



Understanding anxiety in autistic adolescents: The predictive role of interoceptive beliefs and insight

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ABSTRACT

It is well-established that anxiety and sensory differences are common among autistic adolescents. Interoception has been increasingly studied in relation to anxiety, with alexithymia also considered due to its role in emotional processing and its higher prevalence in autistic populations. This study examined the relationships between interoception, alexithymia, and anxiety in 37 autistic adolescents. Participants completed questionnaires assessing autism traits, anxiety, alexithymia, and interoceptive beliefs, along with cardiac interoception tasks measuring interoceptive accuracy and insight. Correlation, regression, and moderated mediation analyses were conducted. Interoceptive beliefs reflecting autonomic reactivity (BPQ-ANSR) significantly predicted anxiety and remained the only interoceptive variable associated with anxiety in regression models. Interoceptive insight and heartbeat counting accuracy were both associated with alexithymia, although alexithymia did not predict anxiety and did not mediate the interoception–anxiety relationship. Moderated mediation analyses showed that autism traits amplified the direct effect of interoceptive beliefs on anxiety. These findings highlight the importance of considering subjective interoceptive beliefs, particularly those perceived as distressing, rather than focusing solely on objective accuracy. They further suggest that interoceptive-affective mismatches may initially manifest as alexithymia during adolescence, potentially serving as a precursor to later anxiety.

Lay summary: Autistic adolescents that reported greater attention to feelings from their autonomic nervous system (the system that controls processes in the body such as heart rate, blood pressure, digestion, and breathing), but not generally from their bodies, also reported being more anxious. The other factors explored, namely participants' accuracy at detecting their internal bodily signals and their reported difficulty identifying and understanding their emotions (alexithymia), were not associated with anxiety. However, adolescents who were more accurate at detecting their heartbeats, or more aware of their bodily signals, tended to report greater difficulty identifying and describing their emotions. While alexithymia was not linked to anxiety in this age group, these difficulties may play a role in emotional development and could contribute to anxiety later in life. We also found that autistic traits strengthened the link between distressing bodily sensations and anxiety.

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1. Introduction

It is well established that anxiety is prevalent amongst autistic children and young people (e.g., [Joshi et al., 2010](#)) with research indicating that up to 82% of autistic youth experience long-term clinically significant anxiety ([Kerns et al., 2021](#); [Ben-Itzhak et al., 2020](#); [Bougeard et al., 2021](#); [Hollocks et al., 2023](#)). Anxiety poses numerous challenges for autistic young people including exacerbating restricted and repetitive behaviours ([Baribeau et al., 2020](#)) and sensory sensitivities ([Mazurek et al., 2013](#)) and has been associated with social challenges ([Factor et al., 2017](#); [McVey et al., 2018](#)), reduced school engagement ([Wood, 2006](#)), difficulty completing schoolwork ([Adams & Emerson, 2021](#)), depression, self-harming behaviours ([Kerns et al., 2015](#)), physical health issues and sleep problems ([Williams et al., 2015](#)). Consequently, a greater understanding of factors contributing to anxiety in this population could help to inform effective avenues for support.

Interoception, the processes by which individuals sense, interpret, and regulate signals from inside the body ([Chen et al., 2021](#)), is increasingly being explored in relation to anxiety. The multidimensional nature of interoception involves both unconscious and conscious processes that determine how bodily states are experienced and measured ([Garfinkel et al., 2015](#); [Suksasilp & Garfinkel, 2022](#)). Prominent emotion theorists have long argued that emotion is closely linked with our bodily experiences is shaped by signals from our internal systems. For example, [Damasio's \(2000\) Somatic Marker Hypothesis](#) posits that emotion is an outcome of physiological changes in the body resulting from interactions with the environment that create somatic markers. [Feldman Barrett's \(2017\) Theory of Constructed Emotion](#) also posits that the brain constantly draws upon previous experience to predict and categorise physiological signals in order to provide meaning regarding our emotional state ([Feldman Barrett, 2017](#)). Interoception is therefore believed to play a vital role in our emotional experience, and interoceptive differences across different dimensions have been associated with mental health, including anxiety ([Khalsa et al., 2018](#); [Paulus & Stein, 2010](#)).

Research indicates that the perception and response to our internal bodily signals is not equal for everyone, and these differences may contribute to individuals' experiences of anxiety. Research highlights that a greater internal focus on interoceptive signals is associated with greater anxiety, in adolescents ([De Berardis et al., 2007](#)) and adults ([Olatunji et al., 2007](#)). And anxiety disorders are associated with an increased focus on autonomic bodily processes ([Mumford et al., 1991](#)). In addition, individuals that experience anxiety may present with a tendency to catastrophise their interpretations of their bodily signals ([Ehlers, 1993](#)), a response which may become conditioned over time, and play a subsequent role in maintaining anxiety symptoms ([Bouton et al., 2018](#); [Paulus & Stein, 2006, 2010](#)). In terms of interoceptive accuracy, earlier studies reported positive associations between heartbeat-perception performance and anxiety in adults with ([Van der Does et al., 2000](#); [Zoellner & Craske, 1999](#); [Pollatos et al., 2007](#)) and without ([Critchley et al., 2004](#)) an anxiety diagnosis, a finding that has also been extended to children ([Eley et al., 2004](#)). Conversely, some research has found the opposite to be true ([De Pascalis et al., 1984](#)) or demonstrated no relationship at all ([Ehlers et al., 1988](#)). More recent evidence further highlights this inconsistency: a large meta-analysis found no association between cardiac interoceptive accuracy and anxiety, with neither age nor gender moderating the relationship ([Adams et al., 2022](#)). In addition, a recent meta-analysis examining self-reported interoception and anxiety reported mixed results, with effects varying depending on the interoceptive facet assessed and the characteristics of the samples included ([Clemente et al., 2024](#)). Together, these mixed findings in the research could be indicative of other factors playing a role in the complex relationship between interoception and anxiety.

Sensory processing differences are commonly experienced by autistic individuals ([Schaaf & Lane, 2015](#)) and there is a growing body of research exploring interoception in this group, with mixed findings. Numerous studies have reported interoceptive differences between autistic and non-autistic groups with autistic adults ([Bonete et al., 2023](#); [Fiene & Brownlow, 2015](#); [Fiene et al., 2018](#); [Garfinkel et al., 2016](#); [Hassen et al., 2023](#); [Mul et al., 2018](#)) and children and adolescents ([Nicholson et al., 2019](#); [Palser et al., 2018a](#); [Yang et al., 2021](#)) demonstrating reduced interoceptive ability. Qualitative studies have also reported that many autistic individuals describe limited awareness of, or difficulty understanding, their internal bodily signals (e.g., [Trevisan et al., 2021](#)). However, the findings in relation to differences in interoception between autistic and non-autistic individuals are also mixed with other research, finding no differences on measures of interoception between autistic and non-autistic adults ([Failla et al., 2020](#); [Mash et al., 2017](#); [Nicholson et al., 2018](#); [Nicholson et al., 2019](#); [Shah et al., 2016](#)) and children and adolescents ([Butera et al., 2023](#); [Failla et al., 2020](#); [Mash et al., 2017](#); [Schauder et al., 2015](#)) or a heightened awareness to internal bodily signals ([Garfinkel et al., 2016](#); [Zdankiewicz-Ścigala et al., 2021](#)).

The discrepancy in findings in relation to autism and interoception, and interoception and anxiety indicates that these relationships require further exploration. [Garfinkel et al., \(2016\)](#) propose that the discrepancy between subjective and behavioural interoception measures, termed Interoceptive Trait Prediction Error (ITPE), contributes to anxiety. Their study with autistic adults showed that differences between interoceptive accuracy (the ability to detect internal bodily signals) and self-reported awareness of those signals were associated with anxiety. [Palser et al. \(2018a\)](#) replicated this finding in autistic children and adolescents, again demonstrating that higher ITPE was linked to greater anxiety. This aligns with theoretical accounts suggesting that anxiety is associated with a failure to accurately predict interoceptive changes ([Paulus & Stein, 2010](#)), which may disrupt the mapping between bodily sensations and emotional experiences, ultimately reducing emotion identification and impairing regulation ([Maisel et al., 2016](#)).

Research further suggests that alexithymia, a difficulty identifying and describing emotions ([Nemiah et al., 1976](#)), may be associated with interoception in autistic individuals. Though not a universal co-occurrence, the prevalence of alexithymia is observed to be greater in autistic populations than the general population ([Kinnaird et al., 2019](#)). The discrepancy in findings in relation to autism and interoception has been theorised to be a result of alexithymia, with the suggestion being that interoception is central to alexithymia, not autism. This theory, labelled the 'alexithymia hypothesis', posits that those that experience reduced interoception do so as a result of co-occurring alexithymia rather than autism ([Bird & Cook, 2013](#); [Brewer et al., 2016](#)). Subsequently, this hypothesis posits that differences in participants' experiences of alexithymia between studies provides an explanation for the mixed findings ([Shah et al.,](#)

2016) with research findings lending support to this hypothesis (Herbert et al., 2011; Shah et al., 2016; Trevisan et al., 2019).

It has been proposed that alongside interoception, alexithymia contributes to anxiety in autistic individuals. It is suggested that in this group, sensory processing difficulties and alexithymia both contribute to intolerance of uncertainty, which subsequently leads to heightened anxiety (Boulter et al., 2013; Maisel et al., 2016; South & Rodgers, 2017). Alexithymia has been shown to be associated with heightened anxiety in non-autistic adults (Besharat, 2008; Devine et al., 1999; Marchesi et al., 2004) and adolescents (Karukivi et al., 2010) and to mediate the relationship between interoceptive beliefs and anxiety in a non-autistic sample (Palser et al., 2018b). Alexithymia has not been explored in relation to interoception and anxiety in autistic adolescents, despite alexithymia being elevated in this population (Milosavljevic et al., 2016).

The current study aims to explore the relationship between interoception, alexithymia, and anxiety in autistic adolescents. Specifically, we examine whether interoceptive accuracy, interoceptive beliefs (reported experiences interoception), interoceptive insight (how well an individual's interoceptive accuracy and beliefs correspond with each other), and ITPE (Garfinkel et al., 2016), are associated with anxiety in autistic adolescents. Furthermore, we will investigate the relationship between the different dimensions of interoception and alexithymia, as well as the role of alexithymia in the relationship between interoception and anxiety.

2. Research questions and hypotheses

This study aims to answer the following research questions: (a) Are alexithymia, interoceptive accuracy, beliefs, and insight associated with anxiety in autistic adolescents? It was predicted that these constructs would be associated with anxiety in this population; (b) are interoceptive accuracy, beliefs, and insight associated with alexithymia in autistic adolescents? Specifically, we hypothesised that interoceptive accuracy, beliefs, and insight would be associated with alexithymia in autistic adolescents; (c) are differences between performance on measures of interoceptive accuracy and interoceptive beliefs (i.e. ITPE) associated with anxiety in autistic adolescents? It was hypothesised that ITPE would be associated with anxiety in autistic adolescents. An additional aim was included, though due to the size of the sample, analyses related to this aim was exploratory: (d) does alexithymia mediate the relationship between interoception and anxiety in autistic adolescents? It was predicted that alexithymia would mediate the relationship between interoception and anxiety.

3. Method

3.1. Participants

A priori power analysis was conducted in G*Power (Faul et al., 2007) using effect sizes reported in Garfinkel et al. (2016); ($r = .54-.69$) and Palser et al. (2018a); ($r = .518$). Using a conservative expected correlation of $r = .50$, $\alpha = .05$, and power = .80, the Exact test for bivariate correlations indicated a required minimum sample of $N = 29$.

Thirty-nine participants were recruited for the study from eight participating schools and colleges in the South East of England, between March 2023 and January 2024. Two participants withdrew from the study before data collection. Participants ranged from 11 to 18 years of age ($M = 13.7$; $SD = 1.97$). Eleven participants identified as female (29.7%). One participant was Black, Black British, Caribbean or African, whilst the remainder of the participants were White British. All participants taking part in the study either had a formal diagnosis or self-identified as autistic (identified through a question on the screening questionnaire). All participants were asked to complete the Autism Symptom Self-Report (ASSERT; Posserud et al., 2013), a seven item self-report questionnaire exploring autism traits. A large-scale analysis of ASSERT has demonstrated that it has good validity when used with an adolescent sample (Posserud et al., 2013). Two participants (5.4%) self-identified as autistic. In addition, 11 participants (29.7%) reported having an additional neurodevelopmental or medical diagnosis. No participants were diagnosed with an anxiety disorder or taking any medication for anxiety. Written parental consent was provided for all participants under the age of 16 and assent gained from participants. For those aged 16 and over, written consent was gained from the participants themselves.

4. Measures

4.1. Screening questionnaire

A researcher-created screening questionnaire was used to collect data relating to demographic characteristics (age, sex, race), diagnostic status, and additional diagnoses.

4.2. Interoceptive accuracy – heartbeat perception tasks

Two behavioural measures of cardiac interoception, the Heartbeat Counting Task (HCT; Schandry, 1981) and the Heartbeat Discrimination Task (HDT; Whitehead et al., 1977) were used to measure interoceptive accuracy. A pulse oximeter was used in both tasks, tracking heartbeats in real time.

In the HCT participants were asked to silently count their heartbeat over six different, randomly presented, time intervals (25, 30, 35, 40, 45, and 50 s) without putting their hands on their body and report the number of heartbeats they had counted. This task has been shown to have good reliability (Santos et al., 2023) and to be sensitive to individual differences (Garfinkel et al., 2015). After each trial, participants were asked to rate how confident they were in counting their heartbeats successfully by marking a visual analogue

scale, 100 mm long, one end labelled, 'Not confident at all' and the other end labelled, 'Very confident'. The point at which participants marked the line was measured, providing a number out of 100 (mm) for each trial, reflecting participants' confidence on that trial.

In the HDT participants were played a series of tones through headphones, which were either in sync or slightly delayed by 300 ms relative to their heartbeat. Participants were asked to indicate if they thought the tones were in or out of sync with their heartbeat. Average accuracy was calculated for analysis. Each participant completed 20 trials. Similarly, participants were asked to rate their confidence after each trial on a 100 mm visual analogue scale.

4.3. Interoceptive beliefs

The Body Perception Questionnaire Short Form (BPQ-SF; Porges, 1993) was utilised to measure subjective experiences of interoceptive processes. This questionnaire consists of two subscales, Body Awareness (BPQ-BA) and Autonomic Nervous System Reactivity (BPQ-ANSR). The questionnaire consists of 46 items which participants are required to respond to using a 5-point ordinal scale ranging from 'Never' to 'Always.' Scores for each subscale are calculated by attributing 1 point for answers of, 'Never', increasing by one point for every scale item up to 5 points for, 'Always'. The BPQ-BA subscale has 26 items and measures an individuals' sensitivity to internal bodily function. Participants were asked to rate their awareness of characteristics related to their bodily signals (e.g., 'how hard my heart is beating'). The BPQ-ANSR subscale consists of 20 items and provides a measure of the responses of the autonomic nervous system. Participants were asked to indicate how often they are aware of bodily sensations related to the autonomic nervous system (e.g., 'my heart often beats irregularly'). The mean was calculated for each subscale. Cabrera et al., (2017) demonstrated that BPQ-SF has good internal consistency ($\alpha = .92$), convergent validity, and test-retest reliability ($\alpha = .99$).

4.4. Interoceptive insight

Interoceptive insight was calculated for each interoceptive accuracy task by evaluating the relationship between accuracy and confidence judgements. As outlined in (Garfinkel et al., 2015), for the HDT a receiver operating characteristic (ROC) curve analysis of the extent to which confidence judgements reflected accuracy, was carried out to establish interoceptive insight for this measure. For the HCT, a Pearson correlation was carried out between accuracy scores and confidence judgements for each participant.

4.5. Interoceptive trait prediction error (ITPE)

As outlined in Garfinkel et al., (2015), ITPE was determined by calculating the difference between scores on the interoceptive accuracy tasks and scores on the BPQ-BA subscale. Scores for each measure were converted into Z-scores. The differences between beliefs Z-scores and accuracy Z-scores were calculated to establish two ITPE scores, one for the HDT (ITPE-D) and one for the HCT (ITPE-C). Negative values were indicative of a tendency for individuals to underestimate their interoceptive accuracy, and positive values were indicative of a tendency to overestimate.

4.6. Alexithymia

The Alexithymia Questionnaire for Children (AQC; Rieffe et al., 2006) was utilised as a measure of alexithymia in the current study. The AQC was adapted from the Toronto Alexithymia Scale (Bagby et al., 2005) for use with children and adolescents and consists of 20 items within three subscales: Difficulty Identifying Feelings (DIF; 7 items), Difficulty Describing Feelings (DDF; 5 items), and Externally Oriented Thinking (EOT; 8 items). The internal consistency for the DIF and DDF subscales has been shown to be good ($\alpha = 0.73$ and $\alpha = 0.75$, respectively). The internal consistency of the EOT subscale, however, is low ($\alpha = 0.29$) (Rieffe et al., 2006) and a two-factor model, excluding the EOT subscale, has been shown to be a better fit (Loas et al., 2017). Subsequently, scores for the EOT subscale were not analysed.

4.7. Anxiety

The Generalized Anxiety Disorder 7-item (GAD-7) scale was utilised as a measure of anxiety. This has been shown to have good construct validity and internal consistency in adolescent populations ($\alpha = 0.91$; Tiirikainen et al., 2019) and good validity in adolescents with autistic traits ($\alpha = 0.89$; Schwartzman & Bettis, 2024). The GAD-7 self-report questionnaire requires individuals to rate how often in the previous two weeks they have experienced seven items. Answers are rated on a 4-point scale of not at all, several days, more than half the days, and nearly every day. Higher scores are indicative of more severe anxiety symptoms.

4.8. Procedure

Representatives from the involved schools and colleges sent out information sheets and consent forms to the parents of autistic pupils or to the pupils themselves in colleges and sixth forms. Following receipt of informed consent forms, participants were sent a Qualtrics link to complete the screening questionnaire, BPQ-SF, AQC, and ASSERT online at home, with the alternate option to complete the questionnaires at their school/college on the day they were visited by the lead researcher.

Participants met with the researcher in a quiet room at their school or college during the school day to complete the HDT, HCT, and the GAD-7, taking approximately 25–30 min per participant. Following their involvement, participants were thanked and provided

with a debrief sheet. A £ 10 voucher was given to all participants as thanks for their participation. To ensure the project reflected the needs of participants, a Lived Experience Advisory Panel (LEAP) of four autistic adolescents was held in a school in the South East of England. This consisted of a one-hour session in which the lead researcher sought to gain the views of participants on the accessibility of the research materials and procedures as well as the relevance of the topic prior to the research commencing. LEAP participants were paid £ 25 each for their time with the option of receiving this as a voucher or in cash. In addition, steps were taken based on the practical guidelines for conducting research with the autistic community outlined by [Gowen et al., \(2019\)](#).

4.9. Data analysis

Initial tests were carried out to assess normality. Independent *t*-tests and Pearson's correlations were conducted to identify any differences in variables as a result of age, gender, race, diagnostic status, or additional diagnoses. Within-group correlational analyses were carried out to explore the relationships between the different facets of interoception, alexithymia, and anxiety. A series of regression and moderated mediation analyses were conducted to examine whether the two alexithymia subscales, difficulty identifying feelings (DIF) and difficulty describing feelings (DDF), mediate the relationship between interoceptive accuracy, beliefs, and insight, and symptoms of anxiety (GAD-7). Twelve models were tested, each including one interoception predictor, one alexithymia subscale (either DIF or DDF) as the mediator, and anxiety (GAD-7) as the outcome variable. Autism trait scores (ASSERT) were included as a moderator of the direct effect, given theoretical links between autism traits and altered interoceptive and emotional processing. Age was entered as a covariate due to its significant negative correlation with ASSERT scores. Regression models were used to assess direct relationships between predictors, mediators, and anxiety symptoms. Moderated mediation analyses were conducted using the PROCESS macro for SPSS (Model 5), with 5000 bootstrap samples to estimate indirect effects and their confidence intervals ([Hayes et al., 2011](#)).

5. Results

5.1. Data screening

Independent *t*-tests and bivariate correlations were conducted to identify any between-group differences in age, sex, race, autism diagnostic status, and additional diagnoses, and each dependent variable. A significant correlation between age and ASSERT scores ($r = -0.420$, $p = 0.01$) was found. No other significant relationships were identified. Notably, there was no significant difference in ASSERT scores between those that were formally diagnosed and those that self-identified as autistic, as indicated by a Mann-Whitney *U* test, $U = 29$, $z = -0.41$, $p = .721$ (two-tailed, exact), $N = 37$.

Shapiro-Wilks tests indicated that there was deviation from normality for some variables, however observations of Q-Q plots showed that this deviation from normality was minimal. Three of the dependent variables contained outliers, however, when removed there was minimal change to the means, and therefore data were not removed for subsequent analyses.

5.2. Descriptive Statistics

Descriptive statistics for each of the dependent variables can be found in [Table 1](#). [Fig. 1](#) displays violin plots of the same measures.

5.3. Correlational analysis

Correlational analyses revealed significant positive associations between ASSERT scores and the AQC subscales: Difficulty Identifying Feelings (DIF; $r = .470$, $p = .003$) and Difficulty Describing Feelings (DDF; $r = .473$, $p = .003$). A significant positive correlation was also found between BPQ-ANSR scores and GAD-7 scores ($r = .398$, $p = .015$). In addition, Heartbeat Counting Accuracy showed a significant positive correlation with DIF ($r = .337$, $p = .042$), while Heartbeat Counting Insight was positively and significantly associated with both DIF ($r = .366$, $p = .026$) and DDF ($r = .431$, $p = .008$). Heartbeat Discrimination Insight showed a significant positive association with DIF ($r = .329$, $p = .047$). For correlation coefficients, see [Table 2](#).

Table 1
Means and standard deviations for dependent variables.

Variable	M	SD
Anxiety (GAD7)	8.24	3.57
Autism traits (ASSERT)	10	1.91
HB counting accuracy	0.60	0.18
HB discrimination accuracy	0.51	0.11
HB counting insight	0.05	0.52
HB discrimination insight	0.52	0.12
Interoceptive beliefs (BPQ – BA)	2.63	0.62
Interoceptive beliefs (BPQ – ANSR)	1.67	0.52
Alexithymia (AQC – DIF)	0.99	0.48
Alexithymia (AQC – DDF)	1.17	0.49

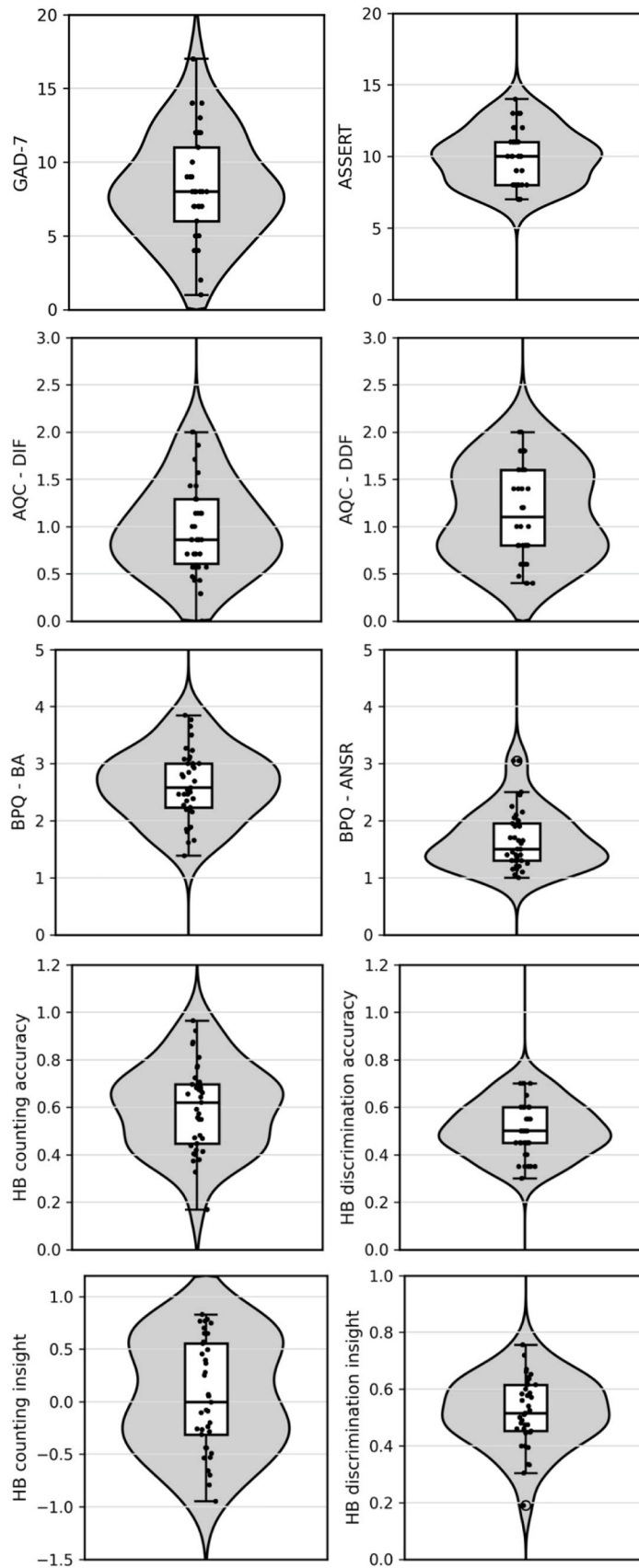


Fig. 1. Violin plots illustrating the distribution of scores for anxiety (GAD-7), autism traits (ASSERT), alexithymia (AQC-DIF and AQC-DDF), interoceptive beliefs (BPQ-BA and BPQ-ANSR), interoceptive accuracy (heartbeat counting and discrimination), and interoceptive insight (heartbeat counting and discrimination).

5.4. Interoceptive insight and anxiety

A one-sample *t*-test was conducted to identify whether heartbeat counting accuracy-confidence correlations significantly differed from zero to establish if interoceptive insight was present across the sample. Heartbeat counting accuracy-confidence correlations did not significantly differ from zero ($t(36) = 0.630, p = 0.533$). Individuals with high ($N = 19$) and low ($N = 18$) interoceptive accuracy scores, as determined by a median split (Median = 0.62), did not differ significantly on their heartbeat counting accuracy-confidence correlations ($t(35) = -0.655, p = 0.517$).

Similarly, a one-sample *t*-test was carried out to identify if the ROC curve analysis of heartbeat discrimination data significantly differed from chance (0.5). The data did not reach above chance significance ($t(36) = 0.940, p = 0.354$). Additionally, ROC curve analysis scores did not differ significantly for individuals categorised as having high ($N = 21$) or low ($N = 16$) scores on the HDT as determined by a median split (Median = 0.5), ($t(35) = 0.732, p = 0.469$). There was a significant negative correlation between interoceptive insight, determined by the ROC curve analysis of heartbeat discrimination data, and heartbeat discrimination accuracy ($r = -0.382, p = 0.02$) suggesting that those that performed better on the HDT had lower confidence in their performance.

Interoceptive insight did not correlate with anxiety scores for heartbeat counting accuracy-confidence correlations ($r = 0.039, p = 0.821$) or for ROC curve analysis of heartbeat discrimination data ($r = 0.121, p = 0.474$). In addition, interoceptive insight on each of the two tasks was not correlated ($r = 0.279, p = 0.095$).

5.5. Interoceptive trait prediction error and anxiety

There were no significant correlations between ITPE-D and anxiety ($r = 0.205, p = 0.225$) or between ITPE-C and anxiety ($r = 0.196, p = 0.244$).

5.6. Regression and mediation analyses

To investigate the role of alexithymia in the relationship between interoception and anxiety, a series of regression and moderated mediation models were tested. Each model included one interoceptive predictor, one alexithymia subscale (DIF or DDF), and anxiety symptoms (GAD-7) as the outcome. ASSERT scores were included as a moderator of the direct effect, and age was controlled for (see Fig. 2).

Body perception measuring autonomic reactivity (BPQ-ANSR) showed a significant association with anxiety symptoms across models. BPQ-ANSR was significantly associated with both DIF ($b = 0.33, p = .034$) and DDF ($b = 0.33, p = .037$), but neither DIF ($p = .374$) nor DDF ($p = .856$) was significantly associated with anxiety. In the DIF model, the direct relationship between BPQ-ANSR and anxiety was non-significant ($b = 2.19, p = .074$). However, examination of the conditional effects showed that at high levels of ASSERT, the association became statistically significant ($b = 4.08, p = .020$). In the DDF model, the direct association between BPQ-ANSR and anxiety was significant ($b = 2.47, p = .048$), and this association also strengthened at high ASSERT levels ($b = 4.33, p = .016$). Indirect effects were non-significant in both models (DIF CI: [-0.68, 1.78]; DDF CI: [-1.14, 1.47]). However, indirect effects were non-significant in both models (DIF CI: [-0.68, 1.78]; DDF CI: [-1.14, 1.47]). Body perception awareness (BPQ-BA) did not significantly predict either DIF ($p = .357$) or DDF ($p = .382$), nor did it significantly predict anxiety (DIF model: $p = .408$; DDF model: $p = .403$). The interaction with ASSERT was also non-significant in both models (DIF: $p = .094$; DDF: $p = .083$), and the indirect effects remained non-significant (DIF CI: [-0.29, 1.40]; DDF CI: [-0.31, 1.12]).

Heartbeat counting accuracy did not show significant associations with DIF ($b = 0.85, p = .066$) or DDF ($b = 0.67, p = .159$), and neither was significantly associated with anxiety (DIF: $p = .087$; DDF: $p = .389$). Indirect effects were non-significant (DIF CI: [-2.15, 5.91]; DDF CI: [-2.71, 4.09]).

Heartbeat counting insight was significantly associated with both DIF ($b = 0.36, p = .019$) and DDF ($b = 0.42, p = .005$), indicating that greater perceived interoceptive insight was associated with higher levels of alexithymia. However, HC insight was not significantly related to anxiety in either model (DIF: $p = .431$; DDF: $p = .682$), and indirect effects were non-significant (DIF CI: [-0.17, 4.12]; DDF CI: [-0.75, 2.70]).

Heartbeat discrimination accuracy showed no significant associations with DIF ($b = -0.54, p = .466$) or DDF ($b = 0.52, p = .487$), and neither DIF ($b = 1.25, p = .374$) nor DDF ($b = 0.25, p = .856$) showed a significant association with anxiety. Heartbeat discrimination insight similarly was not significantly associated with either DIF ($b = 1.23, p = .068$) or DDF ($b = 0.76, p = .272$), and neither DIF ($b = -3.06, p = .414$) nor DDF ($b = 1.94, p = .214$) was significantly associated with anxiety. Indirect effects were non-significant in all models (DIF CI: [-8.48, 2.17]; DDF CI: [-3.29, 5.04] for HD accuracy; DIF CI: [-1.29, 10.23]; DDF CI: [-1.56, 7.27] for HD insight).

Overall, while BPQ-ANSR and HC insight were associated with higher levels of alexithymia, neither DIF nor DDF mediated the relationship between interoception and anxiety. These findings suggest that interoception, specifically as measured by the BPQ-ANSR, may contribute to anxiety independently of self-reported difficulties in identifying or describing feelings.

Table 2
Correlation coefficients for dependent variables.

	GAD-7	HeartbeatCounting (HC) accuracy	HeartbeatDiscrimination (HD) accuracy	HC Insight	HD Insight	BPQ-BA	BPQ-ANSR	DIF (AQC)	DDF (AQC)	ASSERT
GAD-7	1.000									
Heartbeat Counting (HC) accuracy	-0.127	1.000								
Heartbeat Discrimination (HD) accuracy	-0.154	0.212	1.000							
HC Insight	.039	.030	.279	1.000						
HD Insight	.121	.007	-.382*	-.109	1.000					
BPQ-BA	0.161	-0.077	-0.184	.048	.010	1.000				
BPQ-ANSR	0.398*	0.059	-0.093	.099	.029	0.517***	1.000			
DIF (AQC)	0.218	0.337*	-0.117	.366*	.329*	0.136	0.308	1.000		
DDF (AQC)	0.131	0.271	0.125	.431**	.215	0.128	0.302	0.639***	1.000	
ASSERT	-0.020	0.277	-0.046	.166	.051	0.225	0.042	0.470**	0.473**	1.000

Note. Significant results are shown as * $p < .05$. ** $p < .01$. *** $p < .001$ (2-tailed).

6. Discussion

This study aimed to explore the relationship between different dimensions of interoception, alexithymia, and anxiety. In addition, we explored how the different dimensions of interoception are associated with alexithymia and the role of alexithymia in the relationship between interoception and anxiety in autistic adolescents.

Of the interoceptive dimensions examined, only interoceptive beliefs, specifically those measured by the BPQ-ANSR subscale, were significantly associated with anxiety. This subscale captures aversive autonomic experiences such as nausea, chest pain, and gastrointestinal discomfort, which may be perceived as disruptive or distressing. In contrast, the BPQ-BA subscale, which reflects general attention to bodily signals, did not predict anxiety. This distinction suggests that it is not body-focused attention per se, but rather the perception of dysregulated or threatening bodily states that contributes more directly to anxiety in autistic adolescents. These findings align with previous research indicating that anxiety is associated with a tendency to catastrophise bodily sensations (Bouton et al., 2018) and that autistic individuals may struggle to interpret internal cues (Trevisan et al., 2021).

Interoceptive insight related to heartbeat counting significantly predicted alexithymia and remained a consistent predictor across both the DIF and DDF subscales. Heartbeat counting accuracy was also significantly associated with DIF, suggesting that both objective and subjective interoceptive dimensions contribute to difficulties in identifying and describing emotions. These findings contrast with previous adult studies reporting mixed results (e.g., Herbert et al., 2011; Shah et al., 2016; Trevisan et al., 2019) and may reflect developmental differences in interoceptive processing. Given that children and adolescents typically show lower interoceptive accuracy than adults (Yang et al., 2022), the emergence of a significant association in our sample may indicate a unique developmental trajectory or heightened sensitivity to internal signals in autistic adolescents.

Contrary to our hypothesis and previous findings in autistic adults (Garfinkel et al., 2016; Palser et al., 2018a), ITPE was not significantly associated with anxiety in our sample of autistic adolescents. This suggests that mismatches between interoceptive accuracy and beliefs may not yet contribute to anxiety in adolescence, or that their effects are mediated by other developmental factors not captured in this study.

Despite significant associations between interoceptive insight and alexithymia, neither the DIF nor DDF subscales significantly predicted anxiety symptoms. As a result, alexithymia did not mediate the relationship between interoception and anxiety in any model. This finding diverges from some adult studies (Li et al., 2024), suggesting that in adolescents, interoceptive-affective mismatches may initially manifest as alexithymia, potentially serving as a precursor to later anxiety rather than a current mediator.

The Theory of Constructed Emotion (Feldman Barrett, 2017) provides a useful framework for interpreting these findings. According to this model, emotions are constructed through the integration of interoceptive sensations with conceptual and linguistic knowledge. Within this developmental and theoretical context, the absence of a direct association between alexithymia and anxiety in our sample may reflect a stage at which autistic adolescents are still developing the conceptual and language-based resources required to interpret their internal states. We acknowledge that this explanation is partly speculative, but it is consistent with the proposal that heightened interoceptive beliefs—particularly those involving aversive autonomic sensations—may be more readily misinterpreted or catastrophised when individuals have difficulty identifying and labelling bodily cues. Such processes may increase vulnerability to anxiety, as reflected in the observed relationship between BPQ-ANSR and GAD-7 scores. Supporting adolescents in developing more accurate and confident interpretations of bodily signals may therefore help reduce anxiety, particularly when those signals are perceived as threatening or difficult to regulate.

Moderated mediation analyses revealed that ASSERT scores significantly moderated the direct effect of BPQ-ANSR on anxiety, with the relationship being stronger among adolescents with higher autism trait scores. This suggests that autistic traits may amplify the impact of interoceptive beliefs on anxiety, potentially due to increased sensitivity to autonomic arousal or reduced emotional clarity.

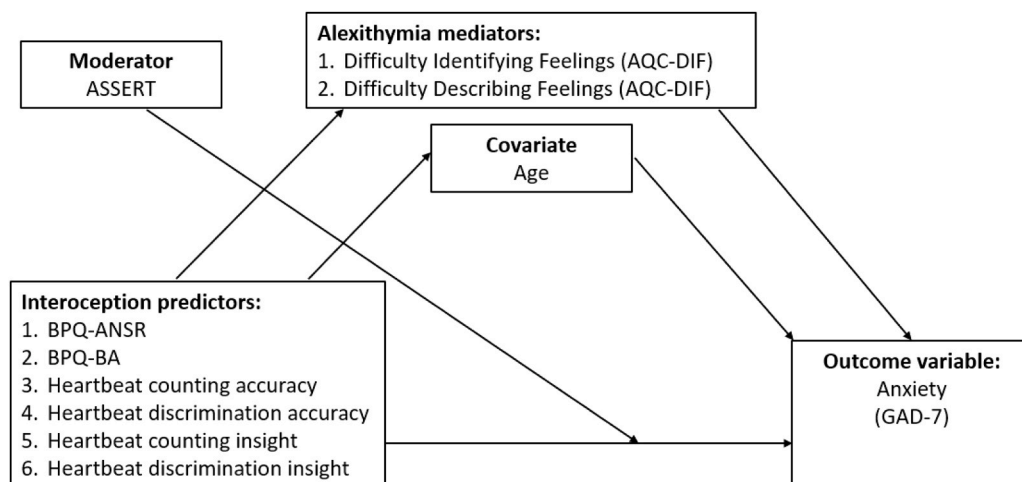


Fig. 2. Schematic representation of the moderated mediation models of interest.

However, no significant indirect effects were found, reinforcing the conclusion that alexithymia does not mediate this relationship in this age group. Notably, 35 of the 37 participants had a formal autism diagnosis, and the two self-identified autistic adolescents did not differ significantly in ASSERT scores. ASSERT scores were negatively correlated with age, suggesting that younger participants reported higher levels of autism-related traits. This age-related variation may reflect developmental differences in self-awareness or symptom expression and should be considered when interpreting the moderating role of ASSERT.

Finally, alexithymia was significantly associated with autism traits, consistent with previous findings (Kinnaird et al., 2019) and highlights the need for continued support in helping autistic adolescents better understand and express their emotional experiences.

7. Limitations

It is important to consider the results of this study in light of its limitations. Firstly, there are some limitations in relation to the sample. The sample size was modest, and whilst sufficiently powered for the correlational analysis, a larger sample would have been beneficial to sufficiently power the multiple regression and moderation analyses. Demographically, the sample was relatively homogenous, consisting mostly of white, male, British participants, and socioeconomic data were not collected.

Concerning methodology, the use of heartbeat perception tasks aligns with current research practices in autism studies (Proff et al., 2022) and allows for comparability. However, these tasks assess interoceptive accuracy in only one sensory channel and, as shown in this study, may not capture a coherent or generalised interoceptive ability across dimensions. For example, the lack of correlation between heartbeat counting and discrimination accuracy suggests that the tasks engage distinct cognitive mechanisms (Garfinkel et al., 2015) and may be influenced by factors such as time estimation (Murphy et al., 2019) or heart rate beliefs (Brener & Ring, 2016). Including control tasks, such as those used by Shah et al. (2016), would have helped to address these confounds. It is also important to note that self-report measures of interoception, such as the BPQ, capture individuals' subjective beliefs about bodily states and do not necessarily correspond to behavioural indices of interoceptive accuracy. This discrepancy has been documented in autistic populations, where subjective ratings may diverge from behavioural or physiological indicators of interoception (Butera et al., 2023; Garfinkel et al., 2016). However, it is not specific to autism. Foundational work in typically developing adults similarly demonstrates that interoceptive sensibility and interoceptive accuracy show only partial overlap and represent related but dissociable constructs (Garfinkel et al., 2015). In the context of this study, BPQ-derived interoceptive beliefs should therefore be interpreted strictly as subjective perceptions rather than objective interoceptive performance. Future research would benefit from integrating self-report, behavioural, and physiological measures to provide a more comprehensive and reliable assessment of interoceptive processes. Importantly, focusing solely on cardiac signals may overlook the potentially broader interoceptive differences experienced by autistic individuals. While sensory abnormalities in autism are typically described as hyper- or hypo-reactivity across exteroceptive sensory modalities (Balasco et al., 2020), similar variability may also exist across interoceptive domains, including cardiac, respiratory, and gastrointestinal axes (DuBois et al., 2016). Future research should incorporate interoceptive measures across multiple domains to reflect the multisensory nature of interoception in autism and to clarify how different internal signals relate to emotional functioning.

8. Conclusion

Our findings suggest that self-reported interoceptive beliefs reflecting autonomic reactivity, as measured by the BPQ-ANSR, were significantly associated with anxiety in autistic adolescents. In contrast, interoceptive accuracy and trait prediction error (ITPE) were not related to anxiety. Interoceptive insight predicted alexithymia, but alexithymia was not associated with anxiety and did not mediate the relationship between interoception and anxiety.

These results add to the mixed literature on interoception in autism, likely reflecting variability in interoceptive and emotional experiences within the autistic population. They also highlight the importance of considering subjective beliefs about interoceptive signals, particularly those perceived as distressing, rather than focusing solely on objective accuracy when supporting autistic adolescents with anxiety.

The findings further suggest that, in autistic adolescents, interoceptive-affective mismatches may initially manifest as alexithymia traits, potentially serving as a precursor to later anxiety rather than a current mediator. This interpretation is supported by the Theory of Constructed Emotion, which emphasises the role of conceptual and linguistic development in shaping emotional understanding. Autistic adolescents may therefore benefit from support in linking bodily sensations to emotional meaning, especially when those sensations are experienced as aversive or difficult to interpret. Interventions could help autistic adolescents develop a clearer understanding of what physiological changes represent and how to respond to them. Specifically, they should be supported in identifying and regulating distressing interoceptive signals associated with anxiety (e.g., raised heart rate), so they feel more equipped to respond adaptively when physiological changes occur.

CRedit authorship contribution statement

Lauren Craik: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lisa Quad:** Writing – review & editing, Validation, Supervision, Methodology, Data curation, Conceptualization. **Matt Garner:** Supervision, Conceptualization. **Gaby Pfeifer:** Writing – review & editing, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Data curation.

Ethics

Ethical approval was gained from the University of Southampton Ethics Board and Research Integrity Governance team (ERGO ID: 79622).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.reia.2026.202860](https://doi.org/10.1016/j.reia.2026.202860).

Data availability

Data will be made available on request.

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