The Relationship between Autistic Tendencies, Social Anxiety and Reinforcement Learning

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Abstract

Humans learn the probabilities of socially rewarding and punishing stimuli (such as facial expressions of basic emotions) to coordinate appropriate responses to their environment, and subsequently navigate social interaction. Many cases of autistic tendencies, a neurodevelopmental condition hallmarked by deficits in social communication and reduced responsiveness to socially rewarding faces, are comorbid with social anxiety, characterised by severe distress and a tendency to avoid socially punishing faces. Both conditions affect the rate of social reinforcement learning patterns. Therefore, it is unclear how much autistic tendencies or co-occurring social anxiety symptoms predict aberrant learning patterns. Thus, we aimed to explore whether social anxiety mediates or moderates this relationship. Participants were recruited from the general population and completed a learning task that assessed their selection of which facial expressions (happy and angry) were followed by a positive or negative outcome. Additionally, questionnaires were administered to measure autistic tendencies and social anxiety symptoms. Regression analyses demonstrated no significant relationships between the predictors and social reward learning (approaching happy faces). However, consistent with the literature, an interaction between autistic tendencies and social anxiety predicted aberrant social punishment learning (avoiding angry faces). Therefore, the level of social anxiety is an important moderator in understanding the broad expression of social deficit symptoms in comorbid diagnoses. Although further research is needed for reward learning, our results implicate that certain individual differences are associated with increased social avoidance tendencies, therapists could tailor treating this bias based on the severity of autistic tendencies and social anxiety in an individual.

Declaration

This thesis contains no material which has been accepted for the award of any other degree of diploma in any University, and, to the best of my knowledge, this thesis contains no material previously published except where due reference is made. I give permission for the digital version of this thesis to be made available on the web, via the University of Adelaide's digital thesis repository, the Library Search and through web search engines, unless permission has been granted by the School to restrict access for a period of time

Contribution Statement

In writing this thesis, my supervisor and I collaborated to develop the research aims of interest and design the appropriate methodology. I conducted the literature search, completed the ethics application, information sheet, and was responsible for most of the participant recruitment as I registered the project on the Research Participation System and credited participants. My supervisor programmed the learning task to be used for the study and we collaborated on writing the instructions for the task. I selected the faces to be incorporated in the learning task from the Warsaw face image database. I wrote up the participant instructions required for downloading and running the task. My supervisor helped me code the R script required for the statistical analyses, but I ran the script and interpreted the analysis.

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Introduction

1.1 Preamble

Social interaction shapes the human mind as our daily environments are typically affected by other humans. Communication between humans is present in various forms such as cooperation, imitation, and competition, and it can provide the basis for learning, motivation, and interpersonal relationships (Hari & Kujala, 2009). Thus, the world is filled with social stimuli that contribute to the development and health of an individual. Facial expressions of the basic emotions (e.g. happiness, sadness, fear, anger) can act as social cues that direct learning associated with predicting other's behaviour and optimising one's own behaviour (Jones et al., 2011). Positive social cues such as smiling can be fundamentally rewarding while negative social cues such as frowning can be fundamentally punishing for humans (Jones et al., 2011). This suggests that social reinforcement learning is an essential process that underpins how humans navigate social interactions by learning probabilities of rewards and punishments in sometimes volatile social environments (Beltzer, Adams, Beling & Teachman, 2019).

Difficulties with social learning and adaptation occur in a range of neurodevelopmental disorders, such as Autism Spectrum Disorder (ASD). ASD is a multifaceted condition with a range of expressions and causes but typically characterised by impairments in social interactions, repetitive behaviours, and restricted interests (Faras, Al Ateeqi & Tidmarsh, 2010). Studies have shown atypical processing of positive and negative social stimuli in individuals with autistic tendencies and thus, response patterns towards social rewards and punishments tend to be different from typically developing individuals (Schuetze, Rohr, Dewey, McCrimmon & Bray,

2017). Such aberrant social learning has also been associated with social anxiety disorder (SAD), which is frequently diagnosed alongside autistic tendencies (Maddox & White, 2015). Similar to individuals with autistic tendencies, socially anxious individuals have been shown to exhibit reduced preference for positive social stimuli and an increased vigilance and avoidance of negative social stimuli (Schulze, Renneberg & Lobmaier, 2013). This comorbidity complicates diagnosis of autism and it is unknown whether both autistic tendencies and social anxiety individually contribute to these difficulties in social interactions.

Therefore, the current study explores the relationship between autistic tendencies and reinforcement learning and whether social anxiety mediates or moderates this relationship. Given that autistic tendencies and social anxiety can be observed in the general population, this study will investigate these relationships in a sample of individuals recruited from the general population. The following sections will describe autistic tendencies and social anxiety symptoms, including their epidemiology, causes and neurobiological mechanisms. The evidence linking autistic tendencies and social anxiety symptoms with aberrant social reinforcement learning patterns will also be reviewed.

1.2 Understanding Autism Spectrum Disorder

1.2.1 Prevalence and Impact

Autism has become increasingly prevalent over time, with 1 in 160 children estimated to have ASD worldwide (World Health Organisation, 2019). In particular, ASD diagnoses in Australia, have shown an general increase of 42.1% from 2012 to 2015¸ with children aged 5-14 being the most commonly diagnosed (Australian Bureau of Statistics, 2017). Additionally, the Australian Bureau Statistics (ABS) (2019) state there were 205, 200 Australians with autism in 2018, which constitute a 25.1% increase from 2015. This surge in the epidemiology of ASD could indicate that awareness and identification of autistic tendencies is improving in Australia. This is crucial when considering the significant impacts of this diagnosis for both the individual and their caregivers and families. Individuals with autistic tendencies have their well-being and quality of life affected in various ways, such as through reduced opportunities for social relationships, poor emotion regulation, and decreased independence and education (Tavernor, Barron, Rodgers & McConachie, 2013). Additionally, a diagnosis of ASD in Australia results in significant financial lifetime burdens estimated at $4.5-7.2 billion nation-wide, mostly due to increased use of health services for children and adults with ASD and their caregivers (Horlin et al., 2014). Thus, the rise in ASD diagnoses highlights an increased need for research on understanding autistic tendencies and to aid professional training tailored towards improving the quality of life for these individuals.

1.2.2 Symptoms and Behavioural Findings

A diagnosis of autism is based on patterns of behaviour and is typically detectable before 3 years of age, when the earliest signs of low responsiveness to social stimuli occur (Baron-Cohen et al., 1996). Since autism refers to a spectrum of developmental disorders, autistic tendencies have a diverse presentation throughout life, from childhood into adulthood, and can differ substantially between individuals (Faras et al., 2010). The Diagnostic and Statistical Manual of Mental Disorders (DSM-5) outlines various diagnostic criteria in terms of symptoms and specificity of severity that capture this range. The first category describes difficulties in social interaction such as social reciprocity (e.g. back and forth conversation) and difficulties in adjusting behaviour according to different social contexts (American Psychiatric Association, 2013).

Autistic tendencies are also often associated with a limited use and understanding of non-verbal communication such as eye gaze and facial expression (APA, 2013). These symptoms are related to reward salience, which is the positive importance of social stimuli, that directs motivation and pleasure and is typically fundamental for social development (Chevallier, Kohls, Troiani, Brodkin & Schultz, 2012). Notably, studies have shown a preference for geometric patterns and shapes and thus, a reduced reward salience and responsiveness to faces, in autistic children compared to typically developing children (Kleinhans et al., 2010; Gale, Eikseth & Klintwall., 2019). Furthermore, eye tracking data found that individuals with autistic tendencies avoid looking at faces and thus, have less experience in reading faces than typically developing individuals (Dawson, Webb & McPartland, 2005; Speer, Cook, McMahon & Clark, 2007). These patterns of behaviour suggest that individuals with autistic tendencies have less interest in such

stimuli since they may not be as rewarding for them (Kohls et al., 2012). Thus, the lack of social coordination, social perception, reward salience, and anticipation of others' responses can make it difficult for individuals with autistic tendencies to develop and maintain social relationships (APA, 2013; Sedgewick, Leppanen & Tchanturia, 2019).

The second category used for diagnosis includes the presence of repetitive motor behaviours, use of objects and speech (e.g. rocking and rigid, repetitive language) (APA, 2013). Additionally, people with autistic tendencies often show restricted interests in specific topics or activities with an intense focus (e.g. a particular movie) and a persisting need for sameness and routines in daily life, that if disrupted can cause anxiousness and frustration (APA, 2013).

1.2.3 Neurobiological Underpinnings Related to ASD and Reinforcement Learning

The neurobiology underlying ASD is a core research area that aims to further our understanding of this condition's development. The literature has found mixed evidence of brain networks and reward pathways associated with social behaviour that are altered in people with autistic tendencies, and could explain the social interaction abnormalities observed in these individuals (Jones et al, 2011; Schuetze et al, 2017).

This is a complex relationship as a bidirectional connection between brain regions and atypical social behaviour has been found (Petinou & Minaidou, 2017). That is, the capability to demonstrate typical social behaviour impacts neurobiological events and such events within brain regions ascertain a person's ability to understand social communication, such as appropriate eye contact and facial expressions (Petinou & Miniadou, 2017; Bal et al., 2010). The mesolimbic dopaminergic pathway is a system that controls sensitivity to reward and the ability

to anticipate future rewards, including positive social stimuli and thus, is involved in social motivation and learning (Supekar et al., 2018). Research on children with autistic tendencies, found reduced structural and functional connectivity in this pathway when children viewed faces, and this was associated with the severity of their social interaction impairments (Supekar et al., 2018).

However, there is conflicting evidence regarding abnormalities within the amygdala, a limbic structure which has been typically linked to social behaviour, emotion, and reward learning (Figure 1) (Kleberg et al., 2017). Structural, and functional abnormalities within the amygdala of people with autistic tendencies have been correlated with atypical emotional processing of facial expressions (Kleinhans et al., 2010). In particular, both increased and decreased amygdala activation has been reported in ASD individuals when viewing emotional facial expressions (Monk et al., 2010; Tottenham et al., 2014). Additionally, other studies investigating the anticipation of social rewards such as smiling and praise, report that individuals with autistic tendencies consistently exhibited decreased amygdala activation compared to typically developing individuals (Cox et al., 2015; Herrington, Miller, Pandey & Schultz, 2016). Thus, atypical activation of this structure could be associated with a lack of motivation and therefore, reduced responsiveness to positive social stimuli, which leads to difficulties in reward learning Schuetze et al, 2017). However, some studies reported no aberrant neural responses in the amygdala during reward processing in ASD individuals, potentially due to the presence of glutamatergic rather than dopaminergic projections (Supekar et al., 2018; Bottini, 2018). Researchers reasoned that glutamatergic projections are more present from the basolateral nucleus of the amygdala to the nucleus accumbens and thus, less connected to social reward

processing than other pathways in the reward system (Supekar et al., 2018). Thus, the literature on the neurobiology of ASD is mixed, although some evidence for abnormalities in learning and motivation pathways in individuals with ASD have been reported.

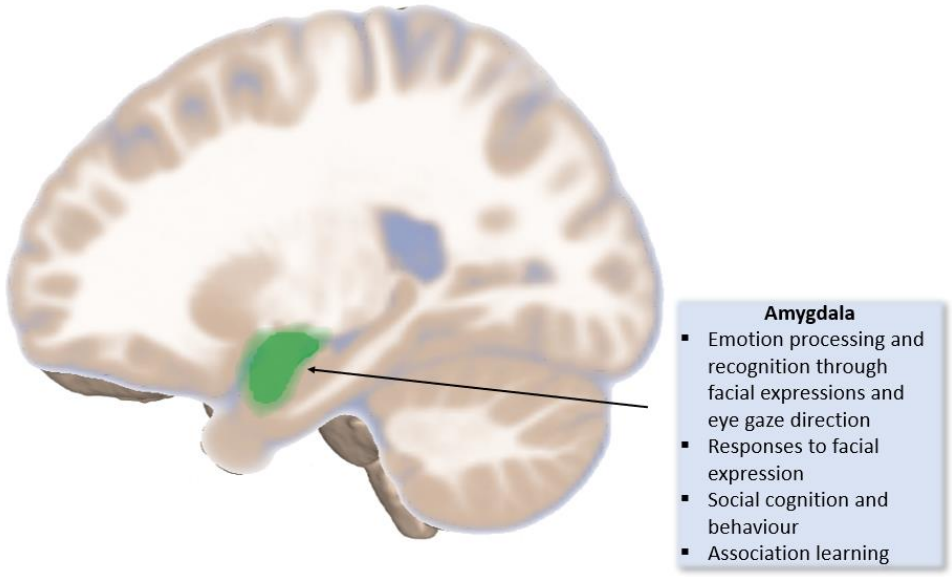

Figure 1- Role of the Amygdala in social behaviour (Barak & Feng, 2016; Sabinasz, 2020)

1.3 Emotional Face Processing and Reinforcement Learning

It is crucial to highlight the importance of facial expressions as these social stimuli typically convey others' emotions (Olszanowski et al., 2015). Understanding emotions is an important aspect in social interactions as it allows humans to interpret intentions and coordinate the appropriate social responses (Bal et al., 2010). Social reinforcement learning involves learning that certain facial expression cues are typically followed by a particular outcome, whether rewarding or punishing, so that the anticipation of these outcomes following such cues

increases over time (Jones et al., 2011). The literature consistently demonstrates that individuals with autistic tendencies struggle to adapt their responses to facial expressions (e.g. approaching smiling faces), which gives rise to the atypical symptoms previously mentioned. A prevalent basis for this observation is the social motivation theory, which proposes that individuals with autistic tendencies are less motivated to interact and adapt to social stimuli such as faces and eye gaze, due to atypical reward processing (Schuetze et al., 2017). This leads to consistently misinterpreting social and emotional cues which can influence the development of social communication. For instance, if an individual experiences social interaction as less rewarding during childhood, they will be less likely to attend to information concerning others and thus, this will impair social behaviour and development of brain circuitry for processing social information (Cox et al., 2015).

This pattern of social motivation and reinforcement learning has been examined in social anxiety disorder, in which higher levels of social anxiety are correlated with low social motivation and more atypical social learning (Spain, Sin, Linder, McMahon & Happe, 2018). For example, greater avoidance of social cues due to social anxiety limits an individual's opportunities to develop typical social competencies and leaves the individual susceptible to negative reactions from the social environment (Beltzer et al., 2019). This pattern is similar to that observed in individuals with autistic tendencies, and thus, investigating the effect of social anxiety could shed light on the mechanisms underlying aberrant social behaviour in those with autistic tendencies.

1.4 Understanding Social Anxiety Disorder and its Link to Autistic Tendencies

1.4.1 Prevalence, Comorbidity and Impact

Social anxiety disorder (SAD) is one of the most prevalent psychiatric illnesses across the world. In Australia, 8.4% individuals had met the criteria for SAD at some point during their life which constitutes a total of 1,345,260 Australians (Crome et al., 2014). Additionally, several studies have shown that SAD is highly comorbid with a range of developmental disorders, such as autism spectrum disorder, with around 17-30% of ASD cases diagnosed with social anxiety symptoms (Zabowski & Storch, 2018). This comorbidity can amplify difficulties associated with both conditions and therefore, presents serious challenges in terms of quality of life for individuals and their caregivers and families. This involves an increased and persistent strain on social relationships, daily social routines, academic and professional areas, similar to ASD alone (Crome et al., 2015). Furthermore, a comorbid diagnosis of SAD and autistic tendencies incurs heavy financial lifetime burdens associated with the management of symptoms for individuals and their families (Zabowski & Storch, 2018). Determining an ASD diagnosis is further complicated by the presence of social anxiety symptoms as the literature has shown a moderate overlap in symptoms and neurological underpinnings between the two conditions (Zabowski & Storch, 2018). Thus, the comorbidity of social anxiety symptoms with autistic tendencies necessitates further research to understand the potential interactions between the two conditions, which would potentially inform management strategies that enhance the wellbeing of these individuals.

1.4.2. Symptoms and Behavioural Findings

Social anxiety symptoms are typically characterised by excessive distress toward and persistent avoidance of social cues and performance situations (APA, 2013). The DSM-5 outlines diagnostic criteria in terms of severity and a duration of at least 6 months (APA, 2013). Individuals diagnosed with SAD typically experience anxiety when faced with unfamiliar people, or scrutiny that leads to feelings of embarrassment, humiliation, and fear of rejection (APA, 2013). Socially anxious individuals often anticipate socially punishing situations (e.g. teasing or bullying) and behave in ways that try to avoid these punishing outcomes or otherwise experience them with increased distress (Spain et al., 2018). This is thought to be due to overestimation of threat in social situations and is reinforced by negative beliefs about oneself, others, or the world (Spain et al. 2018). Before and during social situations, individuals also experience physical symptoms, which includes flushes, chills, trembling, and increased heart rate (Scaini, Belotti & Ogliari, 2014).

Socially anxious individuals have also shown similar behaviour patterns to individuals with autistic tendencies, in studies that investigated eye gaze to different facial expressions. Studies have shown a reduced approach to positive faces and a hypervigilance followed by avoidance of negative faces in socially anxious individuals (Roelefs et al., 2010; Schulze et al., 2013). Additionally, eye tracking data demonstrated that socially anxious individuals tend to avoid direct eye contact, especially with threatening facial expressions compared to healthy individuals (Schulze et al., 2013). The presence of comorbidity of psychiatric diagnoses suggests that the development of social anxiety symptoms could be exacerbated by autistic tendencies. Various studies indicate that an interaction between autistic tendencies and social anxiety may explain the

broad expression of comorbid diagnoses (Wood & Gadow, 2010; Zabowski & Storch, 2018). Kerns et al. (2014) reports that individuals with autistic tendencies have presented social anxiety symptoms akin to those of typically developing individuals and hence, are consistent with DSM criteria, or atypical symptoms that are not in accordance with traditional DSM criteria. For example, Kerns et al. (2014) found that some children with autistic tendencies had typical social anxiety symptoms, that contrast typical ASD diagnostic criteria, these included desires for social interaction, negative automatic thoughts and severe distress of social ridicule. Conversely, other children presented atypical social anxiety symptoms, these included a lack of fear of negative evaluation and social rejection yet still presenting consistent frightfulness and discomfort of social situations (Kerns et al., 2014).

1.4.3 Causes and Evidence Linked to Autistic Tendencies

Social anxiety can be traced to an array of environmental and genetic factors. The literature notes conditioning from traumatic experiences and family factors including parenting style during an individual's childhood and adolescence that can reinforce anxiety and avoidance behaviours over time (Scaini et al., 2014). Evidence for a genetic basis is particularly strong as well as a genetic-environmental interaction, with susceptibility to environmental stressors increasing first-degree relatives (i.e. parents, siblings) have SAD, compared to relatives of healthy individuals (Scaini et al., 2014). Interestingly, considerable literature has noted a genetic overlap with other psychiatric conditions, including ASD (Amaral, 2017). Twin studies have shown that for children with autistic tendencies, their siblings with a broader autism phenotype and siblings non-diagnosed with autistic tendencies had increased social anxiety compared to

healthy controls (Hallett et al., 2013). Thus, while it is suggested that the causes of ASD occur within prenatal events, these links suggest an important heritable factor between autistic tendencies and social anxiety symptoms.

1.4.4 Neurobiological Underpinnings Related to Social Anxiety and Autistic Tendencies

Investigating the neurobiology of social anxiety can further our knowledge of the influence of reinforcement learning abnormalities on the development of autistic tendencies.

Multiple studies have demonstrated atypical functioning and structure of the amygdala leading to individual differences in people with social anxiety symptoms. The amygdala is directly relevant to social anxiety symptoms as it detects motivationally relevant social stimuli (e.g. facial expressions) processing of threatful social cues and initiates behavioural responses (Klumpp & Fitzgerald, 2018). For instance, increased activation of the amygdala in response to negative facial expressions (e.g. angry, fearful) has been widely reported in the literature, along with increased activation in response to such social stimuli in socially anxious individuals (Cremers & Roelofs, 2016). Similarly, a few studies have also demonstrated increased amygdala activation in ASD individuals when presented with angry faces and low intensity fearful faces (Tottenham et al., 2014; Lassalle et al., 2017). Therefore, these findings on individuals with autistic tendencies may be associated with the literature on atypical activation of this structure in socially anxious individuals. Although, it is important to recount the mixed evidence on amygdala activation in social behaviour for individuals with autistic tendencies. That is, the prevalent amygdala hypoactivation previously found in individuals with autistic tendencies is contrasted with the hyperactivation found in socially anxious individuals when viewing

emotional facial expressions (Herrington et al., 2016). This divergent pattern of amygdala activation during face tasks between the two conditions suggests that the amygdala has a complex role in negative affect processing and social learning (Herrington et al., 2016). This begs the question of how this brain structure's activity is modulated by facial expressions in individuals presenting both social anxiety symptoms and autistic tendencies. Interestingly, recent studies have discovered that the amygdala activity of individuals with autistic tendencies and co-occurring social anxiety symptoms demonstrated hyperactivation in response to negative facial expressions (Kleinhans et al., 2010; Herrington et al., 2017). This research suggests that the neural mechanisms that give rise to autistic tendencies and social anxiety symptoms could interact and that co-occurring social anxiety may have an influence on the development and presentation of comorbid diagnoses.

1.5 Reinforcement Learning in individuals with Autistic Tendencies and Co-occurring Social Anxiety- Highlighting the Gaps

1.5.1 Social Reward Learning

The literature reports similar learning patterns in individuals with autistic tendencies and social anxiety, which may explain the overlap of symptoms in terms of social communication deficits (Kerns et al., 2014). In particular, reduced responsiveness to positive facial expressions (e.g. happiness) has been reported in individuals with autistic tendencies, social anxiety, and those who suffer from both (Roelofs et al., 2010; Schulze et al., 2013). In terms of comorbid diagnoses, this may manifest as reduced attention to smiling faces, diminishing the anticipation

of rewarding outcomes and subsequently leading to socially inappropriate responses (e.g. looking away or neutral facial reactions) during social interaction (Rinck et al., 2013; Sato et al., 2019; Beltzer et al., 2019)

However, there is clearly a disparate focus of research between both conditions, with most literature focusing on socially rewarding stimuli in autism and socially punishing stimuli in social anxiety.

1.5.2 Social Punishment Learning

Social anxiety is widely characterised by increased punishment learning of negative social stimuli, such as facial expressions of anger and disgust (Monk & Pine, 2004; Abraham & Herman, 2015; Beltzer et al., 2019). This learning may manifest as a notable attention to scowling faces, that promotes hypervigilance of punishing outcomes (e.g. rejection) and triggers avoidance of such social cues (Abraham & Herman, 2015). Over time, this learning bias to negative facial expressions strengthens and consequently reduces social engagement and interaction (Beltzer et al., 2019).

In contrast, while there have been a few studies on neural responses to negative facial expressions in individuals with autistic tendencies, there is still a considerable gap in the literature on these individuals' learned responses to negative social stimuli.

1.5.3 Reversal Learning

Furthermore, the social environment can be volatile, as people and situations progressively change, calling attention to the complexity of adapting appropriate responses during social interaction (Beltzer et al., 2019). Appropriate social behaviour requires individuals to dynamically monitor these changes and update their knowledge of the probabilities of social reward and punishment (Beltzer et al., 2019). Reversal learning is a form of reinforcement learning, in which individuals adapt appropriate responses to changing learning contingencies, in order to maximise particular outcomes (Murray et al., 2008). Studies have shown that ASD individuals are typically slower to adapt appropriate responses when learning contingencies are changed, suggesting low behavioural flexibility (Schuetze et al., 2017). Additionally, Beltzer, Adams, Beling & Teachman (2019) found that socially anxious individuals were less likely to update expectations of social reward in response to stimuli that were previously punishing, suggesting slower learning rates in updating probabilities of reward and punishment and thus adjusting appropriate responses (Beltzer et al., 2019). However, there seems to be a gap in this learning area when investigating the influence of positive and negative facial expressions with autistic tendencies and social anxiety.

1.5.4 Social Anxiety Mediation or Moderation

In light of all this, there are questions on how autistic tendencies and social anxiety symptoms determine aberrant learning patterns, such as reduced reward learning and increased punishment learning. Some researchers have found that the co-occurrence of social anxiety symptoms reinforces punishment learning in individuals with autistic tendencies, that is

individuals with potential comorbid diagnoses tend to avoid negative social stimuli and are less responsive to positive social stimuli (Spain, Yarar & Happe, 2020). It is not well known whether social anxiety mediates this learning to facial expressions in individuals with autistic tendencies but given the research, there could be an influence of this condition. Furthermore, research suggests that the frequent social difficulties of individuals with higher functioning autism, could result in higher levels of social anxiety (Robertson et al., 2018; Spain et al., 2020). Given that these individuals may have a greater awareness of their social difficulties and social cues from the surrounding environment, this contributes to fears of negative social evaluation (Muller, Schuler & Yates, 2008; Robertson et al., 2018; Spain et al., 2020). The effects of social anxiety in turn could orient individuals' attention to negative social stimuli (e.g. angry faces) and manifests as a learning bias to avoid this type of stimulus (Bellini, 2006; Maddox & White, 2015; Spain et al., 2020). This points to an interaction, as the level of autistic tendencies and social anxiety influence each other and consequently, over time, responses to social stimuli such as facial expressions.

1.6 Current Study

Given the diverse literature it is unclear how much autistic tendencies uniquely contribute to these reinforcement learning patterns, whether it is more influenced by social anxiety or a combination of both. In addition, much of the literature has investigated either autistic tendencies or social anxiety, and learning about positive or negative social stimuli, respectively. Furthermore, despite evidence of slower learning to adapt appropriate responses in the two conditions (Schuetze et al., 2017: Beltzer et al., 2019), there is a gap on changing learning

contingencies with social stimuli such as facial expressions. In particular, learning to adapt newly required responses (i.e. approaching a previously avoided face).

It could be speculated that higher levels of social anxiety may enhance aberrant reinforcement learning, regardless of the level of autistic tendencies (Kleberg et al., 2017). Thus, the present study aims to explore whether social anxiety symptoms mediates the relationship between autistic tendencies and reinforcement learning (Table 1). Based on the aforementioned literature, we would expect that social anxiety would be associated with increased punishment learning (i.e. avoiding angry faces) and reduced reward learning (i.e. approaching happy faces). However, the mixed evidence of overlapping behaviours and learning patterns in the comorbidity of autism and social anxiety suggests there may be an interaction at play between the conditions (Zabowski & Storch, 2018). Thus, given the association between social anxiety and autistic tendencies discussed above, we may expect a similar association between autistic tendencies and social reinforcement learning (Schuetze et al., 2017; Spain et al., 2020). Therefore, another aim of this study is to explore whether the relationship between autistic tendencies and reinforcement learning is moderated by social anxiety (Table 2).

By investigating the effect of autistic tendencies and social anxiety on social reward learning (i.e. approaching positive social stimuli) and social punishment learning (i.e. avoiding negative social stimuli), further insight can be achieved into the subsequent diversity of reinforcement learning patterns.

Table 1

Mediation effect of social anxiety on autistic tendencies and reinforcement learning

	Lower Autism	Higher Autism
Lower Social Anxiety	Normal punishment learning Normal reward learning	Normal punishment learning Normal reward learning
Higher Social Anxiety	Increased punishment learning Reduced reward learning	Increased punishment learning Reduced reward learning

Table 2

Moderation effect of social anxiety on autistic tendencies and reinforcement learning

	Lower Autism	Higher Autism
Lower Social Anxiety	Weak punishment learning Increased reward learning	Moderate punishment learning Moderate reward learning
Higher Social Anxiety	Moderate punishment learning Moderate reward learning	Increased punishment learning Reduced reward learning

Method

2.1 Participants

A power analysis was conducted using G*Power (Faul, Erdfelder, Lang & Buchner, 39). For a multiple linear regression analysis including up to 5 predictors (autistic tendencies, social anxiety, an interaction term and the potentially confounding variables of age and gender) a sample size of 50-60 was required for the current study based on a power of .80 to detect a small effect size of .15 at an alpha level of .05. Members from the University of Adelaide, Flinders University and the general population were recruited via the research participation system, email, social media posts (i.e. Facebook) and snowball sampling. A final sample of 55 participants was collected (42 females, 13 males), with 44 first year psychology students from the University of Adelaide and 11 members from the general population. Participants ages ranged between 18 and 52 years (M = 25, SD = 9.32) and years of education ranged from 14 to 24 years (M = 13.38 years, SD = 2.41). Participants were only included if they were aged 18 years and over, proficient in English, had normal or corrected-to normal vision, had no history of a neurological condition (e.g. stroke, multiple sclerosis), did not have a drug or alcohol dependency, were not smoking more than 5 cigarettes per day and/or used medication that affects neurological function (e.g. antidepressants, sedatives, antipsychotics).

2.2 Measures

Social Reinforcement Learning Task

We used a computerized learning task that assessed how individuals learned to select or avoid positive and negative social stimuli. Participants were presented with pairs of images and used feedback to determine which image in each pair was most likely followed by positive or negative feedback. From this feedback, people learned by trial and error which image to select and avoid in each pair. (see appendix A for learning task instructions).

The stimuli comprised twelve faces with different expressions of happiness (rewarding), anger (punishing) and expressions classified as neutral (Figure 2), as well as non-social stimuli of abstract symbols; Figure 3). The face images were retrieved from the Warsaw set of emotional facial expressions database (Olszanowski et al., 2015).

There were five blocks of trials. The first acquisition block had 8 trials for each trial type shown in Table 3 (96 trials in total). This block assessed the ability to select or avoid happy and angry faces. For example, trial types 1 and 7 in Table 3 involved selecting a positive social stimulus (i.e. happy face) rather than a shape. The following blocks assessed reversal learning, the capability of adapting responses to changing learning contingencies (Murray et al., 2008). These blocks were shorter with 6 trials for each trial type (74 in total). In each reversal block, the feedback was reversed on half of the trial types. For example, trial type 1 in block 2 involved adapting to avoid a previously chosen stimulus (i.e. happy face) and choosing the shape instead (Table 3).

Each stimulus was presented an equal number of times on the left and right of the screen, so participants had to use the identity of the stimuli to make correct choices rather than their location. To encourage participants to make speeded responses, up to 4 seconds was given during each trial to select an option and following a response, participants were informed if their selection was correct or incorrect or if it was too slow (Figure 4). Learning performance was measured as the proportion of choices that were correct for each trial type.

Therefore, the outcome variable to be investigated is learning to approach positive social stimuli (i.e. happy faces) and learning to avoid negative social stimuli (i.e. angry faces). These were computed as a bias to learn faster to select happy faces rather than avoid them, and the reverse for angry faces, that is learning faster to avoid them than to select them.

These are calculated as the following:

Happy approach score = proportion of correct selecting happy faces – proportion of correct avoiding happy faces.

Angry avoid score = proportion of correct avoiding angry faces – proportion of correct selecting angry faces.

These scores were computed for block 1 and for the last two thirds of the reversal blocks.

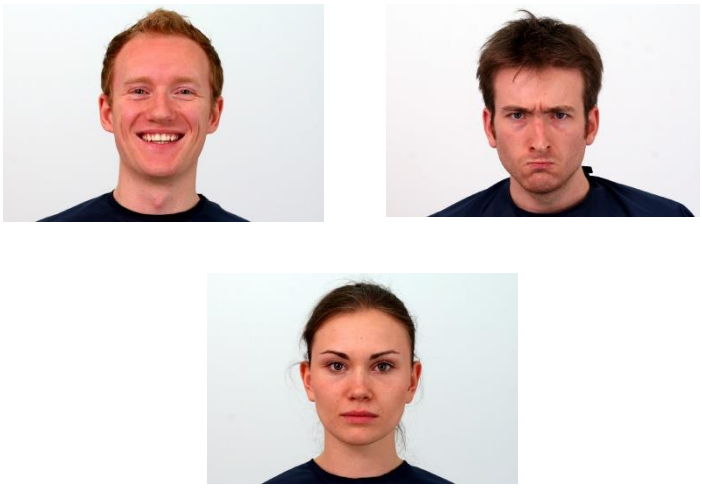

Figure 2- Examples of social stimuli (happy, angry, and neutral)

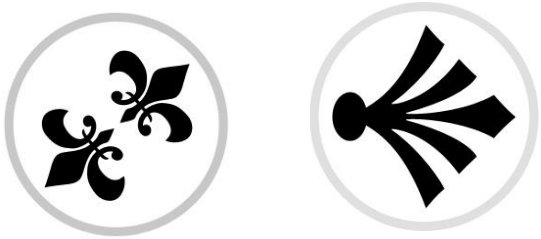

Figure 3- Examples of Non-social stimuli

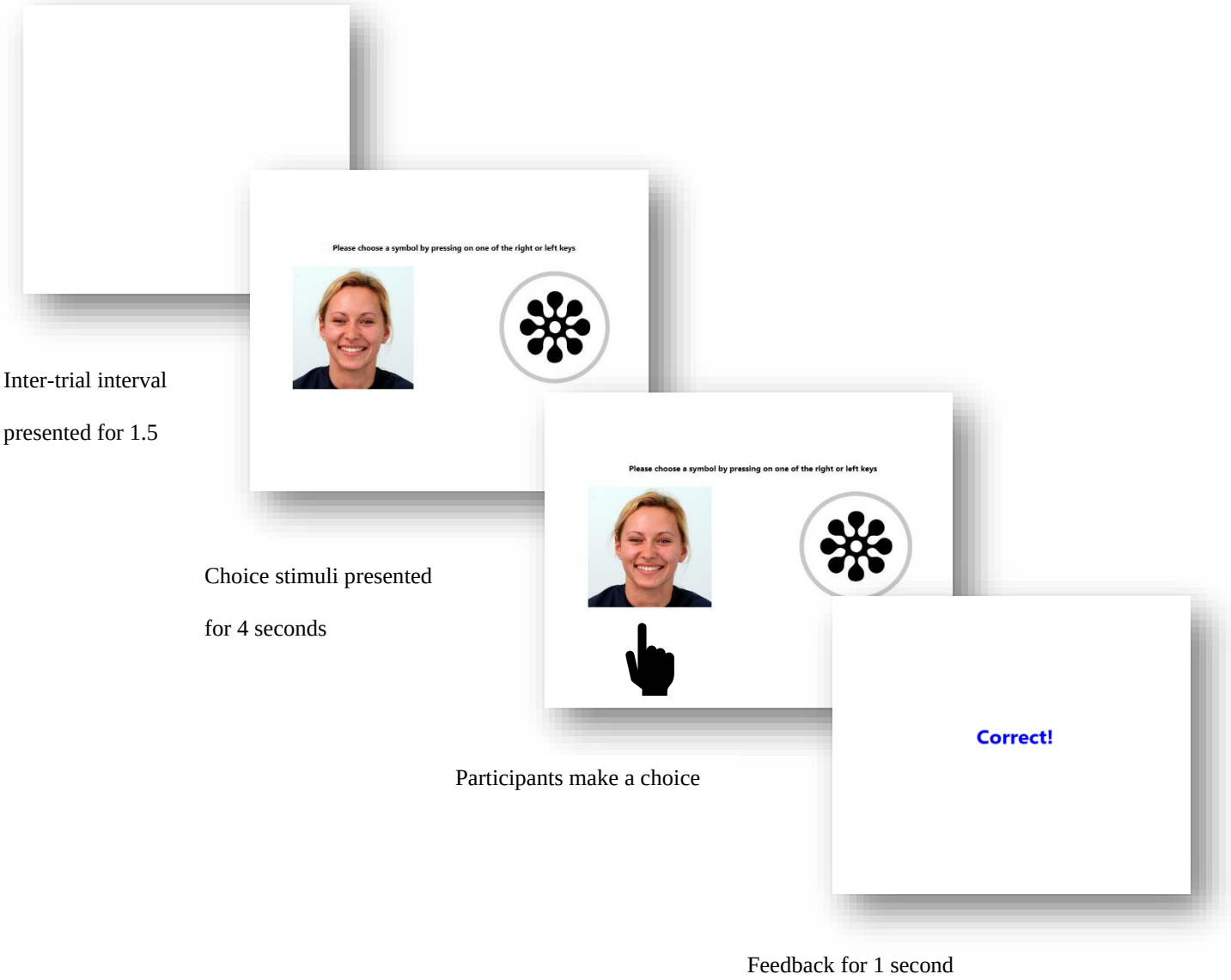

Figure 4- Example of a correct choice trial procedure

Table 3

Design of the learning task

Block number	**Trial type**	**Correct choice**	**Incorrect choice**	**Required response**
Block 1	Trial 1	Happy face A	Shape 1	Learn to select happy face
	Trial 2	Shape 2	Happy face B	Learn to avoid happy face
	Trial 3	Angry face C	Shape 3	Learn select angry face
	Trial 4	Shape 4	Angry face D	Learn to avoid angry face
	Trial 5	Shape 5	Shape 6	Learn to select shape 7/avoid shape 6
	Trial 6	Neutral face E	Neutral face F	Learn to select face E/ avoid face F
	Trial 7	Happy face G	Shape 7	Learn to select happy face
	Trial 8	Shape 8	Happy face H	Learn to avoid happy face
	Trial 9	Angry face I	Shape 9	Learn to select angry face
	Trial 10	Shape 10	Angry face J	Learn to avoid angry face
	Trial 11	Shape 11	Shape 12	Learn to select shape 11/avoid shape 12
	Trial 12	Neutral face K	Neutral face L	Learn to select face K/avoid face L
Block 2	*Trial 1*	*Shape 1*	*Happy face A*	Learn to avoid happy face
	Trial 2	*Happy face B*	*Shape 3*	Learn to select happy face
	Trial 3	*Shape 3*	*Angry face C*	Learn to avoid angry face
	Trial 4	*Angry face D*	*Shape 4*	Learn to select angry face
	Trial 5	*Shape 6*	*Shape 5*	Learn to *avoid* shape 5/ *select* shape 6

	Trial 6	*Neutral face F*	*Neutral face E*	Learn to avoid face E/ select face F
	Trial 7	Happy face G	Shape 7	Learn to select happy face
	Trial 8	Shape 8	Happy face H	Learn to avoid happy face
	Trial 9	Angry face I	Shape 9	Learn to select angry face
	Trial 10	Shape 10	Angry face J	Learn to avoid angry face
	Trial 11	Shape 11	Shape 12	Learn to select shape 11/ avoid shape 12
	Trial 12	Neutral face K	Neutral face L	Learn to select face K/ avoid face L
Block 3	Trial 1	Shape 1	Happy face A	Learn to avoid happy face
	Trial 2	Happy face B	Shape 2	Learn to select happy face
	Trial 3	Shape 3	Angry Face C	Learn to avoid angry face
	Trial 4	Angry Face D	Shape 4	Learn to select angry face
	Trial 5	Shape 6	Shape 5	Learn to avoid shape 7/select shape 6
	Trial 6	Neutral Face F	Neutral face E	Learn to avoid face E/select face F
	Trial 7	*Shape 7*	*Happy face G*	*Learn to avoid happy face*
	Trial 8	*Happy Face H*	*Shape 8*	*Learn to select happy face*
	Trial 9	*Shape 9*	*Angry face I*	*Learn to avoid angry face*
	Trial 10	*Angry face J*	*Shape 10*	*Learn to select angry face*
	Trial 11	*Shape 12*	*Shape 11*	*Learn to avoid shape 11/select shape 12*
	Trial 12	*Neutral face L*	*Neutral face K*	*Learn to avoid face K/select face L*
Block 4	*Trial 1*	*Happy face A*	*Shape 1*	Learn to select happy face

	Trial 2	*Shape 2*	*Happy face B*	Learn to avoid happy face
	Trial 3	*Angry face C*	*Shape 3*	Learn to select angry face
	Trial 4	*Shape 4*	*Angry face D*	Learn to avoid angry face
	Trial 5	*Shape 5*	*Shape 6*	Learn to *select* shape 7/*avoid* shape 6
	Trial 6	*Neutral face E*	*Neutral face F*	Learn to select face E/avoid face F
	Trial 7	Shape 7	Happy face G	Learn to avoid happy face
	Trial 8	Happy face H	Shape 8	Learn to select happy face
	Trial 9	Shape 9	Angry face I	Learn to avoid angry face
	Trial 10	Angry face J	Shape 10	Learn to select angry face
	Trial 11	Shape 12	Shape 11	Learn to avoid shape 11/select shape 12
	Trial 12	Neutral face L	Neutral face K	Learn to avoid face K/select face L
Block 5	Trial 1	Happy face A	Shape 1	Learn to select happy face
	Trial 2	Shape 2	Happy face B	Learn to avoid happy face
	Trial 3	Angry face C	Shape 3	Learn to select angry face
	Trial 4	Shape 4	Angry face D	Learn to avoid angry face
	Trial 5	Shape 5	Shape 6	Learn to select shape 7/avoid shape 6
	Trial 6	Neutral face E	Neutral face F	Learn to select face E/avoid face F
	Trial 7	*Happy face G*	*Shape 7*	Learn to select happy face
	Trial 8	*Shape 8*	*Happy face H*	Learn to avoid happy face
	Trial 9	*Angry face I*	*Shape 9*	Learn to select angry face
	Trial 10	*Shape 10*	*Angry face J*	Learn to avoid angry face
	Trial 11	*Shape 11*	*Shape 12*	Learn to *select* shape

Trial 12	*Neutral face K*	*Neutral face L*	11/*avoid* shape 12 Learn to *select* face K/*avoid* face L

Note. Reversal trials are italicized

2.3 Questionnaires

The Autism Spectrum Quotient

We used the Autism Spectrum Quotient (AQ-10) to assess the degree to which adults exhibited autistic tendencies. The questionnaire was originally developed by Baron-Cohen et al. (2001) and published as a short form containing 10 items, by Allison, Auyeung and Baron-Cohen (2012). Items were worded with regards to typically developing behaviour from *'I find it easy to work out what someone is thinking or feeling just by looking at their face'* to behaviour observed on the autism spectrum such as *'I find it difficult to work out people's intentions'*. The response format was a four-point Likert scale with the following labels: 4- Definitely Agree, 3- Slightly Agree, 2- Slightly Disagree and 1- Definitely Disagree. Scoring was allocated as 1 point for Definitely or Slightly Agree on items 1, 7, 8 and 10 which comprised of an autistic trait and 1 point for Definitely or Slightly Disagree on items 2, 3, 4, 5, 6 and 9 which comprised of a typically developing trait. A score of 6 and above is indicative of further diagnostic assessment. This scale has shown high internal consistency with a Cronbach's alpha of 0.85 or above and good test-retest reliability (Allison, Auyeung & Baron-Cohen, 2012). In terms of validity, the AQ-10 has shown to discriminate between individuals diagnosed with and without a diagnosis of ASD, demonstrating discriminative validity (Allison, Auyeung & Baron-Cohen, 2012).

Additionally, exceptional predictive validity has been evidenced with a value of 0.85 (Allison, Auyeung & Baron-Cohen, 2012). This refers to the positive predictive value, which is the probability of identifying true positive cases, that is those with a positive screening result of autistic tendencies truly do have the condition (Allison, Auyeung & Baron-Cohen, 2012; Trevethan, 2017).

The Social Avoidance and Distress Scale

We used the Social Avoidance and Distress Scale (SAD), developed by Watson and Friend (1969) in which 14 items assess social avoidance and another 14 items assess social anxiety towards social cues. There are an equal number of positively and negatively worded items from '*I feel relaxed even in unfamiliar social situations*' to '*I often feel on edge when I am with a group of people*'. The original true-false response format was used, and scoring ranged from 0 (lowest avoidance and distress) to 28 (highest avoidance and distress). This scale has demonstrated high internal consistency with a biserial correlation of 0.77 and moderately good test-retest reliability of 0.68 (Watson & Friend). In terms of validity, SAD scores correlated highly with other similar measures such as social anxiety, shyness and general anxiety and thus, demonstrated good convergent validity (Watson & Friend, 1969). The SAD was also shown to correlate moderately negatively (r= -.25) with a measure of social desirability, which indicated sufficient discriminant validity (Watson & Friend, 1969).

The Sensitivity to Reward and Sensitivity to Punishment Questionnaire

We used the short-form version of the Sensitivity to Reward and Sensitivity to Punishment Scale (SPSRQ) developed by Cooper and Gomez (2008) in which 10 items assessed

responsiveness to rewards and another 10 items assessed responsiveness to punishment in specific situations. Items ranged from *'Do you often do things to be praised?'* and *'Whenever possible, do you avoid demonstrating your skills for fear of being embarrassed?'* with a yes/no response format. This measurement has demonstrated good internal consistency and test-retest reliability, with a Cronbach's alpha of 0.85 for the sensitivity to punishment (SP) subscale and a Cronbach's alpha of 0.75 for the sensitivity to reward (SR) subscale (Cooper & Gomez, 2008). Convergent validity was demonstrated as the SP scale significantly and positively correlated with other measures such as the Spielberger Trait Anxiety Inventory (STAI) and the SR scale positively and significantly correlated with the Behavioural Approach System scale (BAS) (Cooper & Gomez, 2008). Discriminant validity has been evidenced as the SP scale had low and negative correlations with the BAS scale and the SR scale had low nonsignificant correlations with the STAI (Cooper & Gomez, 2008). Concurrent validity was shown as the SP scale negatively correlated with Extraversion (r = -49) while the SR scales positively correlated with Extraversion (r = .36) (Cooper & Gomez, 2008). Given the emphasis on social situations, we expected the SP scale to deliver another measure of social anxiety.

2.4 Procedure

Participants read a study information sheet and were asked to provide informed consent prior to participating in the study. Before commencing the experiment, participants completed demographic information including gender, age, and number of years of education. There were two sections of the study to be completed, the first part was an experimental learning program that tested social reinforcement learning and the second part was 3 questionnaires on autistic tendencies (AQ-10) and social anxiety (SAD and SPSR). The experimental learning program

was downloaded and conducted on the participants personal computers. Participants who completed the experiment uploaded or emailed a de-identified data file generated by the experimental program. The study received approval from the Human Research Ethics Subcommittee, Code Number 20/43.

Results

3.1 Descriptive Statistics

Table 4 displays descriptive statistics, for the demographics, questionnaires and learning measures.

Table 4

Descriptive statistics for demographics, scales and learning measures

	Mean	**Range**	**Standard Deviation**
Demographics			
Age	25	18-52	9.32
Education (years)	13.38	10-24	2.41
Scales			
AQ-10	3.15	0-7	1.84
SAD	10.13	1-27	7.45
SPSRQ	9.8	2-17	3.91
SR	4.69	1-10	2.40
SP	5.11	0-10	2.79

Learning measures			
Acquisition			
Select happy	0.67	0.25- 1	0.18
Avoid happy	0.60	0.06- 1	0.22
Select angry	0.59	0.12- 0.94	0.22
Avoid angry	0.66	0.25-1	0.19
Happy approach score	0.07	-0.54- 0.75	0.28
Angry avoid score	0.07	-0.44- 0.88	0.27
Reversal			
Select happy	0.67	0.19- 1	0.21
Avoid happy	0.61	0.19- 1	0.18
Select angry	0.67	0.31- 1	0.17
Avoid angry	0.61	0.13- 1	0.20
Happy approach score	0.06	-0.56- 0.5	0.23
Angry avoid score	-0.06	-0.67- 0.38	0.22

Note. 'AQ-10' = Autism Spectrum Quotient (short-form), possible scores range from 0-10. 'SAD' = Social Avoidance and Distress Scale, possible scores range from 0-28. 'SPSRQ-20' = Sensitivity to Punishment and Sensitivity to Reward scales (short form), possible scores range from 0-20 aggregated across both the 'SR' = Sensitivity to Reward and 'SP' = Sensitivity to Punishment scales, possible scores range from 0-10 for each. 'Select happy' = proportion correct happy face choices, 'Avoid happy' = proportion correct avoid happy face choices, 'Select angry' = proportion correct angry face choices, 'Avoid angry' = proportion correct avoid angry face choices. 'Happy approach score' = difference between approaching and avoiding happy faces, 'Angry avoid score' = accuracy difference between avoiding and approaching angry faces.

3.2 Overall Learning Performance

The means for the proportion of correct choices suggest there was a stronger tendency to learn to select happy faces and to avoid angry faces, as we expected (Figure 5). In the reversal blocks, however, learning to select rather than avoid faces was stronger for both happy and angry faces (Figure 6). A two-way ANOVA with factors; face type (happy, angry) and action type (select, avoid) revealed only a significant interaction between face type and action type (F (1,54) = 9.21, η^2 = 0.146, p = 0.015) during acquisition learning. Paired t-tests revealed that although learning to select happy faces was numerically better than avoiding happy faces, this difference was not significant, t (54) = 1.770, p = 0.082. Additionally, learning to avoid angry faces was better than selecting angry faces, but this pattern was also not significant, t (54) = 1.926, p = 0.059.

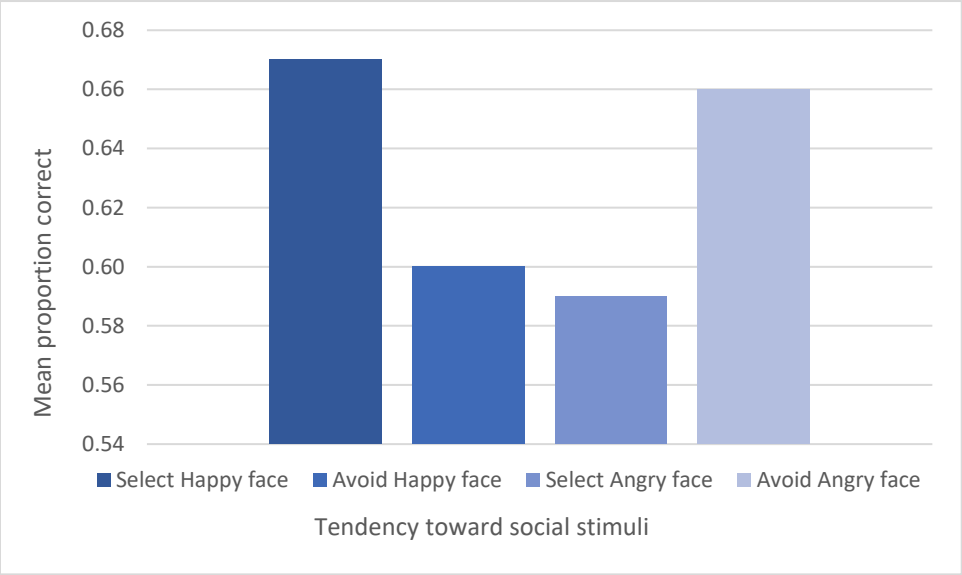

Figure 5- Mean accuracy by action type and face type during block 1 acquisition learning

A similar two-way ANOVA on the reversal blocks indicated that there was a significant main effect of action type (F (1,54) = 6.65, η^2 = 0.109, p = 0.013), and no other significant effects. This suggests that individuals were better at learning to select faces, regardless of their type, during the reversal blocks (Figure 6).

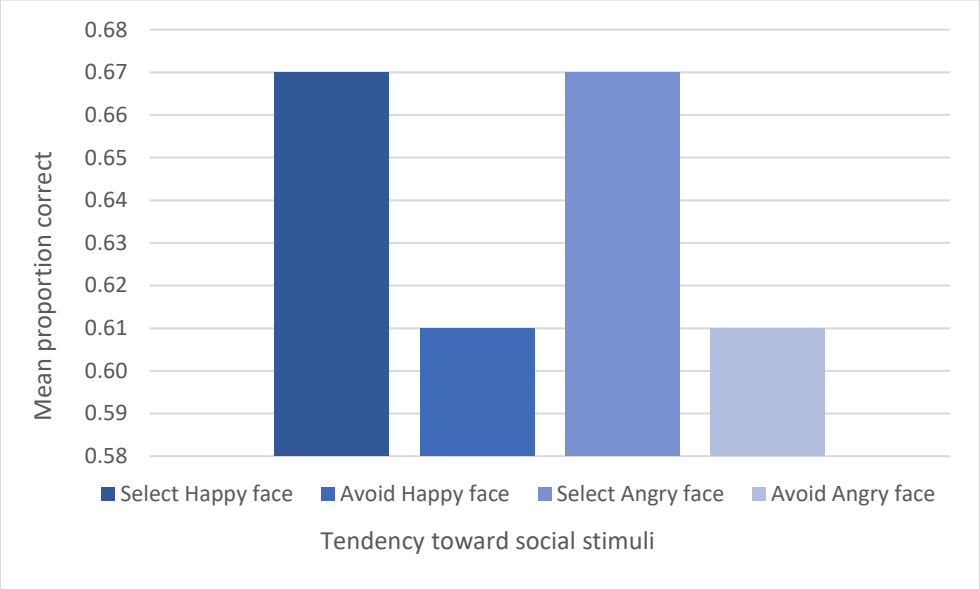

Figure 6- Mean accuracy by action type and face type during reversal learning

3.3 Principal Component Analysis on the Social Avoidance Measures

Principal component analysis (Jollife, 2002) was conducted on the scores for social avoidance and distress (SAD) and sensitivity to punishment (SP), as they were both intended to assess social anxiety and were highly correlated (see Table 5). The first unrotated component (PC1) had an eigenvalue of 1.54 and accounted for 77% of the variance in the measures, with

each measure having a factor loading of 0.88. This overall social anxiety factor was used in the subsequent individual differences analyses.

3.4 Correlations between Autistic tendencies, Social Anxiety Measures and Learning Outcomes

Correlations were calculated to determine if the measures and learning responses were related to each other in the expected directions. The social anxiety measures were highly and significantly correlated but not with sensitivity to reward. As expected, autistic tendencies were positively correlated with sensitivity to punishment, social avoidance and distress and thus, also with the combined construct of social anxiety, but not with sensitivity to reward (Table 5). There were no significant correlations between the learning measures and the scales. The largest correlation was between autistic tendencies and the avoid angry face score during acquisition learning, but it did not reach the significance level (Table 6).

Table 5

Correlation matrix for all scales

	AQ-10	SR	SP	SAD
AQ-10				
SR	-0.06			
SP	0.43*	0.13		
SAD	0.36*	-0.14	0.54*	
Social Anxiety	0.45*	-0.01	0.88*	0.88*

Note. * = p <0.01

Table 6

Correlation matrix for scales scores and learning biases

	Acquisition Happy approach score	Acquisition Angry avoid score	Reversal Happy approach score	Reversal Angry avoid score
AQ-10	0.06	0.24	-0.16	0.03
SR	0.00	-0.05	-0.01	0.13
SP	-0.13	0.10	-0.05	0.11
SAD	-0.08	0.04	-0.09	0.17
Social Anxiety	-0.12	0.08	-0.08	0.15

Note. no significant correlations.

These correlations between the scales and learning outcomes do not reflect any possible interaction between autistic tendencies and social anxiety. Thus, the following regression models tested this possibility.

3.5 Regression Models for Learning Outcomes

Tables 7, 8, 9 and 10 summarise the mediation and moderation regression models that were planned. Even when autistic tendencies do not predict the learning outcome, mediation models are tabulated for the sake of completion and to demonstrate if there was any effect of social anxiety. Controlling for the confounding variables of age, gender and years of education has not changed the pattern of results presented in the following tables. Thus, we present the following regression models without these variables.

Table 7

Regression model for acquisition learning bias to approach happy faces

	R^2	*B*	*SE B*	*p*
Model 1	0.004			
Autistic tendencies		0.010	0.021	0.649
Model 2 (mediation)	0.033			
Autistic tendencies		0.023	0.024	0.329
Social anxiety		-0.054	0.043	0.221
Model 3 (moderation)	0.044			
Autistic tendencies		0.021	0.024	0.384
Social Anxiety		0.112	0.086	0.200
Autistic tendencies x Social Anxiety		0.016	0.021	0.437

Note. R^2 = proportion of explained variance. *B* = regression coefficient. SE B = standard error of regression coefficient. 'Autistic tendencies x Social Anxiety' = the interaction between the autistic tendencies and the principal component scores for social anxiety.

Regression analyses were conducted to determine whether autistic tendencies and social anxiety predict social reinforcement learning outcomes (the bias to learn to approach happy faces and to avoid angry faces). The first model included only the predictor autistic tendencies and it

did not explain the bias to learn to select happy faces, R^2= 0.004, F (1, 53) = 0.223, p = 0.649. The second model addressed the first aim to investigate the possible mediation effect whereby social anxiety might mediate the effect of autistic tendencies and learning. Table 7 shows that the second model was also not significant, R^2= 0.033, F (2, 52) = 0.881, p = 0.420. Although no mediation was expected since the first model was not significant, this second model shows that social anxiety also did not predict approaching happy faces during acquisition learning. The third model addressed the second aim to investigate the possible moderation effect between autistic tendencies and social anxiety. The third model was not significant, R^2= 0.044, F (3, 51) = 0.7874, p = 0.506 and thus there was no interaction effect between the predictor variables. This suggests that neither mediation nor moderation of social anxiety with autistic tendencies predict the learning bias to approaching happy faces.

Table 8

Regression model for acquisition learning bias to avoid angry faces

	R^2	*B*	*SE B*	*p*
Model 1	0.058			
Autistic tendencies		0.035	0.029	0.074
Model 2 (mediation)	0.059			
Autistic tendencies		0.038	0.022	0.093
Social anxiety		-0.009	0.041	0.819
Model 3 (moderation)	0.145*			
Autistic tendencies		0.04	0.021	0.046*
Social Anxiety		0.141	0.077	0.074
Autistic tendencies x Social Anxiety		-0.043	0.019	0.028*

Note. $R^{2\,=}$ proportion of explained variance. *B* = regression coefficient. SE B = standard error of regression coefficient. 'Autistic tendencies x Social Anxiety' = the interaction between the autistic tendencies and the principal component scores for social anxiety. * = $p < 0.05$

Table 8 shows similar regression analyses conducted on the bias to learn to avoid angry faces. As with the first set of regression models, the first (R^2= 0.059, F (1, 53) = 3.313, p = 0.074), and second (R^2= 0.059, F (2, 52) = 1.654, p = 0.201) models were not significant. Thus,

the level of autistic tendencies did not predict learning to avoid angry faces during acquisition, nor did social anxiety. The third model addressed the possible moderation effect between autistic tendencies and social anxiety. This model explained a statistically significant proportion of variance in learning to avoid angry faces, R^2= 0.145, F (3, 51) = 2.884, p = 0.045, and the interaction term was significant. This suggests an interaction between the level of autistic tendencies and social anxiety predict learning to avoid angry faces during acquisition learning.

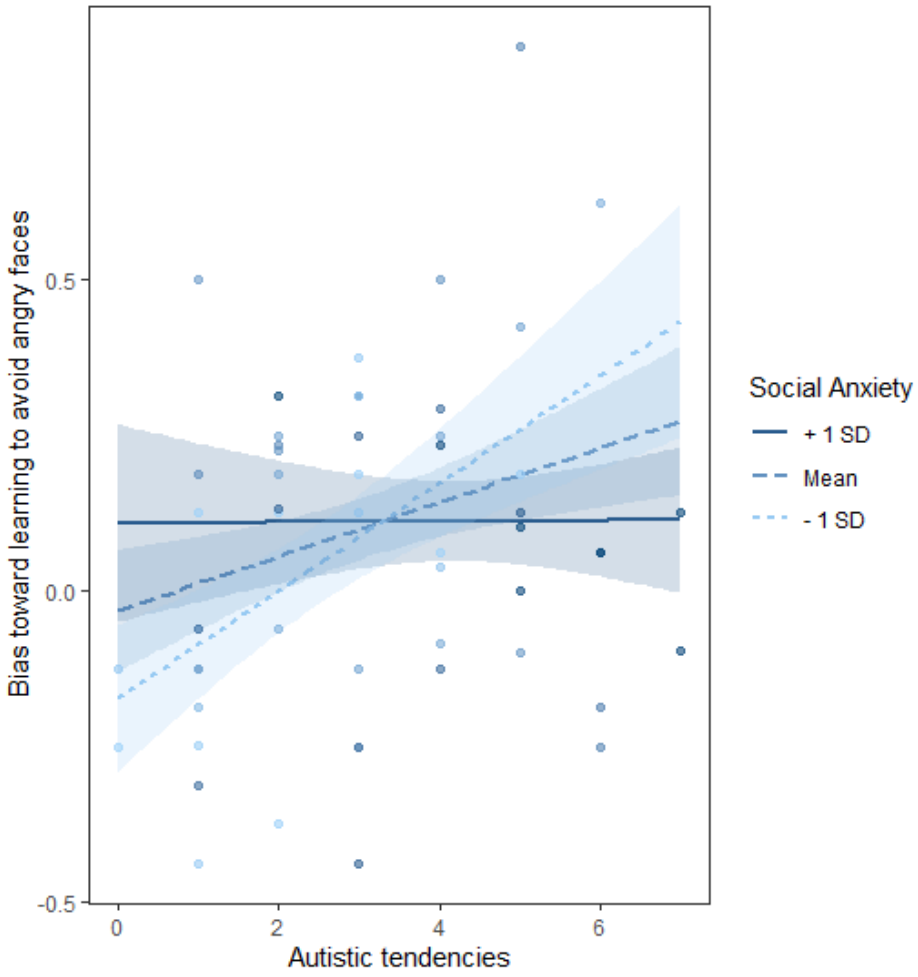

Figure 7- An interaction between social anxiety and autistic tendencies predicts the bias to learn to avoid angry faces

Figure 7 shows that autistic tendencies were associated with a higher learning bias to avoid angry faces, but only when social anxiety is low to moderate. In contrast, when social anxiety is high, there is no effect of autistic tendencies on learning to avoid angry faces.

Table 9

Regression model for reversal learning bias to approach happy faces

	R^2	*B*	*SE B*	*p*
Model 1	0.026			
Autistic tendencies		-0.020	0.017	0.244
Model 2 (mediation)	0.026			
Autistic tendencies		-0.020	0.019	0.317
Social anxiety		-0.002	0.035	0.947
Model 3 (moderation)	0.047			
Autistic tendencies		-0.021	0.019	0.262
Social Anxiety		-0.065	0.068	0.347
Autistic tendencies x Social Anxiety		0.018	0.017	0.294

Note. $R^{2\,=}$ proportion of explained variance. *B* = regression coefficient. SE B = standard error of regression coefficient. 'Autistic tendencies x Social Anxiety' = the interaction between the autistic tendencies and the principal component scores for social anxiety. No significant correlations.

Table 9 shows the regression analyses conducted on the adaptation to approach happy faces during reversal blocks. Neither the first, (R^2= 0.026, F (1, 53) = 1.389, p = 0.244), second (R^2= 0.026, F (2, 52) = 0.6838, p = 0.509) or third (R^2= 0.046, F (3, 51) = 3.313, p = 0.483) models were significant. This suggests that neither mediation nor moderation of social anxiety with autistic tendencies predict adapting to approach happy faces.

Table 10

Regression model for reversal learning bias to avoid angry faces

	R^2	*B*	*SE B*	*p*
Model 1	0.001			
Autistic tendencies		0.004	0.016	0.800
Model 2 (mediation)	0.026			
Autistic tendencies		-0.005	0.018	0.773
Social anxiety		0.038	0.033	0.260
Model 3 (moderation)	0.272			
Autistic tendencies		-0.005	0.018	0.805
Social Anxiety		0.055	0.066	0.413
Autistic tendencies x Social Anxiety		-0.005	0.016	0.769

Note. R^2 = proportion of explained variance. *B* = regression coefficient. SE B = standard error of regression coefficient. 'Autistic tendencies x Social Anxiety' = the interaction between the

autistic tendencies and the principal component scores for social anxiety. No significant correlations.

Table 10 shows the regression analyses conducted on the adaptation to avoid angry faces. As with the previous results, neither the first (R^2 = 0.001, F (1, 53) = 0.065, p = 0.800), second (R^2 = 0.026, F (2, 52) = 0.6838, p = 0.509) or third (R^2 = 0.272, F (3, 51) = 0.027, p = 0.700) models were significant. This suggests that neither mediation nor moderation of social anxiety with autistic tendencies predict adapting to avoiding angry faces.

Discussion

4.1 Summary of Learning Performance Findings

The purpose of the current study was to investigate the relationship between autistic tendencies and reinforcement learning to positive and negative facial expressions, and how social anxiety affects this relationship. As expected, the findings demonstrated a natural learning bias to approach happy faces and avoid angry faces when learning paradigms were consistent (acquisition). Although, there were no significant differences observed between approaching and avoiding facial expressions based upon emotion type, these findings replicated previous research and theory in this area. This is consistent with previous studies that have shown that humans have a natural tendency to approach socially rewarding stimuli (positive facial expressions) and avoid socially punishing stimuli (negative facial expressions) (Jones et al., 2011; Chevallier et al., 2012). Interestingly, the natural learning bias was not replicated when learning contingencies

changed (reversal), even with avoiding angry faces. Instead, there was a signficant learning bias to approach facial expressions, regardless of emotion type, compared to abstract symbols (see Figure 6). We speculate that a reason for this, could be that the volatility of learning paradigms, urges individuals to approach social stimuli over non-social stimuli, suggesting an overall social preference when learning contingencies are frequently changing. This is in line with suggestions that typically developing adults adapt more readily to social stimuli of faces and eye-gaze compared to non-social stimuli (Simion & Di Giorgio, 2015).

Overall, participants in the current study displayed learning performance consistent with typically developing individuals, with a natural tendency to respond to positive social stimuli, and in general, to social stimuli compared with non-social stimuli.

4.2 First aim: Investigating whether Social Anxiety Mediates the Relationship between Autistic Tendencies and Reinforcement Learning

The findings demonstrated that social anxiety did not mediate learning outcomes during acquisition learning and reversal learning. Unlike what was expected, there were no significant results of the level of autistic tendencies or social anxiety independently predicting the learning bias to approach happy faces and avoid angry faces. Although there was a trend for learning to avoiding angry faces in acquisition learning, suggesting that individuals found it easier to avoid angry faces and autistic tendencies was significant in the third model for this learning bias. Nevertheless, neither autistic tendencies or social anxiety predicted learning to approach happy faces, as no relationship was found in either acquisition or reversal blocks. This is contrary to previous research, that suggested a negative relationship between these predictors and positive

social stimuli (i.e. happy faces) (Roelofs et al., 2010; Schulze et al., 2013). Therefore, we did not replicate these previous findings, about either autistic tendencies or social anxiety predicting motivation and responsiveness to positive social stimuli, and consequently social reward learning. Furthermore, the lack of mediation observed between the predictors and the learning bias to approach happy faces could potentially be explained by different reward processing patterns for the two conditions. Richey et al. (2014) found that autistic tendencies have a domain-general pattern of reward dysfunction, in that there is reduced reward responsiveness to both social and non-social stimuli (e.g. money) while social anxiety is specifically linked to reduced responsiveness to social stimuli. Thus, despite the correlations found in our study (see Table 5), this disparity may suggest there is not a significant association between the two conditions to warrant a mediated relationship for processing positive social stimuli (i.e. happy faces) and subsequently social reward learning.

Similarly, none of the mediation models for autistic tendencies and social anxiety predicted learning to avoid angry faces. This contradicts the suggestion, that the level of social anxiety predicts increased punishment learning of negative social stimuli, regardless of the level of autistic tendencies, since it did not appear to strongly influence how individuals orient toward types of social stimuli (i.e. happy faces and angry faces). Furthermore, Beltzer et al. (2019) finding that social anxiety predicts slower reversal learning performance, such as learning to approach a previously punishing stimulus, could not be found in the current study. This may indicate that the effect of autistic tendencies on social reward learning and social punishment learning (as indexed by the approach and avoidance learning bias), does not weaken in the

presence of social anxiety. Thus, no mediating effect of social anxiety towards aberrant learning patterns could be found in the current study. This is discussed in more detail in the next section.

4.3 Second aim: Investigating whether Social Anxiety Moderates the Relationship between Autistic Tendencies and Reinforcement Learning

The findings demonstrated that social anxiety did not moderate the relationship between autistic tendencies and the learning bias to approach happy faces during acquisition learning and reversal learning. Thus, since there was no interaction, the current study failed to support previous research that suggested reduced attention towards happy faces in comorbid diagnoses (Sato et al., 2019; Beltzer, et al., 2019). In addition, the study did not replicate the suggestion that levels of social anxiety in individuals with autistic tendencies influence social reward learning biases through its modulation of face processing (Moser, Hupery, Duval & Simons, 2008), and that higher levels of both autistic tendencies and social anxiety were associated with reduced responsiveness to social rewards (Matyjek, Bayer & Dziobek , 2020). Furthermore, there was no significant interaction between the predictors and the learning bias to avoid angry faces during reversal learning. The literature concerning this area is mostly unexplored and thus, we suggest there could be no relationship between autistic tendencies, social anxiety and learning to avoid angry faces during reversal learning. Given there was a lack of strong correlations between the predictors and this learning bias in this study (see Table 6). Therefore, it is difficult to determine whether the low flexibility attributed to autistic tendencies and the slower adaptation attributed to social anxiety, interact, and subsequently affect adapting to avoid angry faces. To summarise, our findings were not able to demonstrate a contribution of either autistic tendencies or social

anxiety to social reward learning (during both acquisition and reversal learning) and social punishment learning (during reversal learning).

Interestingly, the current study found that social anxiety moderated the relationship between autistic tendencies and the learning bias to avoid angry faces during acquisition learning. The moderation models explained a significant proportion of variance in learning to avoid angry faces, which is attributed to an interaction between the level of autistic tendencies and social anxiety. This was in line with our expectations and is consistent with previous literature that suggested an interaction between autistic tendencies and social anxiety could explain the broad expression and development of comorbid diagnoses (Wood & Gadow, 2010; Kleinhans et al., 2010; Herrington et al., 2017; Zabowski & Storch, 2018). Comorbid diagnoses of autistic tendencies and social anxiety often have overlapping symptomology but have notable differences compared to individuals with autistic tendencies but no social anxiety and typically developing individuals with social anxiety (Kerns et al., 2014; Maddox & White, 2015; Zabowski & Storch, 2018). Thus, the current study's findings could add support to these suggestions.

Furthermore, there are notable trends in our findings, in terms of how the level of autistic tendencies and social anxiety affect social punishment learning patterns. Firstly, the moderating effect of social anxiety is important in predicting learning outcomes, as autistic tendencies interact with a low to moderate level of social anxiety, to predict an increased avoidance to angry faces (see Figure 7). Moreover, higher autistic tendencies and lower social anxiety were associated with the highest learning bias to avoid angry faces, demonstrating that the decreased level of social anxiety had the opposite effect of what was expected on social punishment

learning patterns (see Table 2). In turn, autistic tendencies accompanied by higher levels of social anxiety do not contribute to social punishment learning (see Figure 7). Whereas, in contrast to expectations (see Table 2) lower autistic tendencies and higher social anxiety were associated with a high learning bias to avoid angry faces, demonstrating that the level of social anxiety did increase social punishment learning. Thus, it seems that social anxiety only heightens vigilance towards negative social stimuli in higher-functioning individuals, as they have a low level of autistic tendencies. This is consistent with research on individuals with a lower level of autistic tendencies (higher-functioning end of the spectrum), in which their greater awareness of social difficulties and reactions from the social environment was associated with severe anxiety and consequently, a vigilance and avoidance of social situations (Bellini, 2006; Maddox & White, 2015; Robertson et al., 2018; Spain et al., 2020). Additionally, contrary to our speculations, high levels of autistic tendencies (lower-functioning end of the spectrum) and social anxiety is associated with a blunted learning bias to avoid angry faces and hence blunted social punishment learning (Figure 7). These findings are consistent with previous research that found positive associations between high levels of autistic tendencies and social anxiety, that is individuals with greater ASD symptom severity also had increased social anxiety (Bejerot, Eriksson & Mortberg, 2014; Spain et al., 2020), yet our findings may add to how these interact and manifest in social punishment learning patterns. Thus, there are different relationships between autistic tendencies and aberrant learning patterns depending on the level of social anxiety.

Lastly, the variation in autistic tendencies and social anxiety found in this study predict the development of social punishment learning, highlighting how individual differences influence

avoidance learning biases to negative social stimuli such as facial expressions. Overall, the speculated contribution of high autistic tendencies and high co-occurring social anxiety influencing aberrant learning patterns, in particular predicting increased social punishment learning (see Table 2) was not supported in the current study. Rather while we observed a moderation effect, it was different from the way we expected. The study demonstrated that either low autistic tendencies and high social anxiety, or conversely, high autistic tendencies and low social anxiety were associated with aberrant reinforcement learning patterns, in particular increased social punishment learning.

4.4 Implications

The findings of the present study have provided support for a moderating effect of social anxiety on the relationship between autistic tendencies and social punishment learning (i.e. avoiding angry faces) during acquisition. The study demonstrates that this relationship is complex as individual differences in autistic tendencies and social anxiety symptoms interact with each other in a bi-directional manner and thereby predict aberrant learning outcomes. Thus, considering both autistic tendencies and co-occurring social anxiety symptoms may be important, as the current study suggests their roles in affecting social punishment learning could be responsible for maintaining the social skill deficits often seen in individuals with comorbid diagnoses.

Furthermore, this study contributes insight into how individuals with comorbid autistic tendencies and social anxiety present with overlapping symptoms, and similar learning patterns of avoidance towards negative social stimuli such as facial expressions. Individuals presenting

both conditions have consistently displayed coping strategies involved in avoiding social situations, which indirectly reinforces the aberrant learning over time. Therefore, by understanding the underlying processes of this comorbidity there is important implications for sufferers and practitioners.

Importantly, our findings could help to inform how individuals with both autistic tendencies and social anxiety symptoms approach available therapies such as Applied Behavioural Analysis (ABA) and Cognitive Behavioural Therapy (CBT). The current findings suggest that this could depend on their level of autistic tendencies and social anxiety symptoms, as the interaction between these predict social punishment learning patterns. This calls attention to the importance of individual differences for effective treatment. For instance, individuals on the higher-functioning end of autistic tendencies and with severe social anxiety, may need greater attention towards reducing negative thoughts processes about social interaction, paired with reinforcement learning strategies that encourage social engagement. Since these areas contribute to social punishment learning, ultimately focusing on reducing negative social learning biases, tailored to each individual, depending on their level of autistic tendencies and social anxiety (i.e. severity), could assist with social skills development and improving the wellbeing of these individuals.

4.5 Strengths

The instrument used to measure learning performance had several benefits. We employed a social reinforcement learning paradigm that assessed how fast individuals learned to approach and avoid positive and negative social stimuli (i.e. happy faces and angry faces), and non-social

stimuli (abstract symbols). Participants were required to learn by trial and error which selection was correct or incorrect based upon feedback, with each image positioned an equal number of times on either side of a screen. This enhanced the likelihood of prompting instinctive choices based on the identity of the stimuli, and thus its emotional salience. This was supported by our findings that replicated known natural learning biases for positive social stimuli, during acquisition learning (see Figure 5). Furthermore, to improve external validity, reversal trials were implemented to simulate changing learning contingencies which are regularly found in everyday social environments and hence measure adaptation. Moreover, compared to more subjective methods, the overall design of the computerised task was useful. That is, since it was intended to measure the accuracy of responses during acquisition and reversal learning, this was more objective than self-report measures that require individuals to self-assess their responses to social stimuli.

4.6 Limitations

Despite having strengths, the present study also had limitations. Firstly, the limited characteristics of the sample raise issues, in terms of representativeness. The majority of the participants were university students from the University of Adelaide and with an average age of 25. This is challenging when attempting to generalise the current study's findings, especially when considering that autism, affects a broad range of individuals. As previously mentioned, autistic tendencies differ greatly throughout the lifespan and functioning, in terms of symptom presentation and severity (Faras, et al., 2010). For instance, autistic tendencies are highly variable across the spectrum, with individuals on the lower-functioning end, typically characterised with more social communication, language and intellectual impairments (Bal,

Farmer & Thurm, 2018), whereas individuals on the higher-functioning end are thought to suffer less severe impairments but still have many classic symptoms of difficulties in understanding verbal and nonverbal social cues, repetitive behaviours, and restricted interests (APA, 2013). Thus, there is a great diversity in social experiences and hence the development of aberrant social reinforcement learning. However, the sample used in the current study can be expected to be relatively high functioning, with most individuals having likely undergone typical development. Therefore, it failed to include a range of individual differences in autistic tendencies required for high ecological validity, notably individuals with more severe autistic tendencies.

Furthermore, static facial expressions, rather than dynamic, were used in this study to measure approach and avoidance learning patterns. This is limiting in terms of ecological validity as static facial expressions have been shown to be less realistic in emotion display and associated with reduced emotional arousal (Rymarczyk, Żurawski, Jankowiak-Siuda & Szatkowska, 2016). This can have consequences for investigating social reinforcement learning patterns, since research has shown that the intention to approach positive facial expressions and avoid negative facial expressions is stronger in dynamic facial expressions compared with static facial expressions (Renard, Jon & Pijnenborg, 2017). Dynamic facial expressions present internal features (i.e. eyes, nose, mouth) changing and hence reflect realistic emotional cues during social interaction (Addabbo et al., 2018; Rymarczyk et al., 2016). Thus, static facial expressions seem to be less effective in prompting natural responses, which are desired when studying social learning behaviours.

4.7 Future Directions

This study demonstrates that the relationship between autistic tendencies, social anxiety and aberrant reinforcement learning patterns is complex, and hence further research is warranted. The current study found an interesting learning bias towards facial expressions over abstract symbols, during reversal learning, in which learning contingencies change. This social preference bias should be investigated further to see if it is replicated in future reversal trials. Additionally, one could test whether volatile learning paradigms prompt individuals to approach more familiar stimuli of facial expressions, regardless of emotion type.

To address the limitations, future studies should sample from a more diverse population, in order to capture broader individuals differences in autistic tendencies, social anxiety and consequently aberrant social reinforcement learning patterns. Furthermore, since the association between autistic tendencies and reduced responsiveness to positive facial expressions (i.e. happy faces) usually reported in the literature was not replicated in the current study, improving the sample characteristics could increase the likelihood of discovering such relationships. Moreover, to improve similarity to realistic social situations and hence ecological validity, the study should be replicated with dynamic facial expressions through short video clips of positive and negative facial expressions to investigate the research aims. Likewise, there is the question of whether the findings of the present study extend to different and more complex facial expressions such as affectionate, compassionate, contemptuous and disgust (Benda & Scherf, 2020), as these could predict approach and avoidance, and subsequently social reward learning and social punishment learning patterns.

4.8 Conclusions

The current study is one of the few within the literature, that investigated both autistic tendencies and co-occurring social anxiety, in relation to social reward, punishment and reversal learning towards positive and negative facial expressions. This study provided support for an interaction between autistic tendencies and social anxiety predicting aberrant social punishment learning during acquisition, based upon the level of these two conditions. Interestingly, this interaction was more complex than expected since divergent levels of the predictors (one is higher and the other is lower) affected social punishment learning. While there was no mediating effect of social anxiety found, our study shows its contribution is vital in understanding the diversity of social reinforcement learning patterns, particularly, avoidance of negative social stimuli. These findings have meaningful implications in how individuals with autistic tendencies and co-occurring social anxiety develop social communication difficulties that adversely affect social interaction, social motivation and thus, the formation and maintenance of interpersonal relationships. Further study is required to discern associations between these conditions and social reward learning and adaptation, as this could provide further information on how these individuals navigate social interaction. Finally, the individual differences in comorbid autism and social anxiety is an important aspect to be considered for social learning and hence social skills development.

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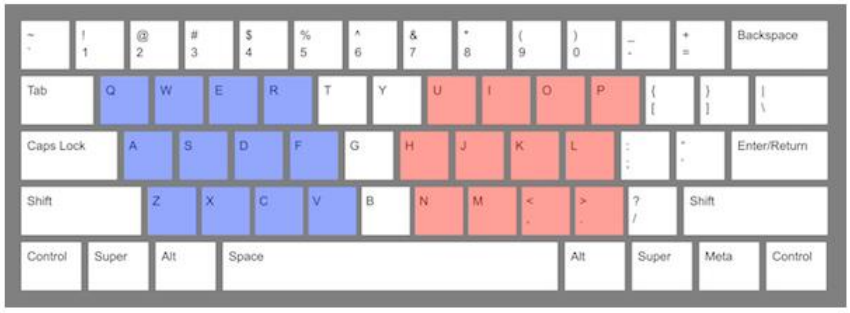
Appendix A: Learning task instructions

In this task you will be presented with different pairs of images, as in the example below. On every trial you will have to choose one of the images by pressing any of the keys on the left or the right side of the keyboard. For example, if you choose the image on the left you would have to press any of the keys highlighted in blue below, and if you choose the image on the right you would have to press any of the keys highlighted in red. You will only have 4 seconds to make a response, so do not waste too much time making a decision.

You will be informed whether your response was correct or incorrect. Your aim is to discover which images are more likely to be correct and to maximise the number of correct choices. To ensure that you respond as quickly as possible, keep the index of your left hand above one of the red keys (e.g. A) and the index of your right hand above one of the blue keys (e.g. L).



Begin