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Autistic traits moderate relations between cardiac autonomic activity, interoceptive accuracy, and emotion processing in college students

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ABSTRACT

The autonomic nervous system (ANS) plays a key role in maintaining physiological homeostasis, and research with neurotypical and autistic individuals has found relations between cardiac autonomic responses, as well as awareness of one's cardiac responses, and social and emotional processing. The current study examined relations between cardiac autonomic activity, heartbeat perception, emotion processing, and levels of autistic traits in a group of college students. Cardiac ANS at baseline and during an emotional picture task was measured, and a heartbeat perception task was used to assess interoceptive accuracy (IA). Questionnaires then assessed autistic traits, alexithymia (difficulties processing one's own emotions), and emotion recognition. Consistent with past work, greatest heart rate deceleration was seen in response to negative images. In the overall sample, no correlations were found between cardiac ANS, IA, autistic traits, and aspects of emotion processing, but when examining individuals high and low on autistic traits separately, distinct associations were found. Within the group of participants with elevated autistic traits, greater baseline respiratory sinus arrhythmia (RSA) was predictive of lower levels of alexithymia and autistic traits, as well as higher IA, but these associations were not seen in participants low on autistic traits. These findings suggest that variability in autistic traits in a non-autistic sample can lead to differential relations between cardiac autonomic responses, awareness of one's cardiac responses, and emotion processing.

1. Introduction

The autonomic nervous system (ANS) is responsible for regulating basic bodily functions such as heart rate, respiration, and perspiration, and is comprised of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). SNS activity has an excitatory influence that increases during physical or psychological stress, while PNS activity has an inhibitory influence that is dominant during periods of rest and relaxation (Appelhans and Luecken, 2006). Although the branches have opposing effects, they do not function in perfect oscillation, where an increase in one branch follows a decrease in the other. Instead, they may respond simultaneously or independently, allowing for the possibility of various patterns of activation (Von Borell et al., 2007).

One marker of ANS activity is heart rate variability (HRV), which refers to the variation in time between individual heartbeats, and represents the constant interaction between the SNS and PNS (Appelhans and Luecken, 2006). When measured in the frequency of respiration, HRV is used as an indicator of PNS control and is known as respiratory sinus arrhythmia (RSA). During social interactions, social and emotional cues must be rapidly inferred, and the adaptability of the ANS can contribute to socio-emotional processing (Eilam-Stock et al., 2014), and higher RSA has been found to indicate a greater response potentiality for cardiac activity to adapt to situational demands (Appelhans and Luecken, 2006; Von Borell et al., 2007; Propper and Holochwost, 2013). Porges' (2007) polyvagal perspective proposes a link between the vagus nerve, which parasympathetically mediates HRV, and the interpretation and response to social cues. The theory suggests that the vagus nerve contributes to our interactions with the environment through its inhibitory regulation of heart rate, encouraging or discouraging social interaction. On the one hand, when an individual feels threatened by their environment, vagal tone would be

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suppressed and sympathetic responses increased to promote survival mechanisms, but when an individual considers their environment to be safe, vagal tone would be applied, promoting a calm physiological state (high parasympathetic control), and an opportunity for optimal social engagement (Porges, 2003).

A wide range of studies have pointed to associations between RSA and socio-emotional competence (e.g., Doussard-Roosevelt et al., 1997; Quintana et al., 2012; Richards and Cameron, 1989; for a review, see Appelhans and Luecken, 2006). For example, higher RSA at baseline corresponds with lower behavioral inhibition in infancy (Richards and Cameron, 1989) and better emotion recognition in adults (Quintana et al., 2012). These relations have also been studied in individuals with autism spectrum disorder (ASD), a group that shows marked difficulties in social and emotional functioning (e.g., Guy et al., 2014). Many studies have found that children with ASD show reduced RSA compared to their typically-developing (TD) peers (e.g., Bal et al., 2010; Ming et al., 2005; Neuhaus et al., 2014), and in ASD, greater RSA at baseline is associated with better emotion recognition (Bal et al., 2010), as well as better social skills (Van Hecke et al., 2009). Van Hecke et al. (2009) and Neuhaus et al. (2014) both found associations between RSA and social skills when looking at combined samples of children with and without ASD as well, and similarly, Cai et al. (2019) showed that higher baseline RSA was associated with fewer autistic traits in a combined sample of adults with and without ASD. In contrast, work with children by Klusek et al. (2013) found that higher RSA was related to lower autism symptom severity in the TD group only, with no relation found in the ASD group. Together, these studies in both typically- and atypically-developing individuals find that higher RSA at baseline is associated with better social and emotional abilities, pointing to higher parasympathetic control in individuals with higher levels of socio-emotional competence.

Another marker of cardiac ANS activity that has been found to relate to emotion processing is heart rate (HR). Across infancy and adulthood, studies have found more pronounced HR deceleration in response to negative images as compared to positive or neutral images, suggesting that HR responses vary based on emotional content (e.g., Bradley et al., 2008; Leppänen et al., 2010). HR deceleration to emotional images has been found to relate to interoceptive accuracy (IA; Pollatos et al., 2007), which refers to the process of sensing and accurately tracking bodily sensations and internal states such as hunger and heart rate (Craig, 2003). Pollatos et al. (2007) examined IA through a heartbeat tracking task (see Schandry, 1981) in which participants were asked to count their heartbeats in different intervals without taking their pulse. Results showed that participants who were more attuned to perceiving their own heartbeats (i.e., showing higher IA) had more pronounced HR deceleration when viewing emotionally-salient (positive and negative) images (Pollatos et al., 2007). This suggests that those with higher IA may experience emotions with heightened intensity (Critchley and Harrison, 2013).

IA has also been examined in individuals with ASD, with several studies finding lower IA in ASD as compared to neurotypical controls (e.g., Garfinkel et al., 2016; Mul et al., 2018; Palser et al., 2018), but other studies finding no differences between groups (e.g., Nicholson et al., 2018; Schauder et al., 2015). No systematic examination of the reasons for these mixed IA results in ASD has been done, but several studies have examined potential explanations (e.g., Mash et al., 2017; Shah et al., 2016). For example, Mash et al. (2017) examined age, IQ, and counting ability as predictors of IA in ASD and TD groups and found that age and IQ interact with clinical group to predict performance on the heartbeat tracking task, highlighting two factors that could contribute to the variation seen in past results.

Relating to emotion processing, one key factor that has been increasingly examined with regard to both autism and IA is alexithymia, a personality construct characterized by impairments in sensing, identifying, and describing one's own emotions (Bird and Cook, 2013; Parker et al., 1993). Studies have shown an elevated incidence of alexithymia in individuals with ASD compared with TD peers across a wide range of ages (e.g., Hill et al., 2004; Milosavljevic et al., 2016; Tani et al., 2004).

With many studies reporting emotion recognition difficulties in individuals with autism (e.g., Ashwin et al., 2006; Wallace et al., 2008), some researchers have hypothesized that such findings are not related to autism, per se, but are instead driven by higher rates of alexithymia that are found in individuals with autism (e.g., Fitzgerald and Bellgrove, 2006; Hill et al., 2004; Poquérusse et al., 2018; for a review, see Bird and Cook, 2013). Related to this, research has found higher IA relating to fewer alexithymic traits in neurotypical adults (e.g., Herbert et al., 2011). In a more recent study of both ASD and neurotypical adults, Shah et al. (2016) examined IA, alexithymia, and autistic traits, and similar to the findings of Herbert et al. (2011), a negative relationship between IA and alexithymia was found in both groups; importantly though, after controlling for alexithymia, there was no evidence for reduced IA in adults with ASD. These results may support previous findings that suggest lower IA in ASD may be the result of high levels of alexithymic traits in the ASD population, however, the complex literature on relations between ASD, alexithymia, and IA prevents strong conclusions on this topic (e.g., Nicholson et al., 2018). These relations are also mixed in neurotypical controls, with different studies pointing to positive, negative, or no association between alexithymia and IA (for discussion, see Zamariola et al., 2018).

While RSA has been theorized as a strong indicator of socio-emotional abilities (e.g., Porges, 2007), few studies have examined how RSA might relate to alexithymia and IA, though recent evidence with neurotypical adults suggests that higher RSA is associated with fewer alexithymic traits (Lischke et al., 2018) and more accurate interoception based on subjective reports (Owens et al., 2018). As of yet, these additional questions have not been studied in relation to autism or autism-related traits.

1.1. The current study

In summary, past work has identified many measures that indicate and/or relate to individual differences in socio-emotional abilities, and some of this work has asked how these measures differ in individuals with and without ASD. With characteristics of ASD seen in varying degrees across individuals with and without ASD, described as the broader autism phenotype (e.g., Pickles et al., 2000), a growing number of studies are moving towards understanding how differences in autistic traits in a non-clinical sample might relate to aspects of behavioral (e.g., Chen and Yoon, 2011; Luo et al., 2017; Swanson et al., 2013) and physiological processing (e.g., DiCriscio et al., 2019; Turi et al., 2018). By looking at the broader autism phenotype in individuals without ASD, this direction of research can elucidate the role of autistic features, more broadly, in accounting for variability in aspects of functioning.

The goal of the present study is to comprehensively examine five measures that have been found to relate to socio-emotional abilities alongside autistic traits in a group of college students without a diagnosis of ASD. This work will extend past studies by looking at cardiac responses (RSA and change in HR), perception of cardiac responses (IA), and emotion processing (alexithymia and emotion recognition) in a single sample, as well as by examining the role of autistic traits in understanding relations among these measures. Further, the current study will attempt to replicate robust findings using these measures in order to situate the present work within the context of past work that has used similar measures.

The first aim of the present study is to replicate three sets of findings: 1) Autistic traits will relate to alexithymia, but will be unrelated to emotion recognition after controlling for alexithymia (e.g., Bird and Cook, 2013); 2) When viewing emotionally-salient images, heart rate deceleration will be greatest in response to negative images (e.g., Bradley et al., 2008), and those with high IA will show greater HR deceleration than those with low IA (Pollatos et al., 2007); and 3) Higher baseline RSA will relate to higher emotion recognition (e.g.,

Quintana et al., 2012), fewer alexithymic traits (e.g., Lischke et al., 2018) and fewer autistic traits (e.g., Klusek et al., 2013). These studies were the focus of replication because they were the findings that were most influential in the design and choice of tasks for the current work. The present study shares strong similarities with the measures used in these past studies, so the first aim is to examine how the current work fits in the context of these past findings.

The second aim of the current study is to look at associations between alexithymia, emotion recognition, HR change, RSA, IA, and autistic traits in a single group of non-clinical participants. This includes novel analyses examining relations between HR change in response to emotional images alongside both autistic traits and alexithymia, where greater HR responses are hypothesized to relate to fewer alexithymic traits and fewer autistic traits. The third aim is to conduct exploratory analyses examining how associations between measures might differ for groups high and low on autistic traits. A similar approach has been examined in studies looking at children with and without ASD, for example, with significant associations between cardiac ANS measures and social and emotional abilities found only in ASD in some work (e.g., Bal et al., 2010; Van Hecke et al., 2009), and only in TD in other work (Klusek et al., 2013). The present study will use established cutoff scores to divide the current non-clinical sample into two groups based on levels of autistic traits, and analyses will then compare correlational findings for the full sample with findings in participants high on autistic traits and low on autistic traits. Together, these three aims will further our understanding of the complex picture that has emerged in the literature on these diverse topics relating to socio-emotional skills.

2. Method

2.1. Participants

Eighty undergraduate students from the College of Staten Island, City University of New York (CSI/CUNY) participated in the current study (47 female, 32 male, 1 trans-male) with a mean age of 20.34 years (SD = 4.59). Three participants were >3 SDs above the mean for age and were excluded from subsequent analyses, leaving 77 participants in the final sample (see Statistical Analysis for more information). Participants were Psychology 100 students at CSI who were recruited through an online system that listed available research study opportunities and non-research alternatives for students to sign up for to satisfy a course requirement. Information about the current study was listed in the online system, and students who were interested could contact the lab to learn more about the study and schedule an appointment during an available timeslot. Participants received credit for their time in the lab completing the current study. Participation was voluntary, and participants could stop or withdraw from participation at any point and still receive credit for their time with no further consequences. All procedures were approved by the CSI/CUNY Institutional Review Board and therefore are in accordance with the ethical standards laid out in the 1964 Declaration of Helsinki.

2.2. Procedure

After participants arrived in lab, all tasks and measures were explained, any questions from the participant were answered, and informed consent was obtained before the study began. Participants were then brought to the experimental room and sensors for measuring physiology were attached. Physiological recordings were obtained using a Biopac MP150WSW system (Biopac Systems, Inc., Santa Barbara, CA) with BioNomadix wireless transmitters. Data collection was done in Biopac's AcqKnowledge software, Version 4.4. Cardiac data was recorded by placing three electrodes in lead 2 configuration (on the right and left lateral portion of the clavicles and over the lower left ribcage), and participants were also fitted with a respiration belt. Once sensors were placed, participants were seated in a dimly lit room with a partition between them and the researchers. The lights were turned off on the participant's side of the partition during the entire duration of the experiment.

The first task administered was the heartbeat perception task. Participants were asked to focus on their heart activity and silently count their heartbeats without physically feeling their heartbeat or pulse. The task was based on Schandry's (1981) Mental Tracking Method, as used by Pollatos et al. (2007), using three intervals of 25, 35, and 45 s presented in random order. A practice interval of 20 s was administered prior to these three intervals, and all intervals were separated by a 30-second rest period. Subjects heard a tone to signify the start and end of each trial, and at the end, they verbally reported the number of heartbeats they counted to the experimenter. Subjects were unaware as to the length of each interval or their accuracy in their counting. Participants were observed via a video camera to ensure they were not feeling their pulse or using any other method that might aid in the detection of heartbeats. To this end, the respiration belt was applied loosely during this first task as well. The heartbeat perception task was followed by a 5-min baseline period, during which participants sat silently in the darkened room while their physiological data was collected (with respiration belt tightened). Participants later completed a picture-viewing task, during which they saw 60 images from the International Affective Picture System (IAPS; Lang et al., 2005). Images included 20 neutral, 20 negative, and 20 positive images in semi-randomized order, with each image presented for 6 s and an intertrial interval varying from 5 to 7 s to prevent anticipatory responses. After completion of these tasks, all sensors were removed, and participants filled out a series of self-report questionnaires assessing social and emotional processing and demographic information.

2.3. Questionnaire measures

2.3.1. Autistic traits

The Social Responsiveness Scale, Second Edition (SRS-2; Constantino and Gruber, 2012) was used to assess participants' level of autistic traits. The SRS-2 is a 65-item self-report measure that identifies subtle symptoms of social impairment and restricted interests and repetitive behaviors related to ASD and the broader autism phenotype. A higher SRS-2 Total score is associated with more autistic traits, and a T-score >59 is typically indicative of clinical concerns related to ASD. The SRS-2 has been used previously to assess variation in autistic traits in the broader population (e.g., DiCriscio and Troiani, 2017). All participants contributed SRS-2 scores. In the current sample, 19 participants fell above the normal cutoff (T-score > 59) and were classified as high on autistic traits, while 58 participants fell below this cutoff score and were classified as low on autistic traits. Cronbach's alpha for the present study was equal to 0.89.

2.3.2. Alexithymia

The Toronto Alexithymia Scale (TAS-20; Bagby et al., 1994) was used to assess participants' levels of alexithymia. The 20-item version of the TAS used in this study examines characteristics of alexithymia along three subscales: difficulty describing feelings, difficulty identifying feelings, and externally-oriented thinking. The TAS-20 has been used in clinical (e.g., Onur et al., 2013) and nonclinical populations (e.g., De Berardis et al., 2009). A total alexithymia score was calculated as the sum of responses to all 20 items. Total scores have a possible range of 20 to 100, with higher scores indicating increased alexithymic traits. Two participants did not complete the TAS-20 in full, and they were excluded from analyses using the TAS-20. For the current sample, Cronbach's alpha was equal to 0.75.

2.3.3. Emotion recognition

The Reading the Mind in the Eyes Test (RMET; Baron-Cohen et al., 2001) was used to measure emotion recognition. Participants were presented with 36 sets of eyes, each with four choices of mental states,

one of which correctly described the emotion depicted in the eyes. Participants were instructed to select the emotion they thought best described each set of eyes and were scored as correct or incorrect based on the 36 trials. This was then used to calculate the percentage of correct responses. Three participants did not complete half or more of the RMET, and they were excluded from analyses using the RMET. For the current sample, Cronbach's alpha was equal to 0.73.

2.3.4. Demographics

A questionnaire assessing demographic variables that could influence cardiac responses was given to participants (see Heathers, 2014; Quintana and Heathers, 2014). Questions included height and weight (for calculation of body mass index, or BMI), exercise frequency, caffeine intake before the study, smoking habits, diagnosis of cardiovascular disease, and medication use for depression or anxiety.

2.4. Data processing

2.4.1. Interoceptive accuracy

Using Biopac AcqKnowledge 4.4 software, focus areas were created to identify each counting interval during the heartbeat perception task. The number of cycles was found by selecting each focus area individually. Heartbeats were detected and classified through the software, then visually scanned to confirm that normal peaks were correctly identified. If any beats within focus areas were missed or mislabeled, the beats were hand counted and the manual count was used in data analysis. Due to weak HR signal during the task, one subject was excluded from IA analysis. For the 76 included participants, based on Pollatos et al. (2007), a heartbeat perception score was calculated as the percent difference in perceived heartbeats and actual heartbeats averaged across trials using the following equation: 1/3 Σ(1 − (|recorded heartbeats − counted heartbeats|) / recorded heartbeats). This calculation gives a score between 0 and 1, with higher scores indicating smaller differences between the numbers of counted and recorded heartbeats, and therefore higher IA. All three test trials were included in the calculation, except for one participant who appeared to physically feel their heartbeat during the first trial, so the average for only the second two trials was used in the calculation of that participant's heartbeat perception score. Based on group analyses used in Pollatos et al. (2007), 85% accuracy was used as a cutoff for comparing high vs. low IA participants. The high IA group (n = 21) had an average IA of 0.91 (SD = 0.04) and the low IA group (n = 55) had an average of 0.59 (SD = 0.17).

2.4.2. Baseline respiratory sinus arrhythmia

MindWare HRV analysis software (version 3.1.5) was used to analyze RSA during baseline. Heart rate data editing consisted of first dividing the five-minute baseline period into five 1-min segments. Each segment was then visually inspected and edited for noise and failure of the software to auto-detect a heartbeat. Segments were excluded from analysis if >10% of peaks required editing or if the measured respiration rate for a participant did not fall within the frequency range corresponding to spontaneous breathing in adults used for calculation of RSA, set at 0.12–0.40 Hz based on past work (e.g., Berntson et al., 1993). Two participants were excluded from the RSA analysis, one due to a heartbeat signal that was too weak to detect and the other due to all five RSA segments showing a respiration rate outside of the expected frequency range. For the remaining 75 participants with useable data, subjects contributed, on average, 4.8 1-min segments (SD = 0.66; Range: 2 to 5 segments), with the majority of participants contributing data from all five segments (67 of 75 = 89%). RSA for useable baseline segments was averaged for each participant to calculate baseline RSA.

2.4.3. Heart rate change during valence task

HR data for the valence task was also analyzed in Biopac AcqKnowledge software (version 4.4) using the 'Find Cycle' function to export cardiac data for 2 s of baseline (prior to stimulus onset) and for 6 s of stimulus presentation. Data were manually inspected for artifacts, and trials were excluded if an artifact appeared within the analysis window (between −2 and + 6 s from stimulus onset). Subjects were included in the valence HR analysis if they contributed artifact-free HR data for at least ten trials for each of the three valence categories during the task (50% for each category). Two participants did not complete the task (one due to sleepiness, one due to time constraints) and were therefore excluded from the current HR analysis. Of the 75 included participants, each subject contributed 57.12 (SD = 5.04) artifact-free trials overall in the valence task, with an average of 19.10 (SD = 1.68) neutral trials, 19.15 (SD = 1.75) negative trials and 18.88 (SD = 1.86) positive trials. Change in HR was calculated as HR during the image (0 to 6 s) minus HR during the pre-image baseline (−2 to 0 s), and average HR change was calculated for each valence category (positive, negative, and neutral).

2.5. Statistical analysis

All statistical analyses were conducted using IBM SPSS software (version 25). To confirm the use of parametric testing, skewness and kurtosis were calculated for the six measures of interest (SRS-2, TAS-20, RMET, RSA, HR change, and IA) as well as age, a factor with well-studied effects on cardiac ANS (e.g., Kuo et al., 1999; O'Brien et al., 1986). Only the variable of age showed a distribution that was highly skewed (skewness of 3.96) and leptokurtic (kurtosis of 17.34). Outliers were then examined for age, and participants who fell >3 SDs outside of the mean age (n = 3) were excluded from the current sample in an effort to reduce effects of age on the present findings, leaving a final sample of 77 participants. Skewness for the remaining variables ranged from −0.55 to 0.86, and kurtosis ranged from −0.97 to 1.49.

Preliminary analyses were conducted to look for influences of demographic variables collected, as well as timing of testing, on RSA. Based on independent-samples t-tests, no significant differences in RSA were found based on time of day (morning vs. afternoon; p = .40), frequency of exercise (0–3 days/week vs. 4+ days/week; p = .31), caffeine consumption on testing day (any vs. none; p = .08), regular smoking habits (yes vs. no; p = .92) or diagnosis of cardiovascular disease (yes vs. no; p = .99). Additionally, BMI was calculated from self-reported height and weight and no significant correlation was found between RSA and BMI in the current sample (p = .67). RSA was significantly lower for participants who took anxiety and/or depression medication (n = 3) as compared to those who did not ($t(73)$ = 3.091, p = .003). Analyses were run both with and without these three participants who reported anxiety/depression medication use, and because the results remained unchanged, reported analyses include these participants.

To test hypotheses about relations between questionnaires (SRS-2, TAS-20, RMET), a series of Pearson correlations were conducted. Because each questionnaire was correlated with five other measures across analyses, an adjusted p-value of 0.05/5, or 0.01, was used for these correlations. A sensitivity analysis was conducted given the current sample with an alpha of 0.01 and a power of 0.8 for one-tailed correlational analyses, and the required effect size was 0.35. Next, to test the hypothesis about heart rate changes to valenced images in relation to interoceptive accuracy, a 3 × 2 repeated-measures ANOVA with the within-subjects factor of image valence (positive, negative, neutral) and the between-subjects factor of IA ability (high, low) was conducted. To situate this work in the context of Pollatos et al. (2007), post-hoc comparisons were done for both significant and non-significant effects. A series of correlational analyses were then conducted to examine associations between questionnaire measures, cardiac autonomic activity, and IA. These were done first across the full sample, and then separately for participants low and high on autistic traits (see Table 1 for descriptive statistics on groups low and high on autistic traits for each measure of interest). As with the questionnaire analysis,

Table 1
Descriptive statistics for questionnaires, cardiac autonomic activity, and interoceptive accuracy in groups low and high on autistic traits.

	Low autistic traits	High autistic traits	Significance
Questionnaires			
SRS-2 total T-Score	n = 58	n = 19	
Mean (SD)	52.86 (4.14)	67.32 (5.64)	$p < .001$
Range	42–59	61–81	
TAS-20 total Score	n = 56	n = 19	
Mean (SD)	46.16 (8.69)	54.95 (8.12)	$p < .001$
Range	28–68	43–73	
RMET	n = 57	n = 17	
Mean (SD)	0.70 (0.12)	0.64 (0.15)	$p = .07$
Range	0.42–0.94	0.36–0.88	
Cardiac ANS activity			
Baseline RSA	n = 57	n = 18	$p = .73$
Mean (SD)	6.36 (0.97)	6.28 (0.80)	
Range	3.8–8.55	4.71–7.39	
HR change to negative	n = 57	n = 18	$p = .13$
Mean (SD)	−1.64 (1.84)	−0.92 (1.30)	
Range	−6.56 − 2.78	−3.43 − 1.69	
Interoceptive accuracy	n = 58	n = 18	$p = .96$
Mean (SD)	0.68 (0.21)	0.68 (0.20)	
Range	0.28–0.99	0.32–0.95	

Note. SRS-2 = Social responsiveness Scale, Second Edition; TAS-20 = Toronto Alexithymia Scale; RMET = Reading the Mind in the Eyes Test; ANS = Autonomic Nervous System; RSA = Respiratory Sinus Arrythmia; HR = Heart Rate. Significance value based on results from independent-samples *t*-tests.

an adjusted *p*-value of 0.01 was used for analyses with the full sample, but because the autistic traits group analyses were exploratory and had smaller samples, this correction was deemed too conservative. An additional sensitivity analysis was conducted given the samples for the high and low autistic trait groups with an alpha of 0.05 and a power of 0.8 for one-tailed correlational analyses, and the required effect size was 0.51 for the high-traits group, and 0.31 for the low-traits group.

For correlational results that differed based on the categorical grouping of high or low on autistic traits, follow-up analyses were conducted using multiple regression to examine autistic traits as a continuous predictor variable as well. Using custom SPSS scripts, a centered variable was created for each variable of interest by calculating the difference between each score and the mean for that variable. Next, interaction terms were created by multiplying the relevant centered variables. The centered variables and interaction terms were then included as dependent and independent variables in relevant regression analyses.

3. Results

3.1. Questionnaire analyses

A positive correlation was found between TAS-20 Total score and SRS-2 Total score ($r(73) = 0.54$, $p < .001$), with more alexithymic traits relating to more autistic traits. A significant negative association was found between RMET accuracy and TAS-20 Total ($r(70) = -0.33$, $p = .004$), with better emotion recognition relating to fewer alexithymic traits. These significant correlations remain significant with the adjusted p-value, $p = .01$. Finally, a marginal correlation was found between SRS-2 Total score and RMET score ($r(72) = -0.20$, $p = .089$), but when examining this association after controlling for TAS-20, this trend went away ($r(69) = -0.027$, $p = .82$).

3.2. Heart rate change in groups high and low on interoceptive accuracy

The 3 (Valence: negative, neutral, positive) × 2 (IA: high, low) repeated-measures ANOVA revealed a significant effect of image valence on HR deceleration, ($F(2,144) = 7.39$, $p = .001$, $\eta_p^2 = 0.093$).

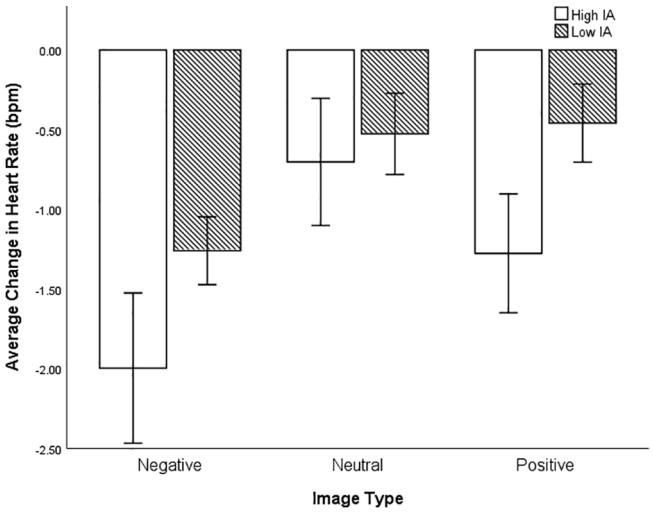

Fig. 1. Average change in heart rate (HR) to negative, neutral, and positive images based on groups high and low on interoceptive accuracy (IA). HR deceleration was greater to negative images as compared to positive and neutral (*ps* = .001). High IA showed marginally greater HR deceleration as compared to low IA ($p = .088$). Error bars reflect ± SEM.

Follow-up *t*-tests showed greater HR change to negative images ($M = -1.47$, $SD = 1.75$) as compared to positive ($M = -0.67$, $SD = 1.79$; $t(74) = 3.50$, $p = .001$, $d = 0.46$) and neutral ($M = -0.54$, $SD = 1.85$; $t(74) = 3.43$, $p = .001$, $d = 0.52$), and no difference between positive and neutral images ($p = .58$). With negative images resulting in the most pronounced HR response, as has been consistently found in past work (e.g., Bradley et al., 2008), this variable was used in subsequent correlational analyses.

There was a marginally significant effect of IA group ($F(1,72) = 2.98$, $p = .088$, $\eta_p^2 = 0.04$), with a trend towards greater HR deceleration in response to images overall in the group with high IA ($M = -1.33$, $SD = 1.45$) as compared to those with low IA ($M = -0.75$, $SD = 1.23$). The valence × IA interaction was not significant ($F(2,144) = 0.81$, $p = .44$, $\eta_p^2 = 0.011$; see Fig. 1), but exploratory post-hoc t-tests were carried out to compare the differences in HR change to the three images between participants high and low on IA, in line with the results reported by Pollatos et al. (2007). As suggested by Fig. 1, results showed trends towards greater HR deceleration to positive and negative images in participants showing high IA as compared to low IA (positive: $t(72) = 1.80$, $p = .076$, $d = 0.47$; negative: $t(72) = 1.64$, $p = .11$, $d = 0.39$), but this was not the case for neutral images ($t(72) = 0.37$, $p = .71$, $d = 0.10$).

3.3. Correlational analyses in full sample and groups high and low on autistic traits

3.3.1. Baseline RSA and questionnaire measures

3.3.1.1. Full sample. When examined in the full sample, no significant correlations were found between baseline RSA and SRS-2 Total score, TAS-20 Total score, or RMET score (*ps* > .23; see Table 2).

3.3.1.2. Groups based on high vs. low autistic traits. In the high autistic traits group, significant negative correlations were found between baseline RSA and both SRS-2 Total score ($r(16) = -0.52$, $p = .026$) and TAS-20 ($r(16) = -0.72$, $p = .001$; see Fig. 2), with greater baseline RSA relating to fewer autistic and alexithymic traits. Surprisingly, in the low autistic traits group, a significant negative correlation was found between baseline RSA and RMET ($r(54) = -0.28$, $p = .038$), with higher RSA associated with worse emotion recognition skills. No other significant correlations were found

Table 2
Correlations between respiratory sinus arrythmia at baseline, interoceptive accuracy and questionnaires.

	SRS-2	TAS-20	RMET	IA
Baseline RSA				
Full sample	−0.07 (0.57)	0.01 (0.91)	−0.14 (0.25)	−0.07 (0.54)
Low traits	0.10 (0.45)	0.21 (0.12)	−0.28 (0.038)*	−0.24 (0.075)
High traits	−0.52 (0.026)*	−0.72 (0.001)**	0.25 (0.35)	0.60 (0.009)**

Note. RSA = Respiratory Sinus Arrythmia; SRS-2 = Social Responsiveness Scale, Second Edition; TAS-20 = Toronto Alexithymia Scale; RMET = Reading the Mind in the Eyes Test; IA = Interoceptive Accuracy; Low traits = Low autistic traits; High traits = High autistic traits. Correlations (r) shown with *p*-value in parentheses. *$p < .05$; **$p < .01$.

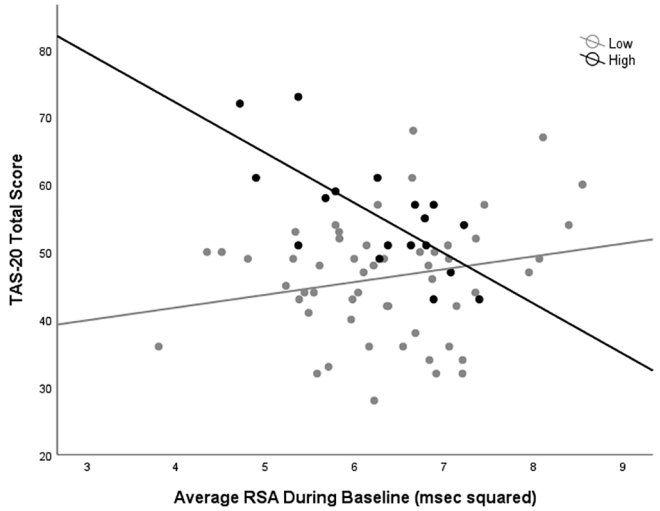

Fig. 2. Correlations between baseline respiratory sinus arrhythmia (RSA) and alexithymia in groups high and low on autistic traits. In the high autistic traits group, higher RSA was correlated with fewer alexithymic traits ($p = .001$), while in the low traits group, there was no association ($p = .12$).

with baseline RSA in either group (*ps* > .11; see Table 2).

A follow-up multiple regression analysis was conducted to examine the contribution of autistic traits and baseline RSA, and the interaction between the two, to alexithymia. A multiple regression model was conducted with TAS-20 Total as the dependent variable, and baseline RSA and SRS-2 Total score, as well as the interaction between the two, as independent variables. The results of the regression indicated that the model explained 30.9% of the variance ($R^2 = 0.31$) and was a significant predictor of alexithymia, $F(4,68) = 7.61$, $p < .001$. While autistic traits independently contributed to the variance in alexithymia (beta = 0.51, $p < .001$), baseline RSA did not (beta = 0.04, $p = .69$), nor did the interaction between baseline RSA and ASD (beta = −0.14, $p = .20$). Therefore, although the relations between RSA and alexithymia differ based on groups who are high vs. low on autistic traits, when autistic traits are examined as a continuous variable, interaction effects with RSA are not significant in predicting alexithymia.

A second follow-up multiple regression analysis was conducted to examine the contribution of autistic traits and baseline RSA, and the interaction between the two, to emotion recognition. A multiple regression model was conducted with RMET as the dependent variable, and baseline RSA and SRS-2 Total score, as well as the interaction between the two, as independent variables. The results of the regression indicated that the model explained 8.7% of the variance ($R^2 = 0.087$) and that the model is not a significant predictor of emotion recognition, $F(4,71) = 1.59$, $p = .19$. None of the model coefficients independently contributed to the variance in emotion recognition ability (*ps* > .15). Therefore, although the relations between RSA and emotion recognition differ based on groups who are high vs. low on autistic traits, when autistic traits are examined as a continuous variable, interaction effects with RSA are not significant in predicting emotion recognition ability.

3.3.2. Heart rate change to negative images and questionnaire measures

3.3.2.1. Full sample. When examining the full sample for correlations with change in HR to negative stimuli, no significant associations were found with SRS-2, TAS-20, or RMET (*ps* > .08; see Table 3).

3.3.2.2. Groups based on high vs. low autistic traits. In the high autistic traits group, change in HR to negative stimuli and TAS-20 Total score were positively correlated and bordering on significance ($r(16) = 0.46$, $p = .052$; see Fig. 3), with greater negative change in HR relating to fewer alexithymic traits. Change in HR to negative stimuli was not

Table 3
Correlations between change in heart rate to negative images, interoceptive accuracy, and questionnaires.

	SRS-2	TAS-20	RMET	IA
ΔHR to negative				
Full sample	0.20 (0.084)	0.16 (0.18)	−0.14 (0.26)	0.04 (0.75)
Low traits	0.02 (0.87)	0.03 (0.84)	−0.07 (0.63)	0.05 (0.70)
High traits	0.39 (0.11)	0.46 (0.052)	−0.27 (0.31)	−0.02 (0.94)

Note. ΔHR = Change in Heart Rate; SRS-2 = Social Responsiveness Scale, Second Edition; TAS-20 = Toronto Alexithymia Scale; RMET = Reading the Mind in the Eyes Test; IA = Interoceptive Accuracy; Low traits = Low autistic traits; High traits = High autistic traits. Correlations (r) shown with p-value in parentheses.

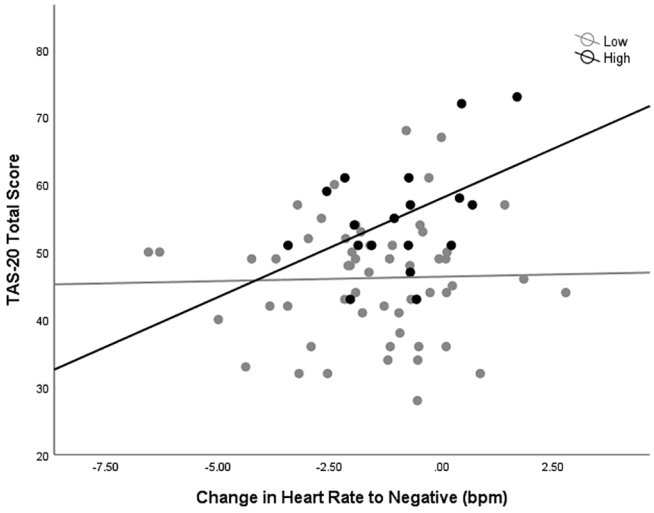

Fig. 3. Correlations between change in heart rate (HR) to negative images and alexithymic traits in groups high and low on autistic traits. In the high autistic traits group, a trend towards greater HR deceleration to negative images relating to fewer alexithymic traits was found ($p = .052$), but this correlation was not significant for the low autistic traits group ($p = .84$).

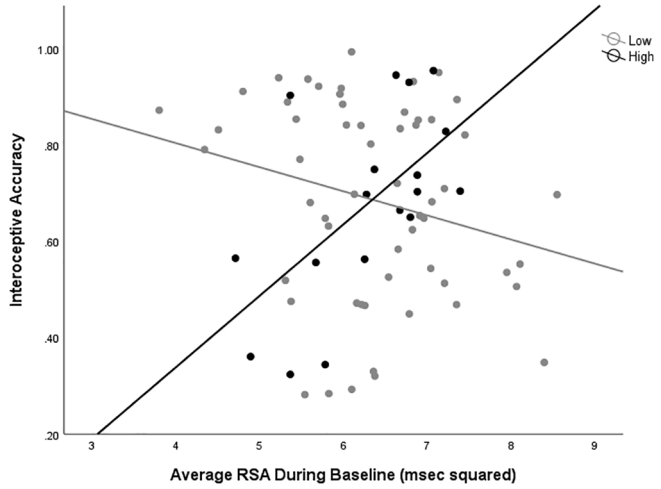

Fig. 4. Correlations between interoceptive accuracy (IA) and baseline respiratory sinus arrhythmia (RSA) in groups high and low on autistic traits. In the high autistic traits group, higher RSA was significantly correlated with higher IA (p = .009), but this was marginally significant in the opposite direction in the low autistic traits group (p = .075).

significantly correlated with SRS-2 or RMET (ps > .10). In the low autistic traits group, no significant correlations were found between change in HR to negative stimuli and SRS-2, RMET, or TAS-20 (ps > .62; see Table 3).

With the correlation bordering on significance in the high autistic traits group but not in the low autistic traits group, a follow-up multiple regression analysis was conducted to examine whether autistic traits and alexithymia explain a significant amount of variation in change in HR to negative stimuli, a measure of emotion processing. A multiple regression model was carried out with change in HR to negative stimuli as the dependent variable, and TAS-20 Total and SRS-2 Total, and the interaction between the two, as independent variables. The results of the regression analysis indicated that the model explained 10.7% of variance in alexithymia (R^2 = 0.11) and that the model was only a marginal predictor of change in HR, $F(4,68)$ = 2.04, p = .099. While autistic traits and alexithymia did not contribute significantly to the model (ps > .63), the interaction between them did (beta = 0.28, p = .034). This shows that in addition to differences in the relations between change in HR and alexithymia for high vs. low autistic trait groups, autistic traits examined as a continuous variable also interact with alexithymia to predict heart rate change to negative images.

3.3.3. IA and RSA

3.3.3.1. Full sample. No significant correlation was found in the full sample between baseline RSA and IA (p = .54; see Table 2).

3.3.3.2. Groups based on high vs. low autistic traits. In the high autistic traits group, a significant positive correlation was found between baseline RSA and IA ($r(16)$ = 0.60, p = .009), suggesting higher RSA at baseline relates to higher IA. In the low autistic traits group, a marginal association in the opposite direction was found ($r(55)$ = −0.24, p = .075), with a trend towards higher RSA relating to lower IA (see Table 2 and Fig. 4).

A follow-up multiple regression analysis was conducted to examine whether autistic traits and baseline RSA explain a significant amount of variance in IA. A multiple regression model was carried out with IA as the dependent variable, and baseline RSA and autistic traits, as well as the interaction between the two, as independent variables. The results of the regression analysis indicated that the model explained 7.5% of the variance in IA (R^2 = 0.075) and that the model is not a significant predictor of IA, $F(4,70)$ = 1.41, p = .24. While none of the independent variables contributed significantly to the model (ps > .37), the interaction between them did (beta = 0.27, p = .034). This suggests that in addition to autistic trait groups (high vs. low) differing in their relations between RSA and IA, when autistic trait levels are treated as a continuous variable, they also interact with RSA to predict IA.

Table 4
Correlations between interoceptive accuracy and questionnaires.

	SRS-2	TAS-20	RMET
Interoceptive accuracy			
Full sample	0.03 (0.78)	−0.11 (0.37)	0.13 (0.26)
Low traits	0.19 (0.16)	−0.08 (0.56)	0.21 (0.12)
High traits	−0.24 (0.33)	−0.20 (0.44)	−0.06 (0.84)

Note. SRS-2 = Social Responsiveness Scale, Second Edition; TAS-20 = Toronto Alexithymia Scale; RMET = Reading the Mind in the Eyes Test; Low traits = Low autistic traits; High traits = High autistic traits. Correlations (r) shown with p-value in parentheses.

3.3.4. IA and heart rate change

3.3.4.1. Full sample. No significant correlation was found in the full sample between IA and change in HR to negative stimuli (p = .75; see Table 3).

3.3.4.2. Groups based on high vs. low autistic traits. In both the high and low autistic traits groups, no significant correlations were found between IA and change in HR to negative images (ps > .69; see Table 3).

3.3.5. IA and questionnaire measures

3.3.5.1. Full sample. No significant correlations were found in the full sample between IA, SRS-2, TAS-20 or RMET (ps > .25; see Table 4).

3.3.5.2. Groups based on high vs. low autistic traits. In both high and low autistic traits groups, no significant correlations were found between IA, SRS-2, TAS-20 or RMET (ps > .11; see Table 4).

4. Discussion

The present study examined cardiac autonomic measures (RSA and HR), awareness of one's cardiac responses (IA), and emotion processing (alexithymia and emotion recognition) as they related to each other and to variability in autistic traits in a group of college students. The main findings were: 1) alexithymic traits mediate the relationship between autistic traits and emotion recognition; 2) heart rate deceleration is greatest in response to negative images; 3) participants with higher interoceptive accuracy show a trend towards greater HR deceleration to emotional images; 4) in individuals with elevated autistic traits, higher baseline RSA was associated with fewer autistic traits, fewer alexithymic traits, and higher IA; and 5) when looking at autistic traits as a continuous variable, autistic traits interact with alexithymic traits to predict HR change to negative stimuli and autistic traits interact with RSA to predict IA.

A large number of studies have identified emotion processing difficulties in individuals with ASD (e.g., Ashwin et al., 2006), but work now points to alexithymia as a key factor underlying these difficulties (e.g., see Bird and Cook, 2013). The current findings support this latter conclusion, as significant associations were found between autistic traits and alexithymia, as well as between alexithymia and emotion recognition, but the marginal relationship between autistic traits and emotion recognition became non-significant after controlling for alexithymia. This work helps to extend the alexithymia hypothesis (Bird and Cook, 2013) into a sample of non-autistic individuals.

Consistent with previous work (e.g., Bradley et al., 2008), heart rate

deceleration to negative images was most pronounced as compared to responses to positive or neutral images in the current study. This has been described as reflecting increased attentional resources to the most attentionally-demanding stimulus (see Leppänen and Nelson, 2009, 2012) and has been associated with increased responding of the parasympathetic nervous system (Bradley et al., 2001). Unlike past work by Pollatos et al. (2007), however, participants who were high on interoceptive accuracy showed only marginally greater HR deceleration as compared to the low IA group, and this did not significantly interact with the emotional content of the image. While exploratory follow-up revealed trends towards a more pronounced HR deceleration to positive and negative images for the group who is more accurate at perceiving their heartbeats, more work is needed to understand why the current study showed diminished effects in comparison to Pollatos et al. (2007). Relationships between heartbeat perception scores as a continuous variable and HR deceleration for each of the three image categories were also found in past work (Pollatos et al., 2007), but the current study found no associations when similar analyses were done. One potential factor that could lead to the discrepancy in findings is the level of emotionality of the images used across the two studies. On examination of HR changes found in Pollatos et al. (2007), high and low IA groups show mean changes in HR ranging from about -1.5 to -3.5 beats per minute, while the current participants have mean changes in HR ranging from -0.5 to -2, suggesting that the current study used images with lower emotional intensity that lead to a diminished HR response.

In the group of participants with elevated autistic traits, the present study found that having fewer alexithymic traits was related to higher RSA and marginally greater HR deceleration to negative images, but these associations were not found in the low autistic traits group. Work by Lischke et al. (2018) also found lower alexithymia was associated with higher RSA, but their finding was not specific to a subgroup of their sample of neurotypical adults. Among individuals with elevated autistic traits, a group that might show increased difficulties with social-emotional skills, the current findings suggest that those who demonstrate stronger parasympathetic responding exhibit fewer emotion processing difficulties. In the high autistic traits group, increased RSA was also related to fewer autistic traits and higher IA, pointing to a link between stronger parasympathetic control and fewer characteristics of the broader autism phenotype and more accurate ability to track one's own physiological responses. For participants low on autistic traits who might have stronger social and emotional abilities, it is possible that these skills have become more automatic and are less dependent on variation in the parasympathetic system. The current findings in the low autistic traits group actually suggest an association in the opposite direction as would be predicted by past work (e.g., Quintana et al., 2012), with higher RSA relating to worse emotion recognition. With an inability to partial out age in correlational analyses because of high levels of skew, and with limited or missing information on additional factors that could influence RSA (e.g., food intake, water consumption, see Quintana and Heathers, 2014), it is difficult to rule out the role of these potential outside variables.

The current study found that for correlations that differed in significance based on grouping into high vs. low autistic traits, few results were significant when modeled examining autistic traits continuously. When the interaction between autistic traits and alexithymic traits was examined, it resulted in a significant predictor of heart rate change to negative images. Additionally, the interaction between autistic traits and RSA was found to be a significant predictor of IA. For models examining the interaction between autistic traits and RSA to predict alexithymia and emotion recognition, no significant effects were seen. More work is needed to examine why some associations might differ depending on autistic traits as a categorical measure but do not show significant predictive value when modeled as an interaction term with autistic traits as a continuous measure (e.g., the interaction between autistic traits and RSA as a predictor of alexithymia).

In work with children with ASD, correlations between RSA and social and emotional processing have been found to be significant in ASD, but not in TD children examined separately (Bal et al., 2010; Van Hecke et al., 2009), though the opposite has also been found (Klusek et al., 2013). For some studies, when looking at a single group containing children with and without ASD, variability in physiological responses has been predictive of autism-related symptoms and adaptive functioning (e.g., DiCriscio and Troiani, 2017; Neuhaus et al., 2014; Nyström et al., 2018; Van Hecke et al., 2009; for a similar finding in adults, see Cai et al., 2019). The current study suggests that this might not reliably be the case when looking at a non-clinical sample of adults. In line with work by Van Hecke et al. (2009) and others, however, the current findings suggest that variation in autistic traits can differentially affect relations between RSA and socio-emotional abilities.

One important limitation of the current study was that correlations with participants above the SRS-2 cutoff score included a small number of participants, and therefore should be interpreted as preliminary. With this, it was deemed too conservative to correct for multiple comparisons in the current analyses with groups based on high and low autistic traits. Future work with larger samples should continue to explore how a non-clinical sample of individuals scoring high and low on traits of the broader autism phenotype might show differences in their relations between cardiac autonomic activity, perception of one's cardiac responses, and social and emotional processing.

The current study was also limited in the demographic questions asked of participants, making it difficult to look in depth at factors that might influence cardiac autonomic activity (e.g., Heathers, 2014). Future work should include more precise measurement of caffeine consumption and exercise intensity in addition to frequency, as well as detailed information about medications and dosage. A more normally distributed age group should also be included in future work in order to allow for use of this variable in parametric testing, including controlling for age in partial correlations. Furthermore, information about food intake and water consumption was not included in the demographic questionnaire in the current study, but these factors are also important to take into account in future work measuring RSA (e.g., Quintana and Heathers, 2014).

The present study expanded past work to examine five measures related to socio-emotional abilities alongside autistic traits in a sample of college students. These measures included cardiac autonomic activity (RSA and change in HR to negative images), heartbeat perception (IA), and emotion processing (alexithymia and emotion recognition). While work has looked at combinations of these markers in individuals with and without ASD, this is the first study to examine these different measures that relate to and/or reflect individual differences in socio-emotional abilities in a single group of participants. Findings revealed that among college students, those high and low on autistic traits differed in their relations between cardiac autonomic measures, perception of one's cardiac responses, and emotion processing. This adds to a complex literature aimed at understanding how ASD and autistic traits might mediate interconnections between autonomic and behavioral markers related to emotional processing.

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Declaration of competing interest

None.

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