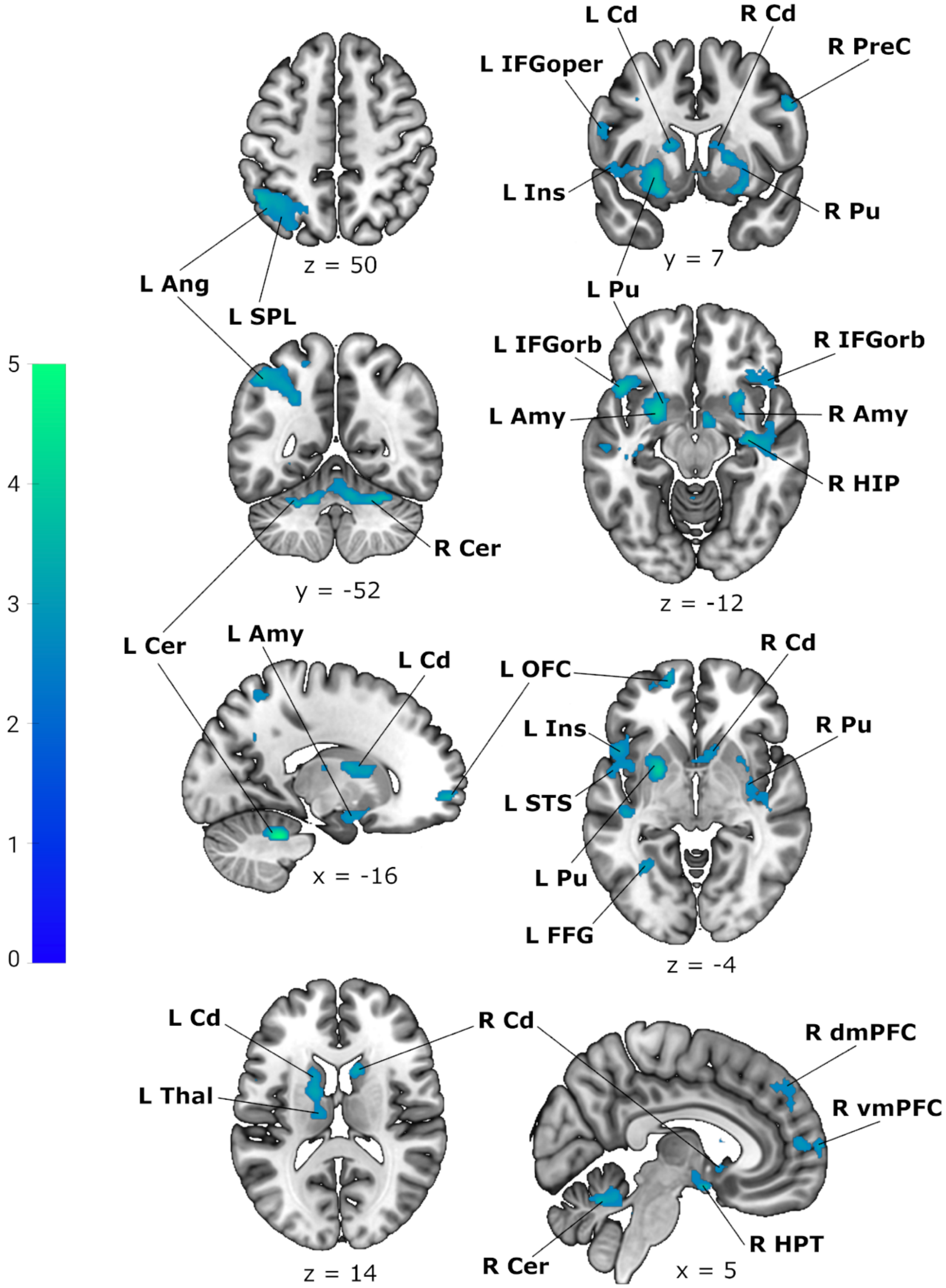
The table includes peak and subpeak activations for contrasting vocal with non-vocal sound trials that were negatively associated with LSRP Total scores. Functional activations were thresholded at voxel level p = .005 (uncorrected) and cluster level k = 55, resulting in a combined p = .05 corrected at the cluster level.

				MNI Coordinates		
Association	**Region**	**Cluster size (k_E)**	**Z value (Z_E)**	**x**	**y**	**z**
Negative	L Cerebellum	890	4.76	-14	-44	-30
	L Putamen	993	4.24	-22	2	-8
	L IFG, pars orbitalis		3.63	-44	18	-12
	L IFG, pars opercularis		3	-48	12	0
	L Parahippocampal Gyrus		2.98	-14	0	-18
	L Insula		2.91	-40	4	-2
	L Superior Temporal Sulcus		2.91	-46	4	-8
	R Hypothalamus	1134	3.78	6	2	-16
	R Hippocampus		3.75	34	-14	-14
	R Olfactory		3.5	26	12	-14
	R Caudate		3.49	12	12	12
	R Putamen		3.29	32	-2	2
	R Globus Pallidus		3.17	20	8	4
	R ventromedial Prefrontal Cortex	96	3.57	4	68	8
	L Inferior Parietal, Angular Gyrus	1034	3.48	-48	-52	50
	L Middle Occipital Gyrus		3.1	-28	-76	36
	L Superior Parietal Lobule		3.06	-32	-64	46
	R Precentral Gyrus	64	3.39	56	8	36
	L Orbitofrontal Cortex	59	3.37	-16	60	-4
	R dorsomedial Prefrontal Cortex	98	3.27	8	50	42
	L white matter	217	3.22	-14	-2	14
	L Caudate		3.06	-14	6	12
	L Thalamus		2.92	-12	-16	14
	L Planum Temporale	150	3.2	-44	-24	-4
	L Middle Temporal Gyrus		2.96	-56	-20	-12
	L Hippocampus		2.76	-34	-20	-12
	L Precentral Gyrus	130	3.01	-38	2	22
	L Fusiform	61	2.99	-30	-56	-4
	L Precentral Gyrus	85	2.93	-36	-4	42
	R IFG, pars orbitalis	82	2.89	34	28	-14
	R Superior Temporal Pole		2.86	46	20	-14

Abbreviations: L, Left; R, Right; IFG, Inferior Frontal Gyrus; MNI, Montreal Neurological Institute;

Figure 3. *Clusters negatively correlated with LSRP Total scores*

The color bar represents the Z value of the cluster with cool colors indicating hypoactivity.



Abbreviations: L, Left; R, Right; Ang, Angular Gyrus; SPL, Superior Parietal Lobule; Ins, Insula; IFGoper, Inferior Frontal Gyrus pars opercularis; Cd, Caudate; PreC, Precentral Gyrus; Pu, Putamen; Cer, Cerebellum; IFGorb, Inferior Frontal Gyrus pars orbitalis; Amy, Amygdala; HIP, Hippocampus; OFC, Orbitofrontal Cortex; STS, Superior Temporal Sulcus; FFG, Fusiform Gyrus; Thal, Thalamus; HPT, Hypothalamus; dmPFC, dorsomedial Prefrontal Cortex; vmPFC, ventromedial Prefrontal Cortex;

3.4.2 F1 (primary psychopathy) multiple regression

Only negative associations were found between HRF and LSRP F1 scores. Clusters negatively associated with F1 were most similar to those seen for the Total score (see previous section). In the Temporal lobe, the left anterior STS was hypoactive with LSRP total and F1. In other regions, similarities between F1 and LSRP total include hypoactivity in the following areas: R dorsomedial Prefrontal Cortex (dmPFC), L Orbitofrontal Cortex (OFC), R Inferior Frontal Gyrus pars orbitalis (IFGorb), L Precentral Gyrus (PreC), bilateral Insula, bilateral Parahippocampal Gyri, L Superior Parietal Lobule, L Middle Occipital Gyrus, bilateral Amygdala, bilateral Hippocampus, bilateral Olfactory Gyri, R Basal Forebrain, R Caudate, bilateral Putamen, L Globus Pallidus, L Thalamus, R Hypothalamus and L Cerebellum.

Differences associated with LSRP F1 and Total scores largely involve the lateralization of hypoactive locations: Right Angular Gyrus (left total), Right Caudate (bilateral total), Left Cerebellum (bilateral total) and Cerebellar Vermis.

Some similarities were also seen with F1 and AQ. The Inferior Frontal Gyrus pars triangularis (IFGtri) was hypoactive with both F1 (right) and AQ (left). The Left Inferior Temporal Cortex (ITC) was hypoactive with F1 (gyrus) and AQ (sulcus). The Left Mid Cingulum was also hypoactive with F1 while the Cingulum Bundle was hypoactive with AQ. Interestingly, Substantia Nigra activity was negatively associated with F1 but positively associated with F2.

Other areas were specifically hypoactive in relation to F1, but not the other assessment scores. These include: The R dorsolateral Prefrontal Cortex (dlPFC), the L inferior colliculus, and Ventral Tegmental Area.

See Table 6 and Figure 4 for more details.

Table 6. *Peak coordinates for the F1 multiple regression analysis*

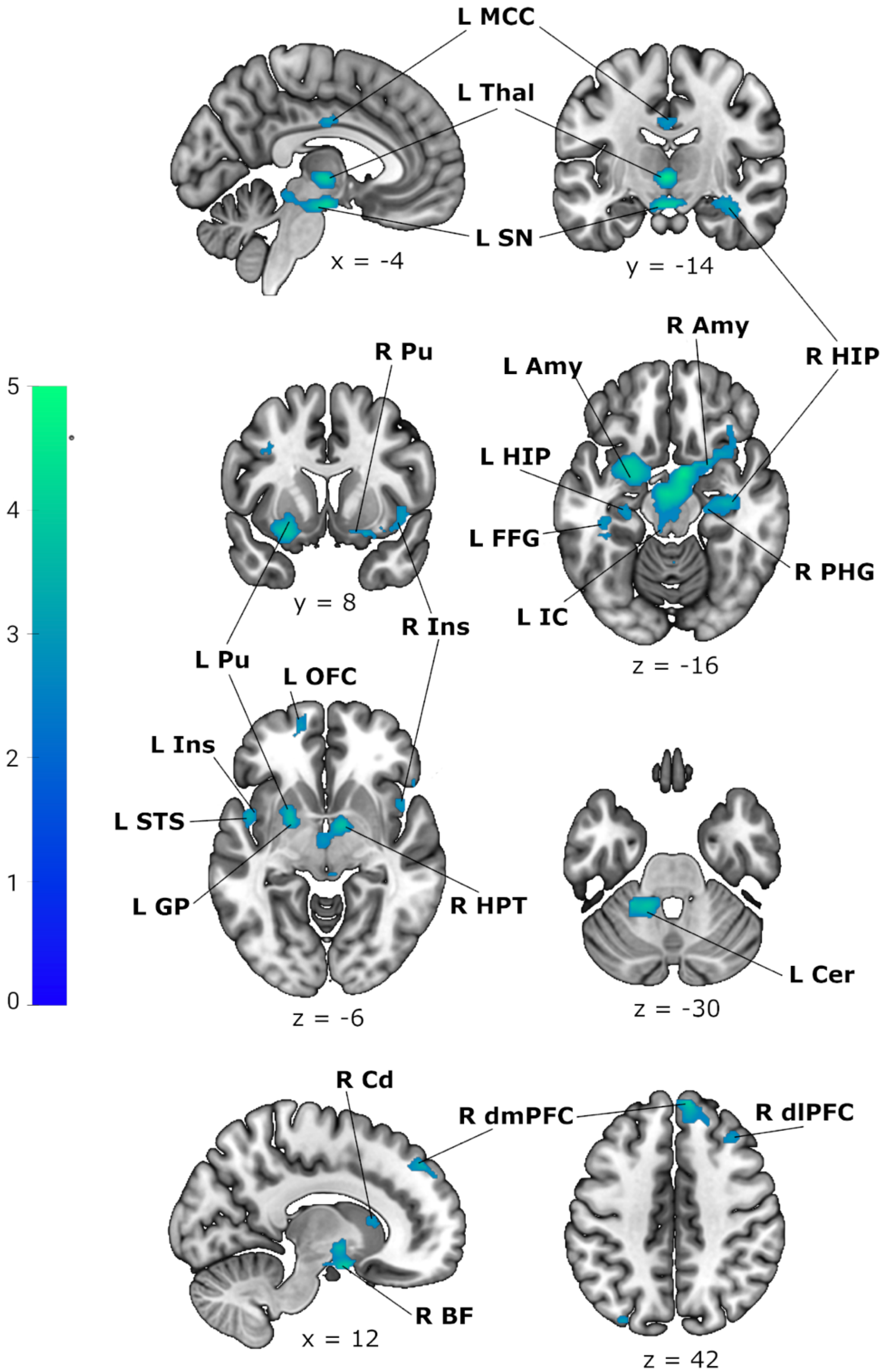
The table includes peak and subpeak activations for contrasting vocal with non-vocal sound trials that were negatively associated with LSRP F1 scores. Functional activations were thresholded at voxel level *p* = .005 (uncorrected) and cluster level *k* = 30, resulting in a combined *p* = .05 corrected at the cluster level.

				MNI Coordinates		
Association	**Region**	**Cluster size (k_E)**	**Z value (Z_E)**	**x**	**y**	**z**
Negative	L Thalamus	1566	4.45	-2	-14	0
	R Amygdala		3.38	22	8	-16
	R Insula		3.12	32	12	-14
	L Inferior Colliculus		3.01	-6	-34	-12
	R Anterior Insula		2.96	44	8	-4
	R dorsomedial Prefrontal Cortex	163	3.81	8	50	42
	L Cerebellum Exterior	170	3.7	-24	-42	-30
	R Hippocampus	174	3.41	36	-16	-18
	L Insula	213	3.4	-36	0	22
	L Superior Parietal Lobule	49	3.39	-24	-68	58
	L Middle Occipital Gyrus	113	3.38	-30	-78	36
	L Orbitofrontal Cortex	37	3.28	-16	52	-6
	L a Superior Temporal Sulcus	82	3.22	-46	2	-6
	R Inferior Frontal Gyrus (IFGtri)	37	3.12	56	22	0
	L Midcingulate Cortex	82	3.09	-4	-12	34
	L Inferior Temporal Gyrus	47	3.08	-40	-28	-14
	R dorsolateral Prefrontal Cortex	39	2.97	36	30	44
	L Hippocampus	54	2.97	-24	-22	-14
	R Angular Gyrus	40	2.91	50	-70	32
	R Caudate	31	2.9	12	18	8
	L Middle Occipital Gyrus	32	2.89	-40	-84	20
	Cerebellar Vermis	59	2.82	4	-50	-20

Abbreviations: L, Left; R, Right; IFGtri, inferior frontal gyrus pars triangularis; MNI, Montreal Neurological Institute;

Figure 4. *Clusters negatively correlated with F1 scores*

The color bar represents the Z value of the cluster with cool colors indicating hypoactivity.



Abbreviations: L, Left; R, Right; MCC, Mid Cingulate Cortex; Thal,Thalamus; SN, Substantia Nigra; HIP, Hippocampus; Amy, Amygdala; Pu, Putamen; PHG, Parahippocampal Gyrus; FFG, Fusiform Gyrus; IC, Inferior Colliculus; OFC, Orbitofrontal Cortex; Ins, Insula; STS, Superior Temporal Sulcus; GP, Globus Pallidus; HPT, Hypothalamus; Cer, Cerebellum; Cd, Caudate; BF, Basal Forebrain; dmPFC, dorsomedial Prefrontal Cortex; dlPFC, dorsolateral Prefrontal Cortex;

3.4.3 F2 (secondary psychopathy) multiple regression

Positive and negative associations were found between HRF and LSRP F2 scores. Location similarities were seen with the other assessments. The Left Middle Temporal Cortex hypoactive at LSRP Total (gyrus), F2 (sulcus and gyrus), and AQ (gyrus). Although L Substantia Nigra was hypoactive with F1, it was hyperactive with F2. Bilateral Calcarine Sulcus hyperactivity is specific to F2.

See Table 7 and Figure 5 for more details.

Table 7. *Peak coordinates for the F2 multiple regression analysis*

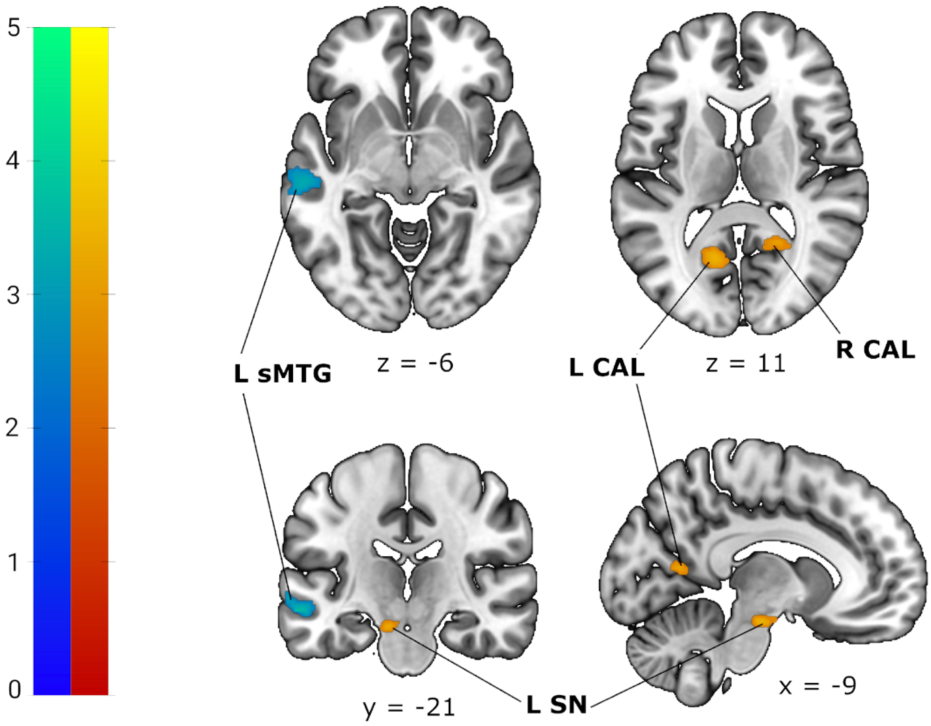
The table includes peak and subpeak activations for contrasting vocal with non-vocal sound trials that were positively and negatively associated with LSRP F2 scores. Functional activations were thresholded at voxel level p = .005 (uncorrected) and cluster level k = 30, resulting in a combined p = .05 corrected at the cluster level.

				MNI Coordinates		
Association	**Region**	**Cluster size (k_E)**	**Z value (Z_E)**	**x**	**y**	**z**
Positive	Substantia Nigra	157	4.53	-2	-12	-16
	L Substantia Nigra		3.42	-8	-18	-18
	L Calcarine Sulcus	112	3.4	-12	-62	10
	R Calcarine Sulcus	52	3.3	22	-52	10
Negative	L Middle Temporal Sulcus	212	3.61	-58	-20	-10
	L Middle Temporal Gyrus		3.23	-64	-20	-2

Abbreviations: L, Left; R, Right; MNI, Montreal Neurological Institute;

Figure 5. *Clusters positively and negatively correlated with F2 scores*

The color bar represents the Z value of the cluster with warmer colors (red to yellow) indicating hyperactivity and cooler colors (blue to green) indicating hypoactivity.



Abbreviations: L, Left; R, Right; sMTG, Middle Temporal Sulcus; SN, Substantia Nigra; CAL, Calcarine.

3.4.4 AQ (Autism Quotient) multiple regression

Only negative associations were found between HRF and AQ scores. Most of these were in areas of white matter including The Right Mid Cingulum Bundle and Left Anterior Cingulum Bundle. White matter area near the right Middle Temporal Gyrus (MTG) also appeared to be hypoactive in relation to the AQ score.

The left MTG appeared to be hypoactive within the more posterior subdivision in relation to the AQ score. The MTC was also hypoactive with LSRP Total (gyrus) and F2 (sulcus and gyrus). The Left Inferior Temporal Cortex (ITC) was hypoactive with AQ (sulcus) and also with F1 (gyrus).

The Left IFGtri was hypoactive with AQ while the Right IFGtri was hypoactive with F1. The left Cinglum Bundle was hypoactive with AQ while the left Mid Cingulum was hypoactive with F1.

See Table 8 and Figure 6 for more details.

Table 8. *Peak coordinates for the AQ multiple regression analysis*

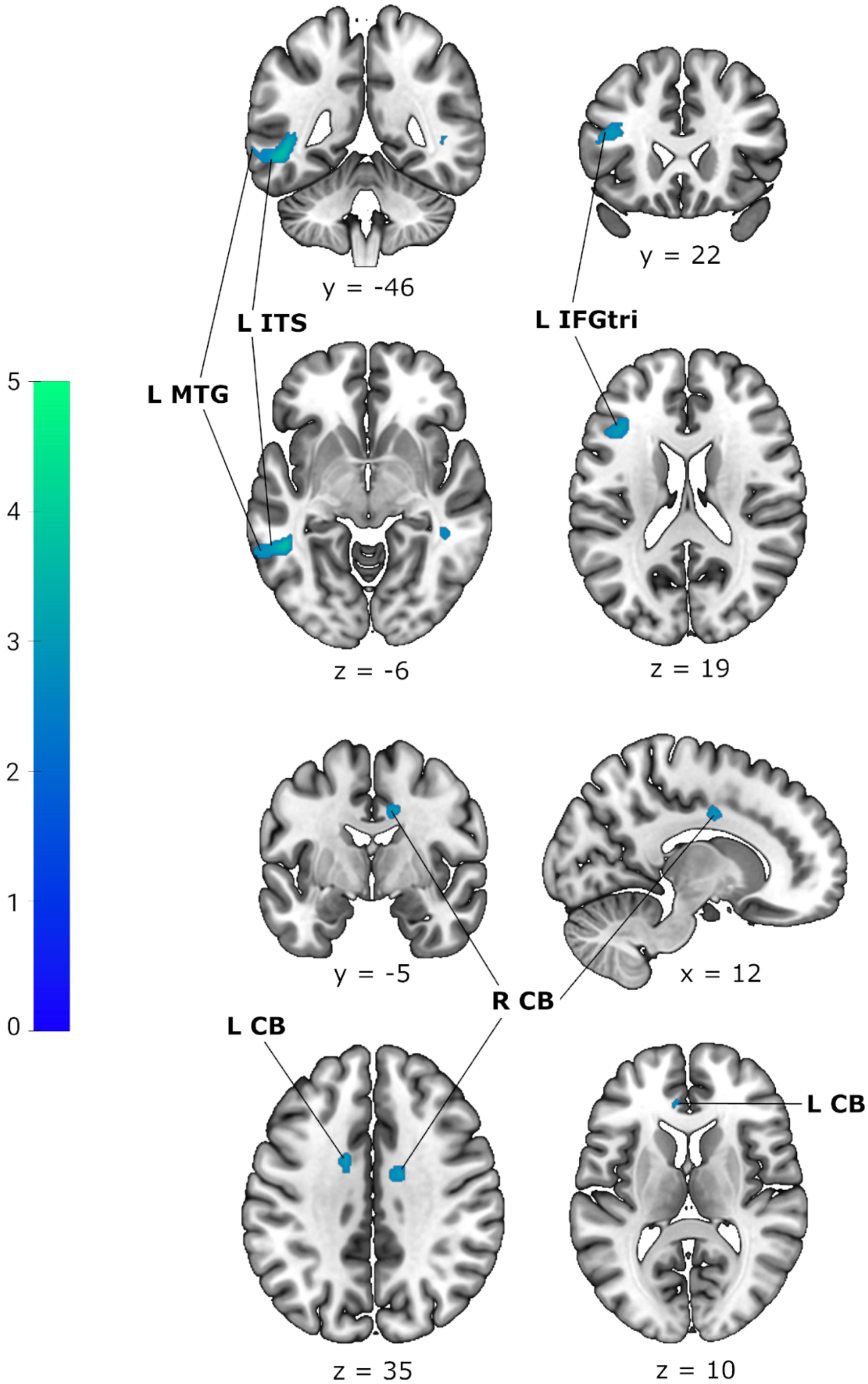
The table includes peak and subpeak activations for contrasting vocal with non-vocal sound trials that were negatively associated with AQ scores. Functional activations were thresholded at voxel level *p* = .005 (uncorrected) and cluster level *k* = 13, resulting in a combined *p* = .05 corrected at the cluster level.

				MNI Coordinates		
Association	**Region**	**Cluster size (k_E)**	**Z value (Z_E)**	**x**	**y**	**z**
Negative	L Inferior Temporal Sulcus	256	3.69	-48	-46	-6
	L p Mid Temporal Gyrus		2.85	-64	-48	-6
	L Middle Cingulum Bundle	45	3.18	-12	0	34
	R Middle Cingulum Bundle	44	3.05	14	-6	36
	White Matter (unidentified)	107	3.01	-38	20	20
	L IFG, pars triangularis		2.86	-46	20	16
	White Matter (near R MTG)	37	2.91	42	-38	-2
	L Anterior Cingulum Bundle	15	2.88	-8	34	10
	White Matter (near R MTG)	18	2.84	52	-32	-12

Abbreviations: L, Left; R, Right; IFG, Inferior Frontal Gyrus; MTG, Middle Temporal Gyrus; MNI, Montreal Neurological Institute; JHU White Matter Labels 1mm

Figure 6. *Clusters negatively correlated with AQ scores*

The color bar represents the Z value of the cluster with cool colors indicating hypoactivity.

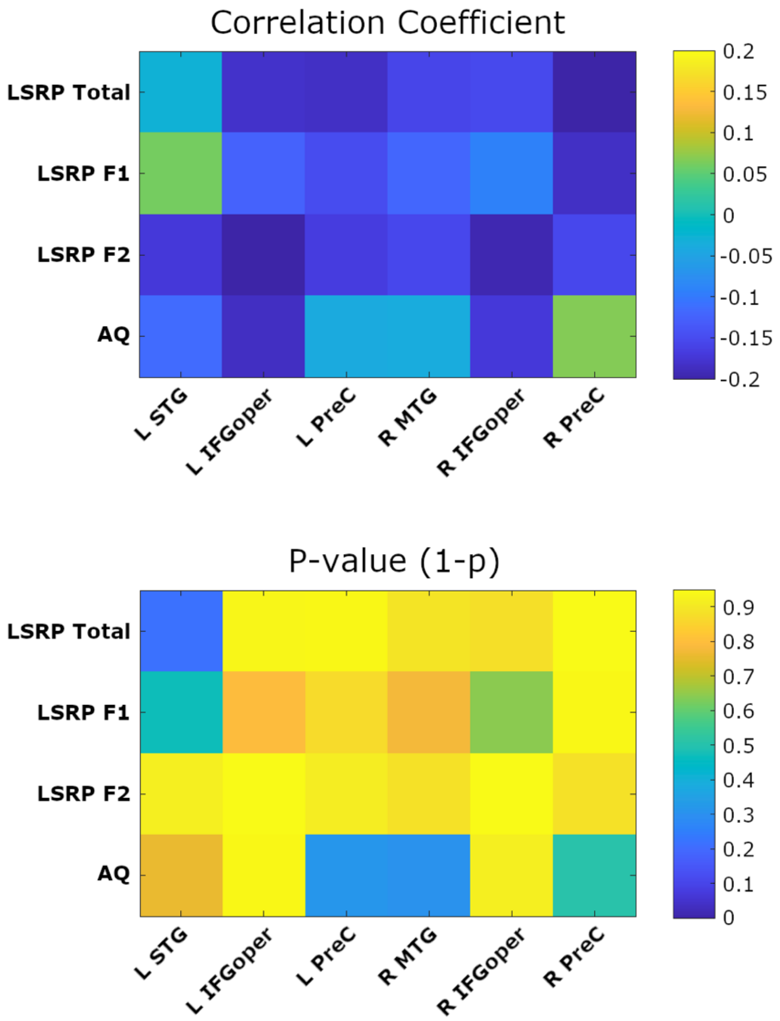


Abbreviations: L, Left; R, Right; ITS, Inferior Temporal Sulcus; MTG, Middle Temporal Gyrus; IFGtri, Inferior Frontal Gyrus pars triangularis; CB, Cingulum Bundle.

3.4.5 Partial correlation

A partial correlation analysis was computed with ROIs using the MNI coordinates of maxima peak locations from the factorial analysis (See Figure 7). LSRP Total, F1, F2 and AQ scores were compared with the mean beta values from contrasted vocal and non-vocal trials in each ROI within a 5 mm radius. Partial correlations were controlled with age, gender, and BFI scores. Most of the correlations were negative and near significant, confirming findings from the previous sections. Significant negative correlations were between LSRP Total and R PreC (r = -.2, p = .04), F2 and L IFGoper (r = -.2, p = .04), and F2 and R IFGoper (r = -.2, p = .04).

Figure 7. *Pairwise partial correlations between ROI activity and assessment scores*
In the top half, darker colors represent greater negative correlation between the trait score and ROI. In the bottom half, lighter colors represent greater significance.



Abbreviations: L, Left; R, Right; STG, Superior Temporal Gyrus; IFGoper, Inferior Frontal Gyrus pars opercularis; PreC, Precentral Gyrus; MTG, Middle Temporal Gyrus. **MNI Coordinates:** L STG (-62, -16, -2); L IFGoper (-50, 16, 18); L PreC (-52, -8, 46); R MTG (62, -6, -6); R IFGoper (50, 18, 20); R PreC (56, 0, 42).

4. Discussion

Results from the factorial design were as expected with significant bilateral TVA activity in response to passively listening to voice sounds in contrast to non-voice sounds, indicating functional voice processing in the core network of the overall group (Belin et al., 2000; Pernet et al., 2015). While less is known about the MTG, it is known to be involved in sound recognition, decoding intelligible speech, and language processing (Xu et al., 2016). Extended network regions such as the orbitofrontal cortex (OFC) and inferior frontal gyri (IFG) were also active. The STS, OFC, IFG, and precentral gyrus (PreC) are also areas involved in the mirror neuron system, contributing to experience sharing and affective empathy (Cerniglia et al., 2019; Rajmohan & Mohandas, 2007; Sommer et al., 2010).

Motor area (PreC) activation during auditory processing, especially in processing voice sounds, is critical in perceiving voice and in discriminating sound as speech (D'Ausilio et al., 2009). The motor system is a part of the mirror neuron system that only becomes active in reaction to the perception of sounds that are within the perceiver's motor repertoire (Froese & González-Grandón, 2020). Auditory perception is not passive but instead involves sensorimotor engagement to make sense of sounds and to further guide potentially relevant actions in response to these sounds (Froese & González-Grandón, 2020). Bodily skills contribute to a perceptual experience by informing on how one's potential actions would change sensations (Froese & González-Grandón, 2020). Therefore, sensorimotor processes allow for perceptual access of the environment and motor system activity reflects that the perceiver's neural processes are influenced by their potential for interaction with the environment (Degenaar & O'Regan, 2015; Froese & González-Grandón, 2020). This means that the group overall does automatically and unconsciously judge the voice sound as a social signal with potential for interaction.

The overall group result from the voice localizer does not consider individual differences and therefore is representative of an average across all different types of people, which removes brain effects that might be further involved in voice perception. Because the voice is a social signal and because individuals engage in social cognition differently, it would be expected that some people have more of a preference for listening to and potentially responding to voices than others, which would be reflected in the brain activity. As the multiple regression analyses revealed, quantification along individual difference factors such as psychopathic and autistic traits proves that more brain areas are involved in voice processing than what is typically reported. This means that individual difference factors influence the way the brain reacts to and processes social signals, but these effects are not apparent across an average group.

4.1 Overall psychopathic traits

The LSRP Total score did not relate to the language, age or gender of the participants but did have significant negative associations with Extraversion, Agreeableness, Openness, and Affect Balance. Both F1 and F2 negatively associated with Agreeableness while F1 negatively associated with Openness and F2 negatively associated with Extraversion and Affect Balance. The single-subject analysis revealed that the LSRP total score was negatively associated with more varied patterns of activation and activity in other regions than the TVA. Because F1 accounts for most of the LSRP total score and much of the hypoactive regions from the multiple regression analysis were similar between LSRP total and F1 scores, regions showing as hypoactive relative to the LSRP total score will be the focus of this section. More specifically: Bilateral planum temporale (PT), bilateral precentral gyrus (PreC), right posterior superior temporal sulcus (pSTS), right ventromedial prefrontal cortex (vmPFC), left inferior frontal gyrus pars opercularis (IFGoper / BA44), left inferior parietal lobule (IPL), and left fusiform gyrus.

The PT is known to be involved in early auditory processing, representing sound location, and auditory attention (Hirnstein et al., 2013; Rauschecker & Scott, 2016). Hypoactivity in the PT reflects that the voice sounds did not automatically capture the attention of those with higher overall psychopathic traits, and thus processing of the voice stimuli was lessened. Hypoactivity in the right pSTS follows that there was a lack of selective attention to the voice sounds hypoactivity in this region reflects a lack of perceiving the voice sound as salient (Yan et al., 2020). A hypoactive pSTS may also indicate that the voice was experienced as socially irrelevant and possibly unpleasant (Davidovic et al., 2016). As emotional voice sounds were included in some clips, right pSTS hypoactivity could reflect a lack of emotional voice processing but likely indicates a propensity towards ineffectively processing and perceiving vocal affective information in regular social situations (Belin, 2018; Young et al., 2020). Bilateral PreC hypoactivity further reflects that the voice is not processed as a socially relevant signal by those with overall psychopathic traits. It is possible that for these individuals, the sound is not being perceived as a human voice (D’Ausilio et al., 2009), or the sound is not perceived as relating to the potential for interaction (Froese & González-Grandón, 2020).

The left IFGoper (BA44) is involved in the speech information pathway (Belin, 2018) and includes speech mirror neurons that are active while listening to voices as this area contributes to understanding and empathizing with others (Rajmohan & Mohandas, 2007; Smith et al., 2015). A dysfunctional IFG relates to atypical social-emotional processing that results in atypical regulation of emotions and behaviors, which are common features of psychopathic traits (Chan & Han, 2020; Seara-Cardoso & Viding, 2015). The IPL is another region of the mirror neuron system that also correlates with understanding action intention and empathic accuracy (Acharya & Shukla, 2012; Chong et al., 2008). IPL dysfunction leads to impairments with imitation, action recognition, and understanding of action intentions within a given context (Acharya & Shukla, 2012; Goldenberg & Karnath, 2006). Hypoactivity of the left IFGoper and IPL in response to listening to voices could mean that those with psychopathic traits are less likely to internally mirror a speaker's mental state to recognize or understand others, which likely contributes to a lack of resonant experience sharing and a lack of affective empathy.

In regard to psychopathy, mPFC dysfunction is associated with behavioral attributes such as dishonesty, lack of empathy and remorse, poor planning and decision-making skills (Sonne & Gash, 2018). vmPFC dysfunction is considered to be involved in the pathogenesis of psychopathic behavioral and affective traits (Del Casale et al., 2015) as it is critically involved in prosocial behavior with dysfunction leading to antisocial behavior (Sonne & Gash, 2018). Together with the amygdala, the vmPFC is involved in emotion-related processing (Johanson et al., 2020). Moreover, the vmPFC is involved in the modulation of impulsivity (Del Casale et al., 2015) and is also important for evaluation of moral stimuli (Seara-Cardoso & Viding, 2015). In the context of listening to voices, vmPFC hypoactivity in relation to psychopathic traits may correspond to an automatic tendency of processing simple social signals in a more unemotional and antisocial manner. The vmPFC is also involved in self-mentalizing and in mentalizing of others with closer attachments such as friends or family (Denny et al., 2012). It is known that individuals with psychopathic traits struggle with self-mentalizing (Cairncross et al., 2013) and lack emotional attachment to others. The insula is necessary for emotional awareness of others and also contributes to an understanding of one's own emotional experience (Gu et al., 2013; Lockwood, 2016; Terasawa et al., 2015). Thus, hypoactive vmPFC and insula activity relates to the Alexithymia commonly described with psychopathy, making it difficult for those with psychopathic traits to empathically understand or connect with even themselves.

The IPL, IFGoper, and fusiform gyrus are involved in an emotional face processing network and mirror neuron system for social cognition (Schmidt et al., 2021). In processing emotional faces, psychopathic traits relate to reduced activity in the fusiform gyrus, inferior occipital gyrus, amygdala, STS, OFC, IFG, and vmPFC. (Decety et al., 2014). In recognizing affective mental states, psychopathic traits relate to widespread hypoactivity in the mirror neuron system including STS, IFG, and the amygdala (Mier et al., 2014). Similar to these previous observations, the amygdala, right pSTS (TVAp), OFC, IFGoper, vmPFC, IPL, and fusiform gyrus hypoactivity were also related to overall psychopathic traits when passively listening to voice stimuli. Thus, areas related to voice processing, emotional voice processing, neural mirroring, and empathy were revealed as hypoactive. This likely means that those with overall psychopathic traits are less likely to process the emotional features of voices, or to recognize the affective mental states of others from the voice signal.

Probabilistic tractography has revealed that the fusiform face area (FFA) is structurally connected with the TVAs, with stronger connections to TVAm and TVAa (Blank et al., 2011). Person recognition is likely optimized by this structural connectivity pattern as it directly links face- and voice- recognition areas (Blank et al., 2011). The fusiform gyrus may also become active during visual imagery (Winlove et al., 2018), which may naturally occur as one listens to a voice as one begins to imagine what a person may look like. Perhaps the fusiform gyrus has some involvement in the social brain network when processing voices, possibly contributing to person identity that is deficit in psychopathy (Belin, 2018). The specialization of the fusiform face area relates to categorization and experiential factors (Gauthier et al., 2000; Philip et al., 2012). Individuals with high psychopathic traits may not recruit the fusiform gyrus as they may not categorize or recognize the voice sound as belonging to a person, which may indicate some level of dehumanization by instead perceiving others as sub-human (Methot-Jones et al., 2019).

4.1.1 Primary psychopathic traits

The F1 score did not relate to the language, age, gender, or affective state of the participants but did have significant negative associations with Agreeableness and Openness. The single-subject analysis revealed that the F1 score was negatively associated with activity in other regions than the TVA, which was largely reflected in the multiple regression analysis. The F1 score related to hypoactivity in many regions across the brain during processing of voice in contrast to non-voice. Primary psychopathy is associated with decreased efficacy in neural communication between local and distal brain regions (Tillem et al., 2018), including between STS and amygdala (Mier et al., 2014), which may have been reflected in the results of the current study. Such decreased communication between STS and amygdala may present as a failure to integrate social information as emotionally relevant, leading to a lack of personal attachment and care to others.

Primary psychopathic traits are known to be associated with characteristically shallow affect and blunted emotional reactivity. This is consistent with numerous observations of dysfunctional limbic (amygdala, hippocampus, olfactory cortex, thalamus, hypothalamus, cingulate gyrus, dorsal striatum), paralimbic (OFC, temporal pole, insula, basal forebrain, ventral striatum, parts of thalamus), and mesolimbic-dopaminergic systems (ventral tegmental area, insula, OFC, striatum, thalamus; Johanson et al., 2020). Primary psychopathy is further associated with an underactive limbic-prefrontal circuit (Veit et al., 2002), which may reflect reduced integration of somatosensory stimuli in the PFC (Del Casale et al., 2015) and lack of top-down executive function (Sonne & Gash, 2018), which are essential for meaningful communication. Primary psychopathy also relates to reduced connectivity on the cingulo-opercular network (ACC-AIC), which may reflect lessened salience detection and less sustained attention (Coste & Kleinschmidt, 2016).

The hypoactive limbic, paralimbic, and mesolimbic systems in response to passively listening to the voice stimuli indicate blunted emotional response toward the voice stimuli, a lack of motivation to listen to voices (Alcaro et al., 2007), and a lack of association between the voice stimuli with social memories which may mean that the voice is not automatically recognized as a social signal. It is very unlikely they experience the voice stimuli as something pleasant. Primary psychopathic traits include affective-interpersonal features and are therefore negatively associated with activity in emotion processing areas (amygdala, hippocampus and insula) in reaction to perceptual information, leading to a lack of emotional awareness of others (Seara-Cardoso & Viding, 2015), which may explain way primary psychopaths are unattached and insensitive to people. Hypoactive limbic and prefrontal regions along with a hypoactive cingulo-opercular network also indicate that those with primary psychopathic traits are less likely to automatically detect the voice as salient, to focus on the voice stimuli, or to use self-control in managing focus towards the speaker.

Areas involved in the vocal affective information pathway (bilateral insula, bilateral amygdala, right IFGorb, right IFGtri), mirror neuron system (PreC, IFG, aSTS, IPL), mentalization of others (dmPFC), empathy (OFC, MCC, AIC, IFG, amygdala), and fronto-parietal network (dlPFC), were also hypoactive in response to listening to voices (Belin, 2018; Belyk et al., 2017; Denny et al., 2012; Rajmohan & Mohandas, 2007). These responses are expected, as primary psychopathy has previously been associated with a hypoactive mirror neuron system and a lack of affective empathy (Mier et al., 2014). Further, dmPFC, OFC, AIC, cingulate cortex, and cerebellum are structures related to emotion recognition and perspective-taking in psychopathy (Bzdok et al., 2013; Del Casale et al., 2015; Pera-Guardiola et al., 2016). Hypoactivity of these regions reconfirm that cognitive empathy processes may not be automatically engaged in those with primary psychopathic traits. The limbic system is also known to recruit the insula in response to socially relevant and emotional stimuli that reflects an internal feeling of emotional significance to the stimuli (Philip et al., 2012). Taken together, not only is there further evidence for lack of automatic affective and empathic processing in response to social stimuli, but also a lack of experiencing the voice as a socially relevant stimulus and a lack of feeling emotional significance towards the speaker, leading to inappropriate behavior towards others and possible dehumanization of others.

The midcingulate cortex (MCC; commonly misnamed as dACC) is involved in reward processing by monitoring and predicting outcomes of decisions in social interactions to track how these decisions lead to meeting goals (Apps et al., 2013; Vogt, 2016). Abnormal activity of this region is also associated with primary psychopathy (Johanson et al., 2020). Primary psychopaths also show functional connectivity abnormalities in the neighboring ACC and posterior cingulate cortex (PCC), which may relate to deficits in internal monitoring of cognitive and attentional processes (Del Casale et al., 2015; Juárez et al., 2013). A hypoactive MCC indicates that those with affective-interpersonal traits may not detect or process the voice as a socially relevant signal, value vocal sounds as rewarding, or evaluate the voice stimuli as something that serves a purpose for meeting goals (Apps et al., 2013; Vogt, 2016). Perhaps in the case of a true social interaction, the MCC may become active in those with primary psychopathic traits once the individual realizes that the other person can serve a purpose towards meeting a goal and can be manipulated to achieve this goal.

Hypoactivity in the left TVAa likely reflects lack of voice acoustic representation which would inhibit processing of speech information in a social setting (Belin, 2018). Decreased superior parietal lobule and angular gyrus activity may indicate a lack of paying attention to the stimuli (Johns, 2014; Seghier, 2013), leading to a lack of manipulating the information in working memory (Koenigs et al., 2009). Reduced hypothalamic activity in response to the voice stimuli may further reflect a lack of motivation to engage with the voices (Petrovich, 2018). A hypoactive OFC also reflects a lack of maintained motivational value in response to hearing the voice (Sadeh et al., 2013), while OFC lesions are known to associated with lack of self-insight leading to socially inappropriate behavior (Beer et al., 2006). Hypoactivity of the right dlPFC also indicates a lack of attention and alertness, and that the participants experienced lack of arousal (low-anxiety levels) in response to the stimuli (Balderston et al., 2020; Mannarelli et al., 2015). Further, hypoactivity of the inferior temporal gyrus may reflect that those with primary psychopathic traits did not perceive the stimuli as unpredictable as other participants may have (Kumar et al., 2017). Hypoactivity in the left inferior colliculus may indicate that those with primary psychopathic traits may not actually be hearing the voice stimuli. Top-down processes related to lack of attention and lack of motivation to engage may impact bottom-up sensory processes in the inferior colliculus. Such an impact on the inferior colliculus is unlikely to be conscious, but automatically inhibited by primary psychopathic personality.

The cerebellum processes information from PFC (Balsters et al., 2013) and is known to be involved in a variety of cognitive functions, including language, executive functions and working memory processes (Stoodley, 2012). The cerebellum is also involved in emotional processing and regulation (Johanson et al., 2020) which underlies morality, and further automatically modulates behavior without conscious awareness (Demirtas-Tatlidede & Schmahmann, 2013). The cerebellum is yet another region involved in empathy, while the parahippocampal gyrus is implicated in morality, where both areas consistently show abnormal activity in relation to psychopathic traits (Johanson et al., 2020). The affective feature of primary psychopathy likely relates to the hypoactive cerebellum and parahippocampal gyrus of the current study (Schutter & van Honk, 2009), and may underlie the immorally deceptive and manipulative characteristics associated with primary psychopathy (Demirtas-Tatlidede & Schmahmann, 2013).

Taken together, these hypoactive regions represent a lack of motivation, emotional investment, and empathy when listening to voices. The hypoactivity may reflect that those with higher primary psychopathy traits are less likely to pay attention to voices, that they may simply not care to hear these voices, and that they do not value them as relevant to their goals. These results may reflect that individuals with higher affective-interpersonal facets are neurally “wired” to react to voice signals in a dulled manner, possibly shedding light onto why these individuals may view others with contempt. Further, a hypoactive cerebellum and parahippocampal gyrus may reflect the primary psychopath’s propensity to behave immorally towards others in social interactions.

4.1.2 Secondary psychopathic traits

The F2 score did not relate to the language, age or gender of the participants but did have significant negative associations with Extraversion, Agreeableness, Conscientiousness, Emotional Stability and Affect Balance. Because positive emotions are the strongest predictors of Extraversion (Verduyn & Brans, 2012), it makes sense that secondary psychopathic traits would negatively correlate with Extraversion due to the fact that F2 was also associated with high Neuroticism and low Affect Balance. The single-subject analysis revealed that the F2 score was associated with less varied activation patterns. The multiple regression analysis further revealed hyperactivity in the substantia nigra and bilateral calcarine sulci, with hypoactivity in the left middle temporal sulcus (sMTG) and the cluster extending into the left anterior middle temporal gyrus (aMTG). Areas involved in neural mirroring, mentalizing, affective and cognitive empathic processes did not appear as hypoactive and thus may have been functioning as “normal”.

The impulsive-antisocial features are related with exaggerated reward activity (Geurts et al., 2016; Seara-Cardoso & Viding, 2015) and are positively associated with ventral striatum activity in anticipation to receiving monetary and positive feedback rewards (Buckholtz et al., 2010; Carré et al., 2013; Geurts et al., 2016). The substantia nigra pars compacta projects to the ventral striatum, supplying it with dopamine (Bolam et al., 2009) as dopaminergic activity increases with new stimuli and unexpected rewards (Ljungberg et al., 1992). In regard to secondary psychopathy, the ventral striatum is related to positive reinforcement from the reward system, reward-dominant learning and decision making, which may explain their risky and impulsive behavior (Reidy et al., 2017; Sonne & Gash, 2018). Considering this, it is possible that those with secondary psychopathic traits are more motivated, aroused, or prepared for reinforcement and reward when hearing human voices (Seara-Cardoso & Viding, 2015). Unlike primary psychopaths, secondary psychopaths may associate voices with the possibility of reward, and may be more likely to enjoy social interaction, despite being related with low Extraversion. This would make sense as those with secondary psychopathic traits are likely to experience empathy and concern towards others (Seara-Cardoso et al., 2015; Seara-Cardoso & Viding, 2015).

However, increased striatal functioning may not necessarily relate to receipt of reward in those with impulsive-antisocial traits, but may instead be inappropriately processing the lack of reward (Glenn & Yang, 2012). In so doing, secondary psychopaths may continue to respond to a stimulus that is no longer rewarding, which may impair their ability to respond flexibly to the environment, thus contributing to impulsive-antisocial behavior (Glenn & Yang, 2012). For individuals with impulsive-antisocial tendencies, the degree to which reward-related striatal regions communicate with frontal brain regions that control behavior distinguishes overt criminals from non-criminals (Geurts et al., 2016). Enhanced communication between striatal and frontal regions enables people to behave according to their impulsive-antisocial traits, leading to overt criminality, while others are better able to deny their reward-related urges and behave adaptively instead (Geurts et al., 2016). Because hyperactivity of the substantia nigra was not related to hyperactive prefrontal activity, it seems likely the participants of the current study with some of these traits are better able to behave adaptively and not impulsively. If so, this could also indicate some level of consideration towards others.

While the calcarine sulcus is typically known for its involvement with processing faces, it is also a plastic and cross-modal area that integrates face with voice information (Joassin et al., 2011), and is functionally connected to areas of the temporal cortex that are sensitive to auditory information (Van Ackeren et al., 2018). A study using depth electrodes in humans found that auditory stimuli evoke spatially specific activity in the calcarine sulcus in the absence of concurrent visual stimulation that follows retinotopic mapping of the visual cortex (Brang et al., 2015). The authors of the study suspect that this transfer of peripheral sound information to the visual cortex may be involved in initiating an attentional shift towards the stimuli (Brang et al., 2015). The calcarine sulcus also plays a role in processing the semantics from intelligible speech in blind individuals who have been deprived from visual signal from birth and functionally reorganizes to support this process (Van Ackeren et al., 2018). Deaf participants using sign language also have a larger calcarine volume than those with hearing, which may be related to enhanced reaction and attention to visual stimuli and changes in multisensory integration networks (Allen et al., 2013). Considering this, the results of the current study may indicate that those with secondary psychopathic traits may be more likely to pay attention to voices, may be sensitive to the voice location, and may be more inclined to direct their attention towards the speaker.

The F2 score also correlated with hypoactivity in the left middle temporal sulcus (sMTG) and anterior middle temporal gyrus (aMTG). Secondary psychopathy has previously been related to decreases in gray matter volume (GMV) in MTG (Johanson et al., 2020). In the context of voice processing, aMTG is related to sound recognition and semantic retrieval, while the sMTG is associated with decoding intelligible speech (Xu et al., 2016). Perhaps the hypoactivity of this region in the current study could be related to less GMV. It is also likely that it could relate to lack of sound recognition or lack of attempt in decoding the vocal stimuli as something meaningful. Lack of sound recognition may also link with the hyperactive substantia nigra, which could have been in reaction to new stimuli.

Finally, the partial correlation analysis using ROIs revealed that the F2 score related to bilateral IFGoper hypoactivation. The cluster sizes may have been smaller than would have been considered significant for the multiple regression, though hypoactivation of this region was seen in relation to the LSRP total score.

4.2 Autistic traits

The AQ score was not related to the language, age, or affective state of the participants but was more related to males than females, as is typically seen with autism (Loomes et al., 2017). A previous meta-analysis found that ASD is positively associated with Neuroticism and negatively associated with the remaining Big Five traits (Lodi-Smith et al., 2019). The current study found that AQ scores were significantly negatively associated with Emotional Stability, Extraversion, Agreeableness, Openness. The AQ score also negatively correlated with Conscientiousness, though insignificantly. The reason for this might be that the participants were largely students at the University of Zürich, and students tend to be higher in Conscientiousness. AQ scores were positively related with LSRP Total, F1 and F2 scores, but the highest association was with F2. ASD severity does not seem to relate to psychopathic tendencies, though autistic and psychopathic traits can co-occur (Rogers et al., 2006). In such cases of cooccurrence, these individuals tend to exhibit behavioral and cognitive traits that are more similar to psychopathy than autism (Rogers et al., 2006).

In line with previous findings, the single-subject analysis revealed a tendency for AQ scores to be more related to lateralized right temporal activations (Bigler et al., 2007; Eyler et al., 2012). However, the multiple regression analysis did not reveal hyperactivity in any regions but did reveal hypoactivity in the left inferior temporal sulcus (ITS) with the cluster extending to the left posterior middle temporal gyrus (pMTG), and in a cluster extending to the left pars triangularis inferior frontal gyrus (IFGtri / BA 45). This suggests that the bilateral TVA and voice processing in the core network function as normal while hypoactivity of the left IFGtri may reflect some dysfunction in the speech information pathway.

The left pMTG and IFGtri are connected and are both related to sensory language and semantic processing (Xu et al., 2016). The pMTG and IFG are also both regions of the mirror neuron system that are involved in representing human action or behavior and in processing the overt mental states when observing an action currently taking place (Schurz et al., 2014). Hypoactivity of IFGtri may reflect repetition priming or some unattendance to the stimuli (Demb et al., 1995), while hypoactivity of the ITS may reflect that the voice stimuli was likened to being repetitive or predictable (Kumar et al., 2017). However, hypoactivity in both the left pMTG and IFGtri regions may reflect some lack in deciphering the meaning of the vocal information. This further inhibits the translation of vocal content into a vivid sensory experience, leaving an inability to imagine or personally relate to what the speaker might be saying through experiencing it oneself. Given that some with autistic traits struggle with visual imagination while others excel, such a conclusion makes sense (Grandin, 2009). Interpersonally, hypoactivity of the pMTG and IFG may also relate to less understanding of the overt mental state of the speaker, or how the speaker's actions may relate to particular goals that the speaker may have (Schurz et al., 2014). Those with autistic traits are known to struggle with attributing intentional causality.

The AQ scores were also related to hypoactivity across areas of white matter including the bilateral cingulum bundle and left anterior cingulum bundle. White matter (WM) near the left IFGtri and right MTG also were hypoactive. While most studies ignore WM responses, they should instead at least be considered as WM is critical in neural networks and is an important component of functional neural tissue (Grajauskas et al., 2019). BOLD response may detect WM activity from action potentials because oxygen is required by the axon in producing ATP for cellular processes (Grajauskas et al., 2019). Further, neural activity encoded in WM BOLD signals show similarities with gray matter activations and the structures correspond with tracts from diffusion MRI (Ding et al., 2018; Huang et al., 2020; Peer et al., 2017). WM fMRI activation may expand brain research by aiding the investigation in how WM contributes to cognition and how WM disturbances relate to neuropsychiatric disorders such as ASD (Gawryluk et al., 2014; Peer et al., 2017). However, standard methods need modification to accurately characterized HRFs in WM (Li et al., 2019).

Numerous neuroimaging, electrophysiological and postmortem studies provide evidence for widespread disruption of functional and structural neural connectivity in individuals with ASD (Philip et al., 2012). Such abnormal functional and structural brain connectivity disruptions in those with autism are considered to underlie the deficits and behavioral manifestations associated with ASD (Chan & Han, 2020; Philip et al., 2012). Insufficient cortical connections and WM abnormalities lead to decreased synchronized activation, primarily in cortico-cortical networks, that are not task specific (Philip et al., 2012). Siblings of those with ASD who are personally unaffected also exhibit reduced fractional anisotropy of WM tracts, although less severe, reflecting less WM fiber density as well (Jou et al., 2016). The WM hypoactivity observed in the current study may be a symptom of underconnectivity, though it is not direct evidence of underconnectivity.

The cingulum bundle is important for social and emotional processes and is largely driven by the cingulate gyrus, where the ACC and MCC are both involved in affective and cognitive empathy processes (Bubb et al., 2018; Seara-Cardoso & Viding, 2015; Smith et al., 2015). The ACC is involved in avoiding social conflict (Braem et al., 2017) and the MCC is involved in monitoring decision outcomes to reach goals in social interactions (Apps et al., 2013). The cingulum bundle is related to reduced fractional anisotropy, increased diffusivity and altered development in ASD (Bubb et al., 2018). Greater disturbances of the cingulum relate to executive dysfunctions in ASD that result in worse behavioral regulation, leading to social impairments that are characteristic of ASD (Ikuta et al., 2014), such as incorrect attribution of behavioral outcomes to oneself or others (Chiu et al., 2008). Generally, higher fractional anisotropy of the cingulum bundle is correlated with cognitive performance while lower fractional anisotropy is correlated with reduced functional activation of the default mode network (Bathelt et al., 2019). Default mode network dysfunction is also a prominent feature of autism, which reflects as problems with attending to socially relevant stimuli and integrating information about the self in relation to another (Padmanabhan et al., 2017).

A decrease in temporal cortex WM among adults with autism has also been indicated using fractional anisotropy (Lee et al., 2007), which may be reflected in the results of the current study. The right MTG is involved in processing metaphorical aspects of language and with integrating information from an ongoing context to make inferences about the overall meaning (Bottini et al., 1994; Diaz et al., 2011). Decreased WM connectivity near the right MTG may lead to difficulty in deduction of metaphors, idioms, and indirect requests. Such a lack of communication with the right MTG would likely make it more difficult to extract meaning from such statements that would instead be taken literally (Banich & Compton, 2018). Although the current study did not involve metaphors, the results may reflect a change in WM near the right MTG, which may provide some indication as to why those with autistic traits tend to understand things in a more literal sense.

4.3 Limitations

The participants were reflective of an academic community and may not accurately reflect psychopathic traits within the general population. It might be expected that those with "successful" primary psychopathic traits could be overrepresented while those with "unsuccessful" secondary psychopathic traits could be underrepresented in such a sample from an academic community. Instead, individuals with secondary psychopathic traits might be more easily found in other settings.

Regarding autistic traits, 14 of the participants who met the screening cut-off can only at best be described as meeting the potential criteria for diagnostic screening. The AQ items that were previously mentioned as being unrepresentative of autistic traits were not updated in the current study. AQ scores were significantly correlated with LSRP Total, F1 and F2 scores, which could indicate co-occurring autistic and psychopathic traits in certain individuals. These individuals were not separated from the autistic traits analysis in the current study, which may have been more appropriate as such individuals tend to exhibit more psychopathic than autistic traits (Rogers et al., 2006).

4.4 Future Research

The multiple regression results reflected the single-subject Pearson correlations results. For example, AQ was associated with right temporal activity at the individual level while the multiple regression revealed hypoactivity in left temporal regions. Also, LSRP Total and F1 were negatively associated with activity outside the TVA while the multiple regression revealed widespread hypoactivity. Therefore, it is likely that different activation patterns would also be seen when analyzing voice localization with the Big Five alone. Extraversion and Conscientiousness may be correlated with activity predominantly in the left hemisphere. Also, Agreeableness may be correlated with strong activations of higher significance and with more activity outside of TVA. Because psychopathy is inversely related to Agreeableness and because Agreeableness seems to relate to voice processing in distal regions, it would be interesting to see which areas may be hyperactive in relation to Agreeableness that were hypoactive in relation to primary psychopathic traits.

In regard to psychopathic traits, brain modulation techniques such as transcranial direct current stimulation (tDCS) along the hypoactive networks may prove useful in treating and reducing cognition and behavior that may lead to social problems such as manipulation or aggression (van Dongen, 2020). In regard to autistic traits, cognitive enhancement therapy may prove useful in improving social cognition (Velikonja et al., 2019). When testing for autistic traits, it may be smart to also test for psychopathic traits and to separate individuals with cooccurrence into the category representing psychopathy. In studying subclinical autistic traits, research should focus on analyzing results based on reported symptomatology and specific trait domains (Baron-Cohen et al., 2001; van Laarhoven et al., 2019). WM fMRI activation should be further studied as this can potentially expose how WM relates to cognition and neuropsychiatric disorders, potentially improving diagnostic standards (Gawryluk et al., 2014; Peer et al., 2017).

5. Conclusion

Voice processing is influenced by individual difference factors. Those with overall psychopathic traits may not automatically perceive a voice sound as salient or socially relevant, and therefore may not pay attention to it. It is likely that individuals with such traits have some problems with processing vocal affective information in regular social interactions. Results reconfirm a lack of automatic neural mirroring, leading to problems with recognizing and understanding the mental state of others. Further, results also confirm that these individuals not only seem to lack the capacity to empathically connect others but also with themselves. Finally, results may suggest that such traits are related to an unconscious dehumanization of others with hypoactivity in the fusiform gyrus, which is involved in person perception, categorization, and recognition.

Those with primary psychopathic traits do not seem likely to detect a voice as a salient, socially relevant, or meaningful signal. They are not likely to stay alert and pay attention to vocal sounds and therefore do not focus on voice stimuli. Further, they may not be motivated to listen to or engage with vocal sounds, value them as rewarding, or evaluate them as relevant in pursuing their goals. They likely do not care to hear vocal stimuli. Such top-down influences may inhibit these individuals from hearing vocal sounds, as evidenced by a hypoactive inferior colliculus. Such widespread hypoactivity leads to a lack of awareness of others and a lack of automatic empathic processes. These results may indicate why such individuals are unattached, insensitive, and contemptuous to people and why they may have a propensity to often engage in immoral behavior towards others.

Secondary psychopathic traits are related to exaggerated reward activity in response to voice stimuli. Those with secondary psychopathic traits may associate voices with the possibility of reward and be motivated to pay attention to voices. They may also be more sensitive to the location of voice stimuli and may be more inclined to direct their attention towards the speaker. Regions involved in empathic processing did not appear as significantly hypoactive in the multiple regression analysis. Taken together, these results potentially mean that those with secondary psychopathic traits may be more likely to enjoy social interaction, especially in a new context, or to show more consideration towards others than those with primary psychopathic traits.

Hypoactivity of the left IFG may reflect some dysfunction in the speech information pathway, neural mirroring, and empathic processes. This means that these individuals may struggle with understanding the overt mental states of others from vocal information and with attributing intentional causality to others. White matter areas also showed as hypoactive, which may reflect connectivity disruptions that potentially underlie autistic traits leading to social impairment. Hypoactive communication with the right middle temporal gyrus (MTG) may explain why it is common for individuals with autism to interpret language literally when it is instead intended to be taken otherwise.

6. References

Abrams, D. A., Lynch, C. J., Cheng, K. M., Phillips, J., Supekar, K., Ryali, S., Uddin, L. Q., & Menon, V. (2013). Underconnectivity between voice-selective cortex and reward circuitry in children with autism. *Proceedings of the National Academy of Sciences*, *110*(29), 12060–12065. https://doi.org/10.1073/pnas.1302982110

Abrams, D. A., Padmanabhan, A., Chen, T., Odriozola, P., Baker, A. E., Kochalka, J., Phillips, J. M., & Menon, V. (2019). Impaired voice processing in reward and salience circuits predicts social communication in children with autism. *ELife*, *8*, e39906. https://doi.org/10.7554/eLife.39906

Acharya, S., & Shukla, S. (2012). Mirror neurons: Enigma of the metaphysical modular brain. *Journal of Natural Science, Biology and Medicine*, *3*(2), 118. https://doi.org/10.4103/0976-9668.101878

Adelstein, J. S., Shehzad, Z., Mennes, M., DeYoung, C. G., Zuo, X.-N., Kelly, C., Margulies, D. S., Bloomfield, A., Gray, J. R., Castellanos, F. X., & Milham, M. P. (2011). Personality Is Reflected in the Brain's Intrinsic Functional Architecture. *PLoS ONE*, *6*(11), e27633. https://doi.org/10.1371/journal.pone.0027633

Aglieri, V., Chaminade, T., Takerkart, S., & Belin, P. (2018). Functional connectivity within the voice perception network and its behavioural relevance. *NeuroImage*, *183*, 356–365. https://doi.org/10.1016/j.neuroimage.2018.08.011

Ahrens, M.-M., Awwad Shiekh Hasan, B., Giordano, B. L., & Belin, P. (2014). Gender differences in the temporal voice areas. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00228

Alcaro, A., Huber, R., & Panksepp, J. (2007). Behavioral functions of the mesolimbic dopaminergic system: An affective neuroethological perspective. *Brain Research Reviews*, *56*(2), 283–321. https://doi.org/10.1016/j.brainresrev.2007.07.014

Alho, J., Bharadwaj, H., Khan, S., Mamashli, F., Perrachione, T. K., Losh, A., McGuiggan, N. M., Joseph, R. M., Hämäläinen, M. S., & Kenet, T. (2021). Altered maturation and atypical cortical processing of spoken sentences in autism spectrum disorder. *Progress in Neurobiology*, *203*, 102077. https://doi.org/10.1016/j.pneurobio.2021.102077

Allen, J. S., Emmorey, K., Bruss, J., & Damasio, H. (2013). Neuroanatomical differences in visual, motor, and language cortices between congenitally deaf signers, hearing signers, and hearing non-signers. *Frontiers in Neuroanatomy*, *7*. https://doi.org/10.3389/fnana.2013.00026

Allik, J., & Realo, A. (2015). *Universal and Specific in the Five Factor Model of Personality* (T. A. Widiger, Ed.; Vol. 1). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199352487.013.23

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Antezana, L., Factor, R. S., Condy, E. E., Strege, M. V., Scarpa, A., & Richey, J. A. (2019). Gender differences in restricted and repetitive behaviors and interests in youth with autism: Antezana et al./Gender differences in RRBI. *Autism Research*, *12*(2), 274–283. https://doi.org/10.1002/aur.2049

Apps, M. A. J., Lockwood, P. L., & Balsters, J. H. (2013). The role of the midcingulate cortex in monitoring others' decisions. *Frontiers in Neuroscience*, *7*. https://doi.org/10.3389/fnins.2013.00251

Armstrong, K., & Iarocci, G. (2013). Brief Report: The Autism Spectrum Quotient has Convergent Validity with the Social Responsiveness Scale in a High-Functioning Sample. *Journal of Autism and Developmental Disorders*, *43*(9), 2228–2232. https://doi.org/10.1007/s10803-013-1769-z

Ashwood, K. L., Gillan, N., Horder, J., Hayward, H., Woodhouse, E., McEwen, F. S., Findon, J., Eklund, H., Spain, D., Wilson, C. E., Cadman, T., Young, S., Stoencheva, V., Murphy, C. M., Robertson, D., Charman, T., Bolton, P., Glaser, K., Asherson, P., … Murphy, D. G. (2016). Predicting the diagnosis of autism in adults using the Autism-Spectrum Quotient (AQ) questionnaire. *Psychological Medicine*, *46*(12), 2595–2604. https://doi.org/10.1017/S0033291716001082

Bagley, A. D., Abramowitz, C. S., & Kosson, D. S. (2009). Vocal affect recognition and psychopathy: Converging findings across traditional and cluster analytic approaches to assessing the construct. *Journal of Abnormal Psychology*, *118*(2), 388–398. https://doi.org/10.1037/a0015372

Baird, A. D., Scheffer, I. E., & Wilson, S. J. (2011). Mirror neuron system involvement in empathy: A critical look at the evidence. *Social Neuroscience*, *6*(4), 327–335. https://doi.org/10.1080/17470919.2010.547085

Balderston, N. L., Beydler, E. M., Roberts, C., Deng, Z.-D., Radman, T., Lago, T., Luber, B., Lisanby, S. H., Ernst, M., & Grillon, C. (2020). Mechanistic link between right prefrontal cortical activity and anxious arousal revealed using transcranial magnetic stimulation in healthy subjects. *Neuropsychopharmacology*, *45*(4), 694–702. https://doi.org/10.1038/s41386-019-0583-5

Balsters, J. H., Whelan, C. D., Robertson, I. H., & Ramnani, N. (2013). Cerebellum and Cognition: Evidence for the Encoding of Higher Order Rules. *Cerebral Cortex*, *23*(6), 1433–1443. https://doi.org/10.1093/cercor/bhs127

Banich, M. T., & Compton, R. J. (2018). *Cognitive neuroscience* (Fourth edition). Cambridge University Press.

Baron-Cohen, S., Ring, H. A., Wheelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., & Williams, S. C. R. (1999). Social intelligence in the normal and autistic brain: An fMRI study: *Social intelligence in the normal and autistic brain*. *European Journal of Neuroscience*, *11*(6), 1891–1898. https://doi.org/10.1046/j.1460-9568.1999.00621.x

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-Spectrum Quotient (AQ): Evidence from Asperger Syndrome/High-Functioning Autism, Males and Females, Scientists and Mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. https://doi.org/10.1023/A:1005653411471

Bathelt, J., Johnson, A., Zhang, M., & Astle, D. E. (2019). The cingulum as a marker of individual differences in neurocognitive development. *Scientific Reports*, *9*(1), 2281. https://doi.org/10.1038/s41598-019-38894-z

Beaudoin, C., Leblanc, É., Gagner, C., & Beauchamp, M. H. (2020). Systematic Review and Inventory of Theory of Mind Measures for Young Children. *Frontiers in Psychology*, *10*, 2905. https://doi.org/10.3389/fpsyg.2019.02905

Beer, J. S., John, O. P., Scabini, D., & Knight, R. T. (2006). Orbitofrontal Cortex and Social Behavior: Integrating Self-monitoring and Emotion-Cognition Interactions. *Journal of Cognitive Neuroscience*, *18*(6), 871–879. https://doi.org/10.1162/jocn.2006.18.6.871

Belin, P. (2018). The 'Vocal Brain': Core and Extended Cerebral Networks for Voice Processing. In S. Frühholz & P. Belin (Eds.), *The Oxford Handbook of Voice Perception* (pp. 36–60). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198743187.013.3

Belin, P., & Zatorre, R. J. (2003). Adaptation to speaker's voice in right anterior temporal lobe: *NeuroReport*, *14*(16), 2105–2109. https://doi.org/10.1097/00001756-200311140-00019

Belin, P., Zatorre, R. J., Lafaille, P., Ahad, P., & Pike, B. (2000). Voice-selective areas in human auditory cortex. *Nature*, *403*(6767), 309–312. https://doi.org/10.1038/35002078

Belyk, M., Brown, S., Lim, J., & Kotz, S. A. (2017). Convergence of semantics and emotional expression within the IFG pars orbitalis. *NeuroImage*, *156*, 240–248. https://doi.org/10.1016/j.neuroimage.2017.04.020

Bestelmeyer, P. E. G., Belin, P., & Grosbras, M.-H. (2011). Right temporal TMS impairs voice detection. *Current Biology*, *21*(20), R838–R839. https://doi.org/10.1016/j.cub.2011.08.046

Bigler, E. D., Mortensen, S., Neeley, E. S., Ozonoff, S., Krasny, L., Johnson, M., Lu, J., Provencal, S. L., McMahon, W., & Lainhart, J. E. (2007). Superior Temporal Gyrus, Language Function, and Autism. *Developmental Neuropsychology*, *31*(2), 217–238. https://doi.org/10.1080/87565640701190841

Bishop, S. L., & Seltzer, M. M. (2012). Self-Reported Autism Symptoms in Adults with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *42*(11), 2354–2363. https://doi.org/10.1007/s10803-012-1483-2

Blair, R. J. R. (2005). Responding to the emotions of others: Dissociating forms of empathy through the study of typical and psychiatric populations. *Consciousness and Cognition*, *14*(4), 698–718. https://doi.org/10.1016/j.concog.2005.06.004

Blair, R. J. R. (2013). The neurobiology of psychopathic traits in youths. *Nature Reviews Neuroscience*, *14*(11), 786–799. https://doi.org/10.1038/nrn3577

Blank, H., Anwander, A., & von Kriegstein, K. (2011). Direct Structural Connections between Voice- and Face-Recognition Areas. *Journal of Neuroscience*, *31*(36), 12906–12915. https://doi.org/10.1523/JNEUROSCI.2091-11.2011

Bolam, J. P., Brown, M. T. C., Moss, J., & Magill, P. J. (2009). Basal Ganglia: Internal Organization. In *Encyclopedia of Neuroscience* (pp. 97–104). Elsevier. https://doi.org/10.1016/B978-008045046-9.01294-8

Bottini, G., Corcoran, R., Sterzi, R., Paulesu, E., Schenone, P., Scarpa, P., Frackowiak, R. S., & Frith, D. (1994). The role of the right hemisphere in the interpretation of figurative aspects of language A positron emission tomography activation study. *Brain*, *117*(6), 1241–1253.

Braem, S., King, J. A., Korb, F. M., Krebs, R. M., Notebaert, W., & Egner, T. (2017). The Role of Anterior Cingulate Cortex in the Affective Evaluation of Conflict. *Journal of Cognitive Neuroscience*, *29*(1), 137–149. https://doi.org/10.1162/jocn_a_01023

Brang, D., Towle, V. L., Suzuki, S., Hillyard, S. A., Di Tusa, S., Dai, Z., Tao, J., Wu, S., & Grabowecky, M. (2015). Peripheral sounds rapidly activate visual cortex: Evidence from electrocorticography. *Journal of Neurophysiology*, *114*(5), 3023–3028. https://doi.org/10.1152/jn.00728.2015

Breyer, B., & Bluemke, M. (2016). Deutsche Version der Positive and Negative Affect Schedule PANAS (GESIS Panel). *Zusammenstellung sozialwissenschaftlicher Items und Skalen (ZIS)*. https://doi.org/10.6102/ZIS242

Brinkley, C. A., Diamond, P. M., Magaletta, P. R., & Heigel, C. P. (2008). Cross-validation of Levenson's Psychopathy Scale in a sample of federal female inmates. *Assessment*, *15*(4), 464–482.

Brinkley, C. A., Schmitt, W. A., Smith, S. S., & Newman, J. P. (2001). Construct validation of a self-report psychopathy scale: Does Levenson's self-report psychopathy scale measure the same constructs as Hare's psychopathy checklist-revised? *Personality and Individual Differences*, *31*(7), 1021–1038. https://doi.org/10.1016/S0191-8869(00)00178-1

Broadbent, J., Galic, I., & Stokes, M. A. (2013). Validation of Autism Spectrum Quotient Adult Version in an Australian Sample. *Autism Research and Treatment*, *2013*, 1–7. https://doi.org/10.1155/2013/984205

Brück, C., Kreifelts, B., Kaza, E., Lotze, M., & Wildgruber, D. (2011). Impact of personality on the cerebral processing of emotional prosody. *NeuroImage*, *58*(1), 259–268. https://doi.org/10.1016/j.neuroimage.2011.06.005

Bubb, E. J., Metzler-Baddeley, C., & Aggleton, J. P. (2018). The cingulum bundle: Anatomy, function, and dysfunction. *Neuroscience & Biobehavioral Reviews*, *92*, 104–127. https://doi.org/10.1016/j.neubiorev.2018.05.008

Buccino, G., Binkofski, F., & Riggio, L. (2004). The mirror neuron system and action recognition. *Brain and Language*, *89*(2), 370–376. https://doi.org/10.1016/S0093-934X(03)00356-0

Buckholtz, J. W., Treadway, M. T., Cowan, R. L., Woodward, N. D., Li, R., Ansari, M. S., Baldwin, R. M., Schwartzman, A. N., Shelby, E. S., Smith, C. E., Kessler, R. M., & Zald, D. H. (2010). Dopaminergic Network Differences in Human Impulsivity. *Science*, *329*(5991), 532–532. https://doi.org/10.1126/science.1185778

Bzdok, D., Langner, R., Schilbach, L., Engemann, D. A., Laird, A. R., Fox, P. T., & Eickhoff, S. B. (2013). Segregation of the human medial prefrontal cortex in social cognition. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00232

Cairncross, M., Veselka, L., Schermer, J. A., & Vernon, P. A. (2013). A behavioral genetic analysis of alexithymia and the Dark Triad traits of personality. *Twin Research and Human Genetics*, *16*(3), 690–697.

Carré, J. M., Hyde, L. W., Neumann, C. S., Viding, E., & Hariri, A. R. (2013). The neural signatures of distinct psychopathic traits. *Social Neuroscience*, *8*(2), 122–135. https://doi.org/10.1080/17470919.2012.703623

Ceravolo, L., Debracque, C., Gruber, T., & Grandjean, D. (2020). *Human temporal voice areas are sensitive to chimpanzee vocalizations* [Preprint]. Neuroscience. https://doi.org/10.1101/2020.10.29.360362

Cerniglia, L., Bartolomeo, L., Capobianco, M., Lo Russo, S. L. M., Festucci, F., Tambelli, R., Adriani, W., & Cimino, S. (2019). Intersections and Divergences Between Empathizing and Mentalizing: Development, Recent Advancements by Neuroimaging and the Future of Animal Modeling. *Frontiers in Behavioral Neuroscience*, *13*, 212. https://doi.org/10.3389/fnbeh.2019.00212

Chan, M. M. Y., & Han, Y. M. Y. (2020). Differential mirror neuron system (MNS) activation during action observation with and without social-emotional components in autism: A meta-analysis of neuroimaging studies. *Molecular Autism*, *11*(1), 72. https://doi.org/10.1186/s13229-020-00374-x

Cheung, F. M., Leung, K., Zhang, J.-X., Sun, H.-F., Gan, Y.-Q., Song, W.-Z., & Xie, D. (2001). Indigenous Chinese Personality Constructs: Is the Five-Factor Model Complete? *Journal of Cross-Cultural Psychology*, *32*(4), 407–433. https://doi.org/10.1177/0022022101032004003

Chiarotti, F., & Venerosi, A. (2020). Epidemiology of Autism Spectrum Disorders: A Review of Worldwide Prevalence Estimates Since 2014. *Brain Sciences*, *10*(5), 274. https://doi.org/10.3390/brainsci10050274

Chiu, P. H., Kayali, M. A., Kishida, K. T., Tomlin, D., Klinger, L. G., Klinger, M. R., & Montague, P. R. (2008). Self Responses along Cingulate Cortex Reveal Quantitative Neural Phenotype for High-Functioning Autism. *Neuron*, *57*(3), 463–473. https://doi.org/10.1016/j.neuron.2007.12.020

Chmielewski, M. S., & Morgan, T. A. (2013). Five-Factor Model of Personality. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 803–804). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_1226

Chong, T. T.-J., Cunnington, R., Williams, M. A., Kanwisher, N., & Mattingley, J. B. (2008). FMRI Adaptation Reveals Mirror Neurons in Human Inferior Parietal Cortex. *Current Biology*, *18*(20), 1576–1580. https://doi.org/10.1016/j.cub.2008.08.068

Cleckley, H. (1976). The mask of sanity 5th edn. *St. Louis, MO: Mosby*, 346.

Cohen, S., Doyle, W. J., Turner, R., Alper, C. M., & Skoner, D. P. (2003). Sociability and susceptibility to the common cold. *Psychological Science*, *14*(5), 389–395.

Costa, P. T., & McCrae, R. R. (1992). Four ways five factors are basic. *Personality and Individual Differences*, *13*(6), 653–665. https://doi.org/10.1016/0191-8869(92)90236-I

Coste, C. P., & Kleinschmidt, A. (2016). Cingulo-opercular network activity maintains alertness. *NeuroImage*, *128*, 264–272. https://doi.org/10.1016/j.neuroimage.2016.01.026

Cribbet, M., & Williams, P. (2013). Personality. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 1458–1463). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_975

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., & Iacoboni, M. (2006). Understanding emotions in others: Mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience*, *9*(1), 28–30. https://doi.org/10.1038/nn1611

D'Ausilio, A., Pulvermüller, F., Salmas, P., Bufalari, I., Begliomini, C., & Fadiga, L. (2009). The motor somatotopy of speech perception. *Current Biology*, *19*(5), 381–385.

Davidovic, M., Jönsson, E. H., Olausson, H., & Björnsdotter, M. (2016). Posterior Superior Temporal Sulcus Responses Predict Perceived Pleasantness of Skin Stroking. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00432

Decety, J., Chen, C., Harenski, C., & Kiehl, K. A. (2013). An fMRI study of affective perspective taking in individuals with psychopathy: Imagining another in pain does not evoke empathy. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00489

Decety, J., Skelly, L., Yoder, K. J., & Kiehl, K. A. (2014). Neural processing of dynamic emotional facial expressions in psychopaths. *Social Neuroscience*, *9*(1), 36–49.

Degenaar, J., & O'Regan, J. K. (2015). Sensorimotor theory of consciousness. *Scholarpedia*, *10*(5), 4952.

Del Casale, A., Kotzalidis, G. D., Rapinesi, C., Di Pietro, S., Alessi, M. C., Di Cesare, G., Criscuolo, S., De Rossi, P., Tatarelli, R., Girardi, P., & Ferracuti, S. (2015).

Functional Neuroimaging in Psychopathy. *Neuropsychobiology*, *72*(2), 97–117. https://doi.org/10.1159/000441189

Demb, J. B., Desmond, J. E., Wagner, A. D., Vaidya, C. J., Glover, G. H., & Gabrieli, J. D. (1995). Semantic encoding and retrieval in the left inferior prefrontal cortex: A functional MRI study of task difficulty and process specificity. *Journal of Neuroscience*, *15*(9), 5870–5878.

Demirtas-Tatlidede, A., & Schmahmann, J. D. (2013). Morality: Incomplete without the cerebellum? *Brain*, *136*(8), e244–e244. https://doi.org/10.1093/brain/awt070

Denny, B. T., Kober, H., Wager, T. D., & Ochsner, K. N. (2012). A Meta-analysis of Functional Neuroimaging Studies of Self- and Other Judgments Reveals a Spatial Gradient for Mentalizing in Medial Prefrontal Cortex. *Journal of Cognitive Neuroscience*, *24*(8), 1742–1752. https://doi.org/10.1162/jocn_a_00233

Denollet, J. (2013). Negative Affectivity. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 1304–1305). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_1588

Desikan, R. S., Ségonne, F., Fischl, B., Quinn, B. T., Dickerson, B. C., Blacker, D., Buckner, R. L., Dale, A. M., Maguire, R. P., Hyman, B. T., Albert, M. S., & Killiany, R. J. (2006). An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest. *NeuroImage*, *31*(3), 968–980. https://doi.org/10.1016/j.neuroimage.2006.01.021

Diaz, M. T., Barrett, K. T., & Hogstrom, L. J. (2011). The influence of sentence novelty and figurativeness on brain activity. *Neuropsychologia*, *49*(3), 320–330. https://doi.org/10.1016/j.neuropsychologia.2010.12.004

Digman, J. M. (1990). Personality Structure: Emergence of the Five-Factor Model. *Annual Review of Psychology*, *41*(1), 417–440. https://doi.org/10.1146/annurev.ps.41.020190.002221

Ding, Z., Huang, Y., Bailey, S. K., Gao, Y., Cutting, L. E., Rogers, B. P., Newton, A. T., & Gore, J. C. (2018). Detection of synchronous brain activity in white matter tracts at rest and under functional loading. *Proceedings of the National Academy of Sciences*, *115*(3), 595–600. https://doi.org/10.1073/pnas.1711567115

Doroszuk, M., Kupis, M., & Czarna, A. Z. (2020). Personality and Friendships. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (pp. 3628–3637). Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3_712

Drayton, L. A., Santos, L. R., & Baskin-Sommers, A. (2018). Psychopaths fail to automatically take the perspective of others. *Proceedings of the National Academy of Sciences*, *115*(13), 3302–3307. https://doi.org/10.1073/pnas.1721903115

Eickhoff, S. B., Paus, T., Caspers, S., Grosbras, M.-H., Evans, A. C., Zilles, K., & Amunts, K. (2007). Assignment of functional activations to probabilistic cytoarchitectonic areas revisited. *NeuroImage*, *36*(3), 511–521. https://doi.org/10.1016/j.neuroimage.2007.03.060

Eickhoff, S. B., Stephan, K. E., Mohlberg, H., Grefkes, C., Fink, G. R., Amunts, K., & Zilles, K. (2005). A new SPM toolbox for combining probabilistic cytoarchitectonic maps and functional imaging data. *NeuroImage*, *25*(4), 1325–1335. https://doi.org/10.1016/j.neuroimage.2004.12.034

Ellingsen, V. J. (2020). Personality and Cognitive Abilities. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (pp. 3568–3576). Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3_990

Eyler, L. T., Pierce, K., & Courchesne, E. (2012). A failure of left temporal cortex to specialize for language is an early emerging and fundamental property of autism. *Brain*, *135*(3), 949–960. https://doi.org/10.1093/brain/awr364

Fortenberry, K. T., Jansen, K. L., & Clark, M. S. (2013). Positive Affectivity. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 1509–1511). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_977

Fox, E., & Zougkou, K. (2011). *Influence of Personality Traits on Processing of Facial Expressions*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199559053.013.0026

Fredrickson, B. L., & Cohn, M. A. (2008). *Positive emotions.*

Freeman, S. M., Clewett, D. V., Bennett, C. M., Kiehl, K. A., Gazzaniga, M. S., & Miller, M. B. (2015). The posteromedial region of the default mode network shows attenuated task-induced deactivation in psychopathic prisoners. *Neuropsychology*, *29*(3), 493.

Froese, T., & González-Grandón, X. (2020). How passive is passive listening? Toward a sensorimotor theory of auditory perception. *Phenomenology and the Cognitive Sciences*, *19*(4), 619–651. https://doi.org/10.1007/s11097-019-09641-6

Furnes, D., Berg, H., Mitchell, R. M., & Paulmann, S. (2019). Exploring the Effects of Personality Traits on the Perception of Emotions From Prosody. *Frontiers in Psychology*, *10*, 184. https://doi.org/10.3389/fpsyg.2019.00184

Garofalo, C., Noteborn, M. G. C., Sellbom, M., & Bogaerts, S. (2019). Factor Structure and Construct Validity of the Levenson Self-Report Psychopathy Scale (LSRP): A Replication and Extension in Dutch Nonclinical Participants. *Journal of Personality Assessment*, *101*(5), 481–492. https://doi.org/10.1080/00223891.2018.1519830

Gauthier, I., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature Neuroscience*, *3*(2), 191–197. https://doi.org/10.1038/72140

Gawryluk, J. R., Mazerolle, E. L., & D'Arcy, R. C. N. (2014). Does functional MRI detect activation in white matter? A review of emerging evidence, issues, and future directions. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00239

Gebauer, L., Skewes, J., Hørlyck, L., & Vuust, P. (2014). Atypical perception of affective prosody in Autism Spectrum Disorder. *NeuroImage: Clinical*, *6*, 370–378. https://doi.org/10.1016/j.nicl.2014.08.025

Gerdts, J., & Bernier, R. (2011). The Broader Autism Phenotype and Its Implications on the Etiology and Treatment of Autism Spectrum Disorders. *Autism Research and Treatment*, *2011*, 1–19. https://doi.org/10.1155/2011/545901

Gervais, H., Belin, P., Boddaert, N., Leboyer, M., Coez, A., Sfaello, I., Barthélémy, C., Brunelle, F., Samson, Y., & Zilbovicius, M. (2004). Abnormal cortical voice processing in autism. *Nature Neuroscience*, *7*(8), 801–802. https://doi.org/10.1038/nn1291

Geurts, D. E., Von Borries, K., Volman, I., Bulten, B. H., Cools, R., & Verkes, R.-J. (2016). Neural connectivity during reward expectation dissociates psychopathic criminals from non-criminal individuals with high impulsive/antisocial psychopathic traits. *Social Cognitive and Affective Neuroscience*, *11*(8), 1326–1334.

Gillen, C. T. A., Lee, Z., Salekin, K. L., Iselin, A.-M. R., Harrison, N. A., Clark, A. P., Colins, O. F., & Salekin, R. T. (2018). Psychopathic Traits in Adolescence: The Importance of Examining Components in Face Processing, Voice Processing, and Emotional Skill. *Journal of Psychopathology and Behavioral Assessment*, *40*(1), 50–59. https://doi.org/10.1007/s10862-018-9656-8

Glenn, A. L., & Yang, Y. (2012). The Potential Role of the Striatum in Antisocial Behavior and Psychopathy. *Biological Psychiatry*, *72*(10), 817–822. https://doi.org/10.1016/j.biopsych.2012.04.027

Goldberg, L. R. (1993). The structure of phenotypic personality traits. *American Psychologist*, *48*(1), 26–34. https://doi.org/10.1037/0003-066X.48.1.26

Goldenberg, G., & Karnath, H.-O. (2006). The Neural Basis of Imitation is Body Part Specific. *Journal of Neuroscience*, *26*(23), 6282–6287. https://doi.org/10.1523/JNEUROSCI.0638-06.2006

Grajauskas, L. A., Frizzell, T., Song, X., & D'Arcy, R. C. N. (2019). White Matter fMRI Activation Cannot Be Treated as a Nuisance Regressor: Overcoming a Historical Blind Spot. *Frontiers in Neuroscience*, *13*, 1024. https://doi.org/10.3389/fnins.2019.01024

Grandin, T. (2009). How does visual thinking work in the mind of a person with autism? A personal account. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1437–1442. https://doi.org/10.1098/rstb.2008.0297

Grossman, R. B., Bemis, R. H., Plesa Skwerer, D., & Tager-Flusberg, H. (2010). Lexical and Affective Prosody in Children With High-Functioning Autism. *Journal of Speech, Language, and Hearing Research*, *53*(3), 778–793. https://doi.org/10.1044/1092-4388(2009/08-0127)

Grossmann, T., Oberecker, R., Koch, S. P., & Friederici, A. D. (2010). The Developmental Origins of Voice Processing in the Human Brain. *Neuron*, *65*(6), 852–858. https://doi.org/10.1016/j.neuron.2010.03.001

Gu, X., Hof, P. R., Friston, K. J., & Fan, J. (2013). Anterior insular cortex and emotional awareness: Anterior Insular Cortex and Emotional Awareness. *Journal of Comparative Neurology*, *521*(15), 3371–3388. https://doi.org/10.1002/cne.23368

Gummelt, H. D., Anestis, J. C., & Carbonell, J. L. (2012). Examining the Levenson Self Report Psychopathy Scale using a Graded Response Model. *Personality and Individual Differences*, *53*(8), 1002–1006. https://doi.org/10.1016/j.paid.2012.07.014

Gurven, M., von Rueden, C., Massenkoff, M., Kaplan, H., & Lero Vie, M. (2013). How universal is the Big Five? Testing the five-factor model of personality variation among forager–farmers in the Bolivian Amazon. *Journal of Personality and Social Psychology*, *104*(2), 354–370. https://doi.org/10.1037/a0030841

Hare, R. D. (1991). *The Hare psychopathy checklist-revised. Toronto, Ontario: Multi-Health Systems*. Inc.

Harpur, T. J., Hare, R. D., & Hakstian, A. R. (1989). Two-factor conceptualization of psychopathy: Construct validity and assessment implications. *Psychological Assessment: A Journal of Consulting and Clinical Psychology*, *1*(1), 6.

Harpur, T. J., Hart, S. D., & Hare, R. D. (2002). *Personality of the psychopath.*

Helt, M. S., Sorensen, T. M., Scheub, R. J., Nakhle, M. B., & Luddy, A. C. (2021). Patterns of Contagious Yawning and Itching Differ Amongst Adults With Autistic Traits vs. Psychopathic Traits. *Frontiers in Psychology*, *12*, 645310. https://doi.org/10.3389/fpsyg.2021.645310

Hernandez, L. M., Green, S. A., Lawrence, K. E., Inada, M., Liu, J., Bookheimer, S. Y., & Dapretto, M. (2020). Social Attention in Autism: Neural Sensitivity to Speech Over Background Noise Predicts Encoding of Social Information. *Frontiers in Psychiatry*, *11*, 343. https://doi.org/10.3389/fpsyt.2020.00343

Hirnstein, M., Westerhausen, R., & Hugdahl, K. (2013). The Right Planum Temporale Is Involved in Stimulus-Driven, Auditory Attention – Evidence from Transcranial Magnetic Stimulation. *PLoS ONE*, *8*(2), e57316. https://doi.org/10.1371/journal.pone.0057316

Hoffmann, E., Brück, C., Kreifelts, B., Ethofer, T., & Wildgruber, D. (2016). Reduced functional connectivity to the frontal cortex during processing of social cues in autism spectrum disorder. *Journal of Neural Transmission*, *123*(8), 937–947. https://doi.org/10.1007/s00702-016-1544-3

Hopwood, C. J., Morey, L. C., Ansell, E. B., Grilo, C. M., Sanislow, C. A., McGlashan, T. H., Markowitz, J. C., Gunderson, J. G., Yen, S., Shea, M. T., & Skodol, A. E. (2009). The Convergent and Discriminant Validity of Five-Factor Traits: Current and Prospective Social, Work, and Recreational Dysfunction. *Journal of Personality Disorders*, *23*(5), 466–476. https://doi.org/10.1521/pedi.2009.23.5.466

Huang, Y., Yang, Y., Hao, L., Hu, X., Wang, P., Ding, Z., Gao, J.-H., & Gore, J. C. (2020). Detection of functional networks within white matter using independent component analysis. *NeuroImage*, *222*, 117278. https://doi.org/10.1016/j.neuroimage.2020.117278

Hurst, R. M., Mitchell, J. T., Kimbrel, N. A., Kwapil, T. K., & Nelson-Gray, R. O. (2007). Examination of the reliability and factor structure of the Autism Spectrum Quotient (AQ) in a non-clinical sample. *Personality and Individual Differences*, *43*(7), 1938–1949. https://doi.org/10.1016/j.paid.2007.06.012

Hyman, S. L., Levy, S. E., Myers, S. M., & COUNCIL ON CHILDREN WITH DISABILITIES, SECTION ON DEVELOPMENTAL AND BEHAVIORAL PEDIATRICS. (2020). Identification, Evaluation, and Management of Children With Autism Spectrum Disorder. *Pediatrics*, *145*(1), e20193447. https://doi.org/10.1542/peds.2019-3447

Ikuta, T., Shafritz, K. M., Bregman, J., Peters, B. D., Gruner, P., Malhotra, A. K., & Szeszko, P. R. (2014). Abnormal cingulum bundle development in autism: A probabilistic tractography study. *Psychiatry Research: Neuroimaging*, *221*(1), 63–68. https://doi.org/10.1016/j.pscychresns.2013.08.002

Jiahui, G., Garrido, L., Liu, R. R., Susilo, T., Barton, J. J. S., & Duchaine, B. (2017). Normal voice processing after posterior superior temporal sulcus lesion. *Neuropsychologia*, *105*, 215–222. https://doi.org/10.1016/j.neuropsychologia.2017.03.008

Joassin, F., Pesenti, M., Maurage, P., Verreckt, E., Bruyer, R., & Campanella, S. (2011). Cross-modal interactions between human faces and voices involved in person recognition. *Cortex*, *47*(3), 367–376. https://doi.org/10.1016/j.cortex.2010.03.003

Johanson, M., Vaurio, O., Tiihonen, J., & Lähteenvuo, M. (2020). A Systematic Literature Review of Neuroimaging of Psychopathic Traits. *Frontiers in Psychiatry*, *10*, 1027. https://doi.org/10.3389/fpsyt.2019.01027

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The big five inventory. Berkeley. *CA: University of California, Berkeley, Institute of Personality and Social Research*, *10*.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. *Handbook of Personality: Theory and Research*, *3*(2), 114–158.

John, O. P., & Srivastava, S. (1999). *The Big-Five trait taxonomy: History, measurement, and theoretical perspectives* (Vol. 2). University of California Berkeley.

Johns, P. (2014). Functional neuroanatomy. In *Clinical Neuroscience* (pp. 27–47). Elsevier. https://doi.org/10.1016/B978-0-443-10321-6.00003-5

Jonason, P. K., & Krause, L. (2013). The emotional deficits associated with the Dark Triad traits: Cognitive empathy, affective empathy, and alexithymia. *Personality and Individual Differences*, *55*(5), 532–537.

Jou, R. J., Reed, H. E., Kaiser, M. D., Voos, A. C., Volkmar, F. R., & Pelphrey, K. A. (2016). White Matter Abnormalities in Autism and Unaffected Siblings. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *28*(1), 49–55. https://doi.org/10.1176/appi.neuropsych.15050109

Juárez, M., Kiehl, K. A., & Calhoun, V. D. (2013). Intrinsic limbic and paralimbic networks are associated with criminal psychopathy. *Human Brain Mapping*, *34*(8), 1921–1930.

Karle, K. N., Ethofer, T., Jacob, H., Brück, C., Erb, M., Lotze, M., Nizielski, S., Schütz, A., Wildgruber, D., & Kreifelts, B. (2018). Neurobiological correlates of emotional intelligence in voice and face perception networks. *Social Cognitive and Affective Neuroscience*, *13*(2), 233–244. https://doi.org/10.1093/scan/nsy001

Karpman, B. (1941). On the need of separating psychopathy into two distinct clinical types: The symptomatic and the idiopathic. *Journal of Criminal Psychopathology*.

Karpman, B. (1948). The myth of the psychopathic personality. *American Journal of Psychiatry*, *104*(9), 523–534.

Katsumi, Y., Denkova, E., & Dolcos, S. (2020). Personality and Memory. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (pp. 3646–3655). Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3_992

Keller, L., & Allemand, M. (2020). Personality and Divorce. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (pp. 3608–3613). Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3_710

Knutsen, J., Crossman, M., Perrin, J., Shui, A., & Kuhlthau, K. (2019). Sex differences in restricted repetitive behaviors and interests in children with autism spectrum disorder: An Autism Treatment Network study. *Autism*, *23*(4), 858–868. https://doi.org/10.1177/1362361318786490

Koenigs, M., Barbey, A. K., Postle, B. R., & Grafman, J. (2009). Superior Parietal Cortex Is Critical for the Manipulation of Information in Working Memory. *Journal of Neuroscience*, *29*(47), 14980–14986. https://doi.org/10.1523/JNEUROSCI.3706-09.2009

Koydemir, S., & Schütz, A. (2012). Emotional intelligence predicts components of subjective well-being beyond personality: A two-country study using self-and informant reports. *The Journal of Positive Psychology*, *7*(2), 107–118.

Kreifelts, B., Eckstein, K. N., Ethofer, T., Wiegand, A., Wächter, S., Brück, C., Erb, M., Lotze, M., & Wildgruber, D. (2019). Tuned to voices and faces: Cerebral responses linked to social anxiety. *NeuroImage*, *197*, 450–456. https://doi.org/10.1016/j.neuroimage.2019.05.018

Kreifelts, B., Ethofer, T., Huberle, E., Grodd, W., & Wildgruber, D. (2009). Association of trait emotional intelligence and individual fMRI-activation patterns during the perception of social signals from voice and face. *Human Brain Mapping*, *31*(7), 979–991. https://doi.org/10.1002/hbm.20913

Kuhl, P. K., Coffey-Corina, S., Padden, D., & Dawson, G. (2005). Links between social and linguistic processing of speech in preschool children with autism: Behavioral and electrophysiological measures. *Developmental Science*, *8*(1), F1–F12. https://doi.org/10.1111/j.1467-7687.2004.00384.x

Kumar, S., Kaposvari, P., & Vogels, R. (2017). Encoding of Predictable and Unpredictable Stimuli by Inferior Temporal Cortical Neurons. *Journal of Cognitive Neuroscience*, *29*(8), 1445–1454. https://doi.org/10.1162/jocn_a_01135

Lahey, B. B. (2009). Public health significance of neuroticism. *American Psychologist*, *64*(4), 241–256. https://doi.org/10.1037/a0015309

Lee, J. E., Bigler, E. D., Alexander, A. L., Lazar, M., DuBray, M. B., Chung, M. K., Johnson, M., Morgan, J., Miller, J. N., McMahon, W. M., Lu, J., Jeong, E.-K., & Lainhart, J. E. (2007). Diffusion tensor imaging of white matter in the superior temporal gyrus and temporal stem in autism. *Neuroscience Letters*, *424*(2), 127–132. https://doi.org/10.1016/j.neulet.2007.07.042

Levenson, M. R., Kiehl, K. A., & Fitzpatrick, C. M. (1995). Assessing psychopathic attributes in a noninstitutionalized population. *Journal of Personality and Social Psychology*, *68*(1), 151–158. https://doi.org/10.1037/0022-3514.68.1.151

Li, M., Newton, A. T., Anderson, A. W., Ding, Z., & Gore, J. C. (2019). Characterization of the hemodynamic response function in white matter tracts for event-related fMRI. *Nature Communications*, *10*(1), 1140. https://doi.org/10.1038/s41467-019-09076-2

Ljungberg, T., Apicella, P., & Schultz, W. (1992). Responses of monkey dopamine neurons during learning of behavioral reactions. *Journal of Neurophysiology*, *67*(1), 145–163. https://doi.org/10.1152/jn.1992.67.1.145

Lockwood, P. L. (2016). The anatomy of empathy: Vicarious experience and disorders of social cognition. *Behavioural Brain Research*, *311*, 255–266. https://doi.org/10.1016/j.bbr.2016.05.048

Lodi-Smith, J., Rodgers, J. D., Cunningham, S. A., Lopata, C., & Thomeer, M. L. (2019). Meta-analysis of Big Five personality traits in autism spectrum disorder. *Autism*, *23*(3), 556–565. https://doi.org/10.1177/1362361318766571

Loomes, R., Hull, L., & Mandy, W. P. L. (2017). What Is the Male-to-Female Ratio in Autism Spectrum Disorder? A Systematic Review and Meta-Analysis. *Journal of the American Academy of Child & Adolescent Psychiatry*, *56*(6), 466–474. https://doi.org/10.1016/j.jaac.2017.03.013

Lucas, R. E., & Fujita, F. (2000). Factors influencing the relation between extraversion and pleasant affect. *Journal of Personality and Social Psychology*, *79*(6), 1039.

Lukewich, M. K., & El-Baba, M. (2020). Personality and Disease Susceptibility. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (pp. 3592–3599). Springer International Publishing. https://doi.org/10.1007/978-3-319-24612-3_2107

Lundqvist, L.-O., & Lindner, H. (2017). Is the Autism-Spectrum Quotient a Valid Measure of Traits Associated with the Autism Spectrum? A Rasch Validation in Adults with and Without Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *47*(7), 2080–2091. https://doi.org/10.1007/s10803-017-3128-y

Lynam, D. R., Whiteside, S., & Jones, S. (1999). Self-Reported Psychopathy: A Validation Study. *Journal of Personality Assessment*, *73*(1), 110–132. https://doi.org/10.1207/S15327752JPA730108

Lyons, M. (2019). Introduction to the Dark Triad. In *The Dark Triad of Personality* (pp. 1–37). Elsevier. https://doi.org/10.1016/B978-0-12-814291-2.00001-2

Lyons, M., & Brockman, C. (2017). The Dark Triad, emotional expressivity and appropriateness of emotional response: Fear and sadness when one should be happy? *Personality and Individual Differences*, *104*, 466–469.

Malouff, J. M., Thorsteinsson, E. B., & Schutte, N. S. (2005). The relationship between the five-factor model of personality and symptoms of clinical disorders: A meta-analysis. *Journal of Psychopathology and Behavioral Assessment*, *27*(2), 101–114.

Mannarelli, D., Pauletti, C., Grippo, A., Amantini, A., Augugliaro, V., Currà, A., Missori, P., Locuratolo, N., De Lucia, M. C., Rinalduzzi, S., & Fattapposta, F. (2015). The Role of the Right Dorsolateral Prefrontal Cortex in Phasic Alertness: Evidence from a Contingent Negative Variation and Repetitive Transcranial Magnetic Stimulation Study. *Neural Plasticity*, *2015*, 1–9. https://doi.org/10.1155/2015/410785

McAleer, P., & Belin, P. (2018). The Perception of Personality Traits from Voices. In S. Frühholz & P. Belin (Eds.), *The Oxford Handbook of Voice Perception* (pp. 584–606). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198743187.013.26

McCrae, R. R., & Costa Jr, P. T. (2008). *The five-factor theory of personality.*

Meffert, H., Gazzola, V., den Boer, J. A., Bartels, A. A. J., & Keysers, C. (2013). Reduced spontaneous but relatively normal deliberate vicarious representations in psychopathy. *Brain*, *136*(8), 2550–2562. https://doi.org/10.1093/brain/awt190

Methot-Jones, T., Book, A., & Gauthier, N. Y. (2019). Less than human: Psychopathy, dehumanization, and sexist and violent attitudes towards women. *Personality and Individual Differences*, *149*, 250–260. https://doi.org/10.1016/j.paid.2019.06.002

Meyer, M. L., Masten, C. L., Ma, Y., Wang, C., Shi, Z., Eisenberger, N. I., & Han, S. (2013). Empathy for the social suffering of friends and strangers recruits distinct patterns of brain activation. *Social Cognitive and Affective Neuroscience*, *8*(4), 446–454. https://doi.org/10.1093/scan/nss019

Mier, D., Haddad, L., Diers, K., Dressing, H., Meyer-Lindenberg, A., & Kirsch, P. (2014). Reduced embodied simulation in psychopathy. *The World Journal of Biological Psychiatry*, *15*(6), 479–487. https://doi.org/10.3109/15622975.2014.902541

Miller, J. D., Gaughan, E. T., & Pryor, L. R. (2008). The Levenson Self-Report Psychopathy Scale: An Examination of the Personality Traits and Disorders Associated With the LSRP Factors. *Assessment*, *15*(4), 450–463. https://doi.org/10.1177/1073191108316888

Musek, J. (2007). A general factor of personality: Evidence for the Big One in the five-factor model. *Journal of Research in Personality*, *41*(6), 1213–1233. https://doi.org/10.1016/j.jrp.2007.02.003

Niedenthal, P. M., & Wood, A. (2019). Does emotion influence visual perception? Depends on how you look at it. *Cognition and Emotion*, *33*(1), 77–84. https://doi.org/10.1080/02699931.2018.1561424

Niven, K. (2013). Affect. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 49–50). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_1088

O'Connor, B. P. (2005). A search for consensus on the dimensional structure of personality disorders. *Journal of Clinical Psychology*, *61*(3), 323–345. https://doi.org/10.1002/jclp.20017

Padmanabhan, A., Lynch, C. J., Schaer, M., & Menon, V. (2017). The Default Mode Network in Autism. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *2*(6), 476–486. https://doi.org/10.1016/j.bpsc.2017.04.004

Peer, M., Nitzan, M., Bick, A. S., Levin, N., & Arzy, S. (2017). Evidence for Functional Networks within the Human Brain's White Matter. *The Journal of Neuroscience*, *37*(27), 6394–6407. https://doi.org/10.1523/JNEUROSCI.3872-16.2017

Pegado, F., Hendriks, M. H. A., Amelynck, S., Daniels, N., Steyaert, J., Boets, B., & Op de Beeck, H. (2020). Adults with high functioning autism display idiosyncratic behavioral patterns, neural representations and connectivity of the 'Voice Area' while judging the appropriateness of emotional vocal reactions. *Cortex*, *125*, 90–108. https://doi.org/10.1016/j.cortex.2019.11.008

Pera-Guardiola, V., Contreras-Rodríguez, O., Batalla, I., Kosson, D., Menchón, J. M., Pifarré, J., Bosque, J., Cardoner, N., & Soriano-Mas, C. (2016). Brain Structural Correlates of Emotion Recognition in Psychopaths. *PLOS ONE*, *11*(5), e0149807. https://doi.org/10.1371/journal.pone.0149807

Pernet, C. R., McAleer, P., Latinus, M., Gorgolewski, K. J., Charest, I., Bestelmeyer, P. E. G., Watson, R. H., Fleming, D., Crabbe, F., Valdes-Sosa, M., & Belin, P. (2015). The human voice areas: Spatial organization and inter-individual variability in temporal and extra-temporal cortices. *NeuroImage*, *119*, 164–174. https://doi.org/10.1016/j.neuroimage.2015.06.050

Petrovich, G. D. (2018). Lateral Hypothalamus as a Motivation-Cognition Interface in the Control of Feeding Behavior. *Frontiers in Systems Neuroscience*, *12*, 14. https://doi.org/10.3389/fnsys.2018.00014

Philip, R. C. M., Dauvermann, M. R., Whalley, H. C., Baynham, K., Lawrie, S. M., & Stanfield, A. C. (2012). A systematic review and meta-analysis of the fMRI investigation of autism spectrum disorders. *Neuroscience & Biobehavioral Reviews*, *36*(2), 901–942. https://doi.org/10.1016/j.neubiorev.2011.10.008

Philip, R. C. M., Whalley, H. C., Stanfield, A. C., Sprengelmeyer, R., Santos, I. M., Young, A. W., Atkinson, A. P., Calder, A. J., Johnstone, E. C., Lawrie, S. M., & Hall, J. (2010). Deficits in facial, body movement and vocal emotional processing in autism spectrum disorders. *Psychological Medicine*, *40*(11), 1919–1929. https://doi.org/10.1017/S0033291709992364

Philippi, C. L., Pujara, M. S., Motzkin, J. C., Newman, J., Kiehl, K. A., & Koenigs, M. (2015). Altered resting-state functional connectivity in cortical networks in psychopathy. *Journal of Neuroscience*, *35*(15), 6068–6078.

Pierce, K. (2001). Face processing occurs outside the fusiform `face area' in autism: Evidence from functional MRI. *Brain*, *124*(10), 2059–2073. https://doi.org/10.1093/brain/124.10.2059

Psederska, E., Yankov, G. P., Bozgunov, K., Popov, V., Vasilev, G., & Vassileva, J. (2020). Validation of the Levenson Self-Report Psychopathy Scale in Bulgarian Substance-Dependent Individuals. *Frontiers in Psychology*, *11*, 1110. https://doi.org/10.3389/fpsyg.2020.01110

Rajmohan, V., & Mohandas, E. (2007). Mirror neuron system. *Indian Journal of Psychiatry*, *49*(1), 66. https://doi.org/10.4103/0019-5545.31522

Rammstedt, B., & Danner, D. (2016). Die Facettenstruktur des big five inventory (BFI). *Diagnostica*.

Rauschecker, J. P., & Scott, S. K. (2016). Pathways and Streams in the Auditory Cortex. In *Neurobiology of Language* (pp. 287–298). Elsevier. https://doi.org/10.1016/B978-0-12-407794-2.00024-9

Reidy, D. E., Krusemark, E., Kosson, D. S., Kearns, M. C., Smith-Darden, J., & Kiehl, K. A. (2017). The Development of Severe and Chronic Violence Among Youth: The Role of Psychopathic Traits and Reward Processing. *Child Psychiatry & Human Development*, *48*(6), 967–982. https://doi.org/10.1007/s10578-017-0720-5

Revelle, W. (2007). Experimental approaches to the study of personality. In *Handbook of research methods in personality psychology.* (pp. 37–61). The Guilford Press.

Roberts, B. W., & DelVecchio, W. F. (2000). The rank-order consistency of personality traits from childhood to old age: A quantitative review of longitudinal studies. *Psychological Bulletin*, *126*(1), 3–25. https://doi.org/10.1037/0033-2909.126.1.3

Robertson, C. E., & Baron-Cohen, S. (2017). Sensory perception in autism. *Nature Reviews Neuroscience*, *18*(11), 671–684. https://doi.org/10.1038/nrn.2017.112

Rogers, J., Viding, E., James Blair, R., Frith, U., & Happé, F. (2006). Autism spectrum disorder and psychopathy: Shared cognitive underpinnings or double hit? *Psychological Medicine*, *36*(12), 1789–1798. https://doi.org/10.1017/S0033291706008853

Rolls, E. T., Cheng, W., & Feng, J. (2020). The orbitofrontal cortex: Reward, emotion and depression. *Brain Communications*, *2*(2), fcaa196. https://doi.org/10.1093/braincomms/fcaa196

Rolls, E. T., Huang, C.-C., Lin, C.-P., Feng, J., & Joliot, M. (2020). Automated anatomical labelling atlas 3. *NeuroImage*, *206*, 116189. https://doi.org/10.1016/j.neuroimage.2019.116189

Ronan, G. F., Dreer, L., Maurelli, K., Ronan, D., & Gerhart, J. (2013). *Practitioner's guide to empirically supported measures of anger, aggression, and violence*. Springer Science & Business Media.

Sadeh, N., Spielberg, J. M., Heller, W., Herrington, J. D., Engels, A. S., Warren, S. L., Crocker, L. D., Sutton, B. P., & Miller, G. A. (2013). Emotion disrupts neural activity during selective attention in psychopathy. *Social Cognitive and Affective Neuroscience*, *8*(3), 235–246. https://doi.org/10.1093/scan/nsr092

Salekin, R. T., Chen, D. R., Sellbom, M., Lester, W. S., & MacDougall, E. (2014). Examining the factor structure and convergent and discriminant validity of the Levenson Self-Report Psychopathy Scale: Is the two-factor model the best fitting model? *Personality Disorders: Theory, Research, and Treatment*, *5*(3), 289–304. https://doi.org/10.1037/per0000073

Schelinski, S., Borowiak, K., & von Kriegstein, K. (2016). Temporal voice areas exist in autism spectrum disorder but are dysfunctional for voice identity recognition. *Social Cognitive and Affective Neuroscience*, *11*(11), 1812–1822. https://doi.org/10.1093/scan/nsw089

Schelinski, S., Riedel, P., & von Kriegstein, K. (2014). Visual abilities are important for auditory-only speech recognition: Evidence from autism spectrum disorder. *Neuropsychologia*, *65*, 1–11. https://doi.org/10.1016/j.neuropsychologia.2014.09.031

Schelinski, S., & von Kriegstein, K. (2019). The Relation Between Vocal Pitch and Vocal Emotion Recognition Abilities in People with Autism Spectrum Disorder and Typical Development. *Journal of Autism and Developmental Disorders*, *49*(1), 68–82. https://doi.org/10.1007/s10803-018-3681-z

Schirmer, A. (2018). Is the voice an auditory face? An ALE meta-analysis comparing vocal and facial emotion processing. *Social Cognitive and Affective Neuroscience*, *13*(1), 1–13. https://doi.org/10.1093/scan/nsx142

Schmidt, S. N. L., Hass, J., Kirsch, P., & Mier, D. (2021). The human mirror neuron system—A common neural basis for social cognition? *Psychophysiology*, *58*(5). https://doi.org/10.1111/psyp.13781

Schmitt, D. P., Allik, J., McCrae, R. R., & Benet-Martínez, V. (2007). The Geographic Distribution of Big Five Personality Traits: Patterns and Profiles of Human Self-Description Across 56 Nations. *Journal of Cross-Cultural Psychology*, *38*(2), 173–212. https://doi.org/10.1177/0022022106297299

Schultz, R. T., Gauthier, I., Klin, A., Fulbright, R. K., Anderson, A. W., Volkmar, F., Skudlarski, P., Lacadie, C., Cohen, D. J., & Gore, J. C. (2000). Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry*, *57*(4), 331–340.

Schurz, M., Radua, J., Aichhorn, M., Richlan, F., & Perner, J. (2014). Fractionating theory of mind: A meta-analysis of functional brain imaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 9–34. https://doi.org/10.1016/j.neubiorev.2014.01.009

Schutter, D. J. L. G., & van Honk, J. (2009). The Cerebellum in Emotion Regulation: A Repetitive Transcranial Magnetic Stimulation Study. *The Cerebellum*, *8*(1), 28–34. https://doi.org/10.1007/s12311-008-0056-6

Seara-Cardoso, A., & Viding, E. (2015). Functional Neuroscience of Psychopathic Personality in Adults: Neuroscience of Psychopathic Personality. *Journal of Personality*, *83*(6), 723–737. https://doi.org/10.1111/jopy.12113

Seara-Cardoso, A., Viding, E., Lickley, R. A., & Sebastian, C. L. (2015). Neural responses to others' pain vary with psychopathic traits in healthy adult males. *Cognitive, Affective, & Behavioral Neuroscience*, *15*(3), 578–588.

Seghier, M. L. (2013). The Angular Gyrus: Multiple Functions and Multiple Subdivisions. *The Neuroscientist*, *19*(1), 43–61. https://doi.org/10.1177/1073858412440596

Sethi, A., McCrory, E., Puetz, V., Hoffmann, F., Knodt, A. R., Radtke, S. R., Brigidi, B. D., Hariri, A. R., & Viding, E. (2018). Primary and Secondary Variants of Psychopathy in a Volunteer Sample Are Associated With Different Neurocognitive Mechanisms. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, *3*(12), 1013–1021. https://doi.org/10.1016/j.bpsc.2018.04.002

Sharma, L. A. (2013). Neuroticism. In M. D. Gellman & J. R. Turner (Eds.), *Encyclopedia of Behavioral Medicine* (pp. 1333–1333). Springer New York. https://doi.org/10.1007/978-1-4419-1005-9_607

Shultz, S., Vouloumanos, A., & Pelphrey, K. (2012). The Superior Temporal Sulcus Differentiates Communicative and Noncommunicative Auditory Signals. *Journal of Cognitive Neuroscience*, *24*(5), 1224–1232. https://doi.org/10.1162/jocn_a_00208

Siegel, E. H., Wormwood, J. B., Quigley, K. S., & Barrett, L. F. (2018). Seeing What You Feel: Affect Drives Visual Perception of Structurally Neutral Faces. *Psychological Science*, *29*(4), 496–503. https://doi.org/10.1177/0956797617741718

Sizoo, B. B., Horwitz, E., Teunisse, J., Kan, C., Vissers, C., Forceville, E., Van Voorst, A., & Geurts, H. (2015). Predictive validity of self-report questionnaires in the assessment of autism spectrum disorders in adults. *Autism*, *19*(7), 842–849. https://doi.org/10.1177/1362361315589869

Smith, M. J., Schroeder, M. P., Abram, S. V., Goldman, M. B., Parrish, T. B., Wang, X., Derntl, B., Habel, U., Decety, J., Reilly, J. L., Csernansky, J. G., & Breiter, H. C.

(2015). Alterations in Brain Activation During Cognitive Empathy Are Related to Social Functioning in Schizophrenia. *Schizophrenia Bulletin*, *41*(1), 211–222. https://doi.org/10.1093/schbul/sbu023

Sommer, M., Sodian, B., Döhnel, K., Schwerdtner, J., Meinhardt, J., & Hajak, G. (2010). In psychopathic patients emotion attribution modulates activity in outcome-related brain areas. *Psychiatry Research: Neuroimaging*, *182*(2), 88–95.

Sonne, J. W. H., & Gash, D. M. (2018). Psychopathy to Altruism: Neurobiology of the Selfish–Selfless Spectrum. *Frontiers in Psychology*, *9*, 575. https://doi.org/10.3389/fpsyg.2018.00575

Stoodley, C. J. (2012). The Cerebellum and Cognition: Evidence from Functional Imaging Studies. *The Cerebellum*, *11*(2), 352–365. https://doi.org/10.1007/s12311-011-0260-7

Terasawa, Y., Kurosaki, Y., Ibata, Y., Moriguchi, Y., & Umeda, S. (2015). Attenuated sensitivity to the emotions of others by insular lesion. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01314

Tillem, S., van Dongen, J., Brazil, I. A., & Baskin-Sommers, A. (2018). Psychopathic traits are differentially associated with efficiency of neural communication. *Psychophysiology*, *55*(9), e13194. https://doi.org/10.1111/psyp.13194

Toomela, A. (2003). Relationships between personality structure, structure of word meaning, and cognitive ability: A study of cultural mechanisms of personality. *Journal of Personality and Social Psychology*, *85*(4), 723–735. https://doi.org/10.1037/0022-3514.85.4.723

Van Ackeren, M. J., Barbero, F. M., Mattioni, S., Bottini, R., & Collignon, O. (2018). Neuronal populations in the occipital cortex of the blind synchronize to the temporal dynamics of speech. *ELife*, *7*, e31640. https://doi.org/10.7554/eLife.31640

van der Linden, D., te Nijenhuis, J., & Bakker, A. B. (2010). The General Factor of Personality: A meta-analysis of Big Five intercorrelations and a criterion-related validity study. *Journal of Research in Personality*, *44*(3), 315–327. https://doi.org/10.1016/j.jrp.2010.03.003

van Dongen, J. D. M. (2020). The Empathic Brain of Psychopaths: From Social Science to Neuroscience in Empathy. *Frontiers in Psychology*, *11*, 695. https://doi.org/10.3389/fpsyg.2020.00695

van Laarhoven, T., Stekelenburg, J. J., & Vroomen, J. (2019). Increased sub-clinical levels of autistic traits are associated with reduced multisensory integration of audiovisual speech. *Scientific Reports*, *9*(1), 9535. https://doi.org/10.1038/s41598-019-46084-0

Veit, R., Flor, H., Erb, M., Hermann, C., Lotze, M., Grodd, W., & Birbaumer, N. (2002). Brain circuits involved in emotional learning in antisocial behavior and social phobia in humans. *Neuroscience Letters*, *328*(3), 233–236. https://doi.org/10.1016/S0304-3940(02)00519-0

Velikonja, T., Fett, A.-K., & Velthorst, E. (2019). Patterns of Nonsocial and Social Cognitive Functioning in Adults With Autism Spectrum Disorder: A Systematic Review and Meta-analysis. *JAMA Psychiatry*, *76*(2), 135. https://doi.org/10.1001/jamapsychiatry.2018.3645

Verduyn, P., & Brans, K. (2012). The relationship between extraversion, neuroticism and aspects of trait affect. *Personality and Individual Differences*, *52*(6), 664–669. https://doi.org/10.1016/j.paid.2011.12.017

Vittersø, J. (2014). Positive Affect. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 4909–4918). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_2211

Vogt, B. A. (2016). Midcingulate cortex: Structure, connections, homologies, functions and diseases. *Journal of Chemical Neuroanatomy*, *74*, 28–46. https://doi.org/10.1016/j.jchemneu.2016.01.010

Wai, M., & Tiliopoulos, N. (2012). The affective and cognitive empathic nature of the dark triad of personality. *Personality and Individual Differences*, *52*(7), 794–799.

Wang, J.-E., & Tsao, F.-M. (2015). Emotional prosody perception and its association with pragmatic language in school-aged children with high-function autism. *Research in Developmental Disabilities*, *37*, 162–170. https://doi.org/10.1016/j.ridd.2014.11.013

Wang, M.-C., Shou, Y., Deng, Q., Sellbom, M., Salekin, R. T., & Gao, Y. (2018). Factor structure and construct validity of the Levenson Self-Report Psychopathy Scale (LSRP) in a sample of Chinese male inmates. *Psychological Assessment*, *30*(7), 882–892. https://doi.org/10.1037/pas0000537

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063.

Watson, D., & Pennebaker, J. W. (1989). Health complaints, stress, and distress: Exploring the central role of negative affectivity. *Psychological Review*, *96*(2), 234.

Weiss, B., Sleep, C., & Miller, J. D. (2016). Levenson Self-Report Psychopathy Scale. In V. Zeigler-Hill & T. K. Shackelford (Eds.), *Encyclopedia of Personality and Individual*

Differences (pp. 1–6). Springer International Publishing. https://doi.org/10.1007/978-3-319-28099-8_1242-1

Widiger, T. A. (2016). *A Five Factor Discussion* (T. A. Widiger, Ed.; Vol. 1). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199352487.013.8

Widiger, T. A., & Lynam, D. R. (1998). Psychopathy and the five-factor model of personality. *Psychopathy: Antisocial, Criminal, and Violent Behavior*, 171–187.

Williamson, S., Harpur, T. J., & Hare, R. D. (1991). Abnormal Processing of Affective Words by Psychopaths. *Psychophysiology*, *28*(3), 260–273. https://doi.org/10.1111/j.1469-8986.1991.tb02192.x

Winlove, C. I. P., Milton, F., Ranson, J., Fulford, J., MacKisack, M., Macpherson, F., & Zeman, A. (2018). The neural correlates of visual imagery: A co-ordinate-based meta-analysis. *Cortex*, *105*, 4–25. https://doi.org/10.1016/j.cortex.2017.12.014

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening Adults for Asperger Syndrome Using the AQ: A Preliminary Study of its Diagnostic Validity in Clinical Practice. *Journal of Autism and Developmental Disorders*, *35*(3), 331–335. https://doi.org/10.1007/s10803-005-3300-7

Wood-Downie, H., Wong, B., Kovshoff, H., Cortese, S., & Hadwin, J. A. (2021). Research Review: A systematic review and meta-analysis of sex/gender differences in social interaction and communication in autistic and nonautistic children and adolescents. *Journal of Child Psychology and Psychiatry*, *62*(8), 922–936. https://doi.org/10.1111/jcpp.13337

Xu, J., Wang, J., Fan, L., Li, H., Zhang, W., Hu, Q., & Jiang, T. (2016). Tractography-based Parcellation of the Human Middle Temporal Gyrus. *Scientific Reports*, *5*(1), 18883. https://doi.org/10.1038/srep18883

Yamasaki, K., & Uchida, K. (2016). Effects of positive and negative affect on depression: Considering the activation dimension and balance of affect. *International Journal of Psychology and Behavioral Sciences*, *6*, 139–147.

Yan, Z., Schmidt, S. N. L., Frank, J., Witt, S. H., Hass, J., Kirsch, P., & Mier, D. (2020). Hyperfunctioning of the right posterior superior temporal sulcus in response to neutral facial expressions presents an endophenotype of schizophrenia. *Neuropsychopharmacology*, *45*(8), 1346–1352. https://doi.org/10.1038/s41386-020-0637-8

Young, A. W., Frühholz, S., & Schweinberger, S. R. (2020). Face and Voice Perception: Understanding Commonalities and Differences. *Trends in Cognitive Sciences*, *24*(5), 398–410. https://doi.org/10.1016/j.tics.2020.02.001

Yu, C.-L., & Chou, T.-L. (2018). A Dual Route Model of Empathy: A Neurobiological Prospective. *Frontiers in Psychology*, *9*, 2212. https://doi.org/10.3389/fpsyg.2018.02212

Zaki, J., Weber, J., Bolger, N., & Ochsner, K. (2009). The neural bases of empathic accuracy. *Proceedings of the National Academy of Sciences*, *106*(27), 11382–11387. https://doi.org/10.1073/pnas.0902666106

Appendix A

Big Five Inventory: How I am in general

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

1	**2**	**3**	**4**	**5**
Disagree Strongly	Disagree a little	Neither agree nor disagree	Agree a little	Agree Strongly

I see myself as someone who…

1._____ Is talkative
2._____ Tends to find fault with others
3._____ Does a thorough job
4._____ Is depressed, blue
5._____ Is original, comes up with new ideas
6._____ Is reserved
7._____ Is helpful and unselfish with others
8._____ Can be somewhat careless
9._____ Is relaxed, handles stress well.
10._____ Is curious about many different things
11._____ Is full of energy
12._____ Starts quarrels with others
13._____ Is a reliable worker
14._____ Can be tense
15._____ Is ingenious, a deep thinker
16._____ Generates a lot of enthusiasm
17._____ Has a forgiving nature
18._____ Tends to be disorganized
19._____ Worries a lot
20._____ Has an active imagination
21._____ Tends to be quiet
22._____ Is generally trusting
23._____ Tends to be lazy
24._____ Is emotionally stable, not easily upset
25._____ Is inventive
26._____ Has an assertive personality
27._____ Can be cold and aloof
28._____ Perseveres until the task is finished
29._____ Can be moody
30._____ Values artistic, aesthetic experiences
31._____ Is sometimes shy, inhibited
32._____ Is considerate and kind to almost everyone
33._____ Does things efficiently
34._____ Remains calm in tense situations
35._____ Prefers work that is routine
36._____ Is outgoing, sociable
37._____ Is sometimes rude to others
38._____ Makes plans and follows through with them
39._____ Gets nervous easily
40._____ Likes to reflect, play with ideas
41._____ Has few artistic interests
42._____ Likes to cooperate with others
43._____ Is easily distracted
44._____ Is sophisticated in art, music, or literature

SCORING INSTRUCTIONS

Reverse-score the following items by subtracting the score from 6:
Extraversion: 6, 21, 31
Agreeableness: 2, 12, 27, 37
Conscientiousness: 8, 18, 23, 43
Neuroticism: 9, 24, 34
Openness: 35, 41

Thus, a score of 1 becomes 5, 2 becomes 4, 3 remains 3, 4 becomes 2, and 5 becomes 1.

The scale scores are created by averaging the items belonging to each domain as follows (where **R** indicates the reverse-scored item).
Extraversion: 1, 6**R** 11, 16, 21**R**, 26, 31**R**, 36
Agreeableness: 2**R**, 7, 12**R**, 17, 22, 27**R**, 32, 37**R**, 42
Conscientiousness: 3, 8**R**, 13, 18**R**, 23**R**, 28, 33, 38, 43**R**
Neuroticism: 4, 9**R**, 14, 19, 24**R**, 29, 34**R**, 39
Openness: 5, 10, 15, 20, 25, 30, 35**R**, 40, 41**R**, 44

John, O. P., Donahue, E. M., & Kentle, R. L. (1991). The Big Five Inventory--Versions 4a and 54. Berkeley, CA: University of California, Berkeley, Institute of Personality and Social Research.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative Big Five trait taxonomy: History, measurement, and conceptual issues. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), Handbook of personality: Theory and research (pp. 114-158). New York, NY: Guilford Press.

Appendix B

Die deutsche Version des Big Five Inventory

Im folgenden finden Sie eine Reihe von Beschreibungen, die auf Sie zutreffen können oder nicht. Zum Beispiel, trifft es zu, dass sie jemand sind, der gerne Zeit mit anderen verbringt? Bitte machen Sie ein Kreuz neben jede der aufgeführten Beschreibungen, um anzuzeigen, wie sehr diese Aussage auf Sie zutrifft oder nicht zutrifft.

1	**2**	**3**	**4**	**5**
stimme gar nicht zu	stimme eher nicht zu	unent-schieden	stimme eher zu	stimme voll zu

1._____ gesprächig ist, sich gerne unterhält
2._____ dazu neigt, andere zu kritisieren
3._____ Aufgaben gründlich erledigt
4._____ deprimiert, niedergeschlagen ist
5._____ originell ist, neue Ideen entwickelt
6._____ eher zurückhaltend und reserviert ist
7._____ hilfsbereit und selbstlos gegenüber anderen ist
8._____ etwas achtlos sein kann
9._____ entspannt ist, sich durch Stress nicht aus der Ruhe bringen lässt
10._____ vielseitig interessiert ist
11._____ voller Energie und Tatendrang ist
12._____ häufig in Streitereien verwickelt ist
13._____ zuverlässig und gewissenhaft arbeitet
14._____ leicht angespannt reagiert
15._____ tiefsinnig ist, gerne über Sachen nachdenkt
16._____ begeisterungsfähig ist und andere mitreißen kann
17._____ nicht nachtragend ist, anderen leicht vergibt
18._____ dazu neigt, unordentlich zu sein
19._____ sich viele Sorgen macht
20._____ eine lebhafte Vorstellungskraft hat, phantasievoll ist
21._____ eher still und wortkarg ist
22._____ anderen Vertrauen schenkt
23._____ bequem ist und zur Faulheit neigt
24._____ ausgeglichen ist, nicht leicht aus der Fassung zu bringen ist
25._____ erfinderisch und einfallsreich ist
26._____ durchsetzungsfähig und energisch ist
27._____ sich kalt und distanziert verhalten kann
28._____ nicht aufgibt ehe die Aufgabe erledigt ist
29._____ launisch sein kann, schwankende Stimmungen hat
30._____ künstlerische und ästhetische Eindrücke schätzt
31._____ manchmal schüchtern und gehemmt ist
32._____ rücksichtsvoll und einfühlsam zu anderen ist
33._____ tüchtig ist und flott arbeitet
34._____ ruhig bleibt, selbst in angespannten Situationen
35._____ routinemäßige und einfache Aufgaben bevorzugt
36._____ aus sich herausgeht, gesellig ist
37._____ schroff und abweisend zu anderen sein kann
38._____ Pläne macht und diese auch durchführt
39._____ leicht nervös und unsicher wird
40._____ gerne Überlegungen anstellt, mit Ideen spielt
41._____ nur wenig künstlerische Interessen hat
42._____ sich kooperativ verhält, Zusammenarbeit dem Wettbewerb vorzieht
43._____ leicht ablenkbar ist, nicht bei der Sache bleibt
44._____ sich gut in Musik, Kunst und Literatur auskennt

Appendix C

Levenson Self-Report Psychopathy Scale

The test consists of twenty-six statements that could possibly apply to you. Please rate how much you agree with each of the statements using the following scale:

1 Strongly disagree	**2** Disagree	**3** Neither agree nor disagree	**4** Agree	**5** Strongly agree

Primary Psychopathy
_____ 1. Success is based on survival of the fittest; I am not concerned about the losers.
_____ 2. For me, what's right is whatever I can get away with.
_____ 3. In today's world, I feel justified in doing anything I can get away with to succeed.
_____ 4. My main purpose in life is getting as many goodies as I can.
_____ 5. Making a lot of money is my most important goal.
_____ 6. I let others worry about higher values; my main concern is with the bottom line.
_____ 7. People who are stupid enough to get ripped off usually deserve it.
_____ 8. Looking out for myself is my top priority.
_____ 9. I tell other people what they want to hear so that they will do what I want them to do.
_____ 10. I would be upset if my success came at someone else's expense. **RS**
_____ 11. I often admire a really clever scam.
_____ 12. I make a point of trying not to hurt others in pursuit of my goals. **RS**
_____ 13. I enjoy manipulating other people's feelings.
_____ 14. I feel bad if my words or actions cause someone to feel emotional pain. **RS**
_____ 15. Even if I were trying very hard to sell something, I wouldn't lie about it. **RS**
_____ 16. Cheating is not justified because it is unfair to others. **RS**

Secondary Psychopathy
_____ 1. I find myself in the same kinds of trouble, time after time.
_____ 2. I am often bored.
_____ 3. I find that I am able to pursue one goal for a long time. **RS**
_____ 4. I don't plan anything very far in advance.
_____ 5. I quickly lose interest in tasks I start.
_____ 6. Most of my problems are due to the fact that other people just don't understand me.
_____ 7. Before I do anything, I carefully consider the possible consequences. **RS**
_____ 8. I have been in a lot of shouting matches with other people.
_____ 9. When I get frustrated, I often "let off steam" by blowing my top.
_____ 10. Love is overrated.

RS denotes reverse score items

Levenson, Michael R., Kent A. Kiehl, and Cory M. Fitzpatrick. "Assessing psychopathic attributes in a noninstitutionalized population." *Journal of personality and social psychology* 68.1 (1995): 151.

Appendix D

Autism Spectrum Quotient

Below are a list of statements. Please read each statement very carefully and rate how strongly you agree or disagree with it by marking your answer. DO NOT LEAVE ANY STATEMENT OUT.	Definitely agree	Slightly agree	Slightly disagree	Definitely disagree
1. I prefer to do things with others rather than on my own.				
2. I prefer to do things the same way over and over again.				
3. If I try to imagine something, I find it very easy to create a picture in my mind.				
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.				
5. I often notice small sounds when others do not.				
6. I usually notice car number plates or similar strings of information.				
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.				
8. When I'm reading a story, I can easily imagine what the characters might look like.				
9. I am fascinated by dates.				
10. In a social group, I can easily keep track of several different people's conversations.				
11. I find social situations easy.				
12. I tend to notice details that others do not.				
13. I would rather go to a library than a party.				
14. I find making up stories easy.				
15. I find myself drawn more strongly to people than to things.				
16. I tend to have very strong interests which I get upset about if I can't pursue.				
17. I enjoy social chit-chat.				
18. When I talk, it isn't always easy for others to get a word in edgeways.				
19. I am fascinated by numbers.				
20. When I'm reading a story, I find it difficult to work out the characters' intentions.				
21. I don't particularly enjoy reading fiction.				

22. I find it hard to make new friends.				
23. I notice patterns in things all the time.				
24. I would rather go to the theatre than a museum.				
25. It does not upset me if my daily routine is disturbed.				
26. I frequently find that I don't know how to keep a conversation going.				
27. I find it easy to "read between the lines" when someone is talking to me.				
28. I usually concentrate more on the whole picture, rather than the small details.				
29. I am not very good at remembering phone numbers.				
30. I don't usually notice small changes in a situation, or a person's appearance.				
31. I know how to tell if someone listening to me is getting bored.				
32. I find it easy to do more than one thing at once.				
33. When I talk on the phone, I'm not sure when it's my turn to speak.				
34. I enjoy doing things spontaneously.				
35. I am often the last to understand the point of a joke.				
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.				
37. If there is an interruption, I can switch back to what I was doing very quickly.				
38. I am good at social chit-chat.				
39. People often tell me that I keep going on and on about the same thing.				
40. When I was young, I used to enjoy playing games involving pretending with other children.				
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).				
42. I find it difficult to imagine what it would be like to be someone else.				
43. I like to plan any activities I participate in carefully.				
44. I enjoy social occasions.				
45. I find it difficult to work out people's intentions.				
46. New situations make me anxious.				

47. I enjoy meeting new people.				
48. I am a good diplomat.				
49. I am not very good at remembering people's date of birth.				
50. I find it very easy to play games with children that involve pretending.				

- "Definitely agree" or "Slightly agree" responses to questions 2, 4, 5, 6, 7, 9, 12, 13, 16, 18, 19, 20, 21, 22, 23, 26, 33, 35, 39, 41, 42, 43, 45, 46 score 1 point.
- "Definitely disagree" or "Slightly disagree" responses to questions 1, 3, 8, 10, 11, 14, 15, 17, 24, 25, 27, 28, 29, 30, 31, 32, 34, 36, 37, 38, 40, 44, 47, 48, 49, 50 score 1 point.
- The five domains: social skill (items 1,11,13,15,22,36,44,45, 47,48); attention switching (items 2,4,10,16,25,32,34, 37,43,46); attention to detail (items 5,6,9,12,19,23,28, 29,30,49); communication (items 7,17,18,26,27,31,33, 35,38,39); imagination (items 3,8,14,20,21,24,40,41, 42,50).

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *Journal of autism and developmental disorders*, *31*(1), 5-17.

Appendix E

Autismus-Spektrum Quotient
(Jürgen Kremer - Universitätsklinikum Essen)

Der Fragebogen besteht aus einer Liste von Sätzen. Bitte, lesen Sie jeden Satz sehr aufmerksam durch und überlegen Sie, ob und wie stark Sie dem Satz zustimmen können. Umfahren Sie dann die entsprechende Antwort mit einem Kreis. Bitte, lassen Sie keinen Satz aus.	ich stimme eindeutig zu	ich stimme ein wenig zu	ich stimme eher nicht zu	ich stimme überhaupt nicht zu
1. Ich mache lieber Sachen mit anderen als alleine.				
2. Ich bevorzuge, Dinge immer wieder auf dieselbe Art und Weise zu machen.				
3. Wenn ich mir etwas vorzustellen versuche, fällt es mir sehr leicht, ein Bild im Kopf entstehen zu lassen.				
4. Ich verliere mich in Aufgaben oft so, dass ich alle anderen Dinge rundherum vergesse.				
5. Ich höre oft leise Geräusche, die andere nicht hören.				
6. Ich merke mir oft Autonummer oder Schilder mit ähnlichen Beschriftungen.				
7. Andere Menschen sagen mir häufig, dass das, was ich gesagt habe, unhöflich war, obwohl ich denke, es sei höflich gewesen.				
8. Wenn ich eine Geschichte lese, kann ich mir leicht vorstellen, wie die Figuren in der Geschichte aussehen könnten.				
9. Datumsangaben faszinieren mich.				
10. Ich kann in einer Gruppe leicht den Gesprächen von mehreren unterschiedlichen Menschen folgen.				
11. In sozialen Situationen fühle ich mich wohl.				
12. Ich bemerke öfters Details, die andere Menschen nicht mitbekommen.				
13. Ich würde lieber in die Bibliothek als zu einer Party gehen.				
14. Mir fällt es leicht, Geschichten zu erfinden.				
15. Ich fühle mich eher von Menschen als von Gegenständen angezogen.				
16. Bestimmten Interessen gehe ich sehr gezielt nach und ärgere mich, wenn ich daran gehindert werde.				
17. Ich genieße Gespräche über Land und Leute				
18. Wenn ich mich unterhalte, können mich andere kaum unterbrechen.				

19. Zahlen faszinieren mich.				
20. Wenn ich eine Geschichte lese, fällt es mir schwer, mir die Absichten der Figuren auszumalen.				
21. Mir macht es keinen besonderen Spaß, Romane zu lesen.				
22. Mir fällt es schwer, neue Freunde kennen zu lernen.				
23. Mir fallen ständig Muster an Gegenständen auf.				
24. Ich würde eher ins Theater als in ein Museum gehen.				
25. Es macht mir nichts aus, wenn sich mein Tagesablauf verändert.				
26. Ich stelle oft fest, dass ich nicht weiß, wie ich ein Gespräch aufrechterhalten kann.				
27. Es fällt mir leicht, Zwischentöne zu verstehen, wenn sich jemand mit mir unterhält.				
28. Normalerweise konzentriere ich mehr auf das Gesamtbild als auf Details				
29. Ich kann mir Telefonnummern schlecht merken.				
30. Kleine Veränderungen einer bestimmten Situation oder an Personen fallen mir kaum auf.				
31. Wenn ich mit jemandem rede, merke ich, wenn es ihm/ihr langweilig wird.				
32. Mir fällt es leicht, mehrere Sachen gleichzeitig zu machen.				
33. Wenn ich mit jemandem spreche, weiß ich nicht genau, wann ich an der Reihe bin.				
34. Ich bin gerne spontan.				
35. Ich verstehe Pointen bei einem Witz oft als allerletzte/r.				
36. Mir fällt es leicht herauszufinden, was jemand denkt, wenn ich nur auf ihr/sein Gesicht schaue.				
37. Wenn ich unterbrochen worden bin, kann ich schnell mit meiner vorherigen Tätigkeit weitermachen.				
38. Mir macht es Spaß, mich mit Leuten zu unterhalten.				
39. Oft wird mir erzählt, dass ich ständig über dieselben Dinge spreche.				
40. Als ich klein war, habe ich gerne Rollenspiele mit anderen Kindern gespielt.				
41. Ich sammele gerne Informationen zu Kategorien einer Sache, z.B. zu Autotypen, Vogelarten, Zugtypen oder Pflanzenarten.				
42. Mir fällt es schwer, mich in andere Personen hineinzuversetzen.				

43. Ich plane Sachen, die ich unternehmen will, immer sehr gründlich.				
44. Ich genieße soziale Ereignisse.				
45. Mir fällt es schwer zu erkennen, was andere Menschen vorhaben.				
46. Unbekannte Situationen ängstigen mich.				
47. Ich lerne gerne neue Leute kennen.				
48. Ich bin sehr diplomatisch.				
49. Ich erinnere mich schlecht an Geburtstage.				
50. Mit fällt es leicht, Rollen- oder Phantasiespiele mit Kindern zu spielen.				