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Interoceptive accuracy mediates the longitudinal relationship between attention deficit hyperactivity disorder (ADHD) inattentive symptoms and disordered eating in a community sample

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Abstract

Attention deficit hyperactivity disorder (ADHD) symptoms are associated with disordered eating and interoceptive deficits (as assessed by reliance on hunger/satiety cues) have been suggested as a potential mediating influence. The aim of this longitudinal study was to examine whether the association between ADHD symptoms and disordered eating is explained by deficits in specific facets of interoception. We also aimed to provide further evidence on the previously reported association between ADHD symptoms, negative mood and disordered eating. A community-based sample of 345 adult men and women (*M* age = 33.9, 72.5% women) completed questionnaires assessing disordered eating (restrictive and binge-type), ADHD symptoms, reliance on hunger/ satiety cues, specific facets of interoception (interoceptive accuracy and interoceptive sensibility) and negative mood at two timepoints over a 6-month period. We tested the mediating influence of reliance on hunger/satiety cues, facets of interoception and negative mood on the relationship between ADHD symptoms and disordered eating. Reliance on hunger/satiety cues mediated the relationship between inattentive symptoms of ADHD and both restrictive and binge-type eating. Interoceptive accuracy, but not sensibility mediated the relationship between inattentive ADHD symptoms and binge-type eating. Negative mood mediated the relationship between both ADHD symptom types and restrictive and binge-type eating. The results from this longitudinal study confirm that deficits in interoception and negative mood contribute to the relationship between ADHD symptoms and disordered eating and extend knowledge by highlighting interoceptive accuracy specifically as the most important facet of interoception in the relationship between inattentive symptoms and binge-type eating.

1. **Introduction**

Symptoms of Attention Deficit Hyperactivity Disorder (ADHD) are consistently associated with an increased risk of disordered eating, particularly binge and disinhibited eating (Kaisari et al., 2017). This relationship may suggest that the cognitive symptoms which are central to ADHD (e.g. inattention and impulsivity) foster disordered eating behaviour. To date, it is unclear how exactly ADHD symptoms may contribute towards disordered eating, as few studies have investigated the contribution of specific symptoms of ADHD to disordered eating, or explored potential mediators of this relationship.

One potential mediator is negative mood/emotional dysregulation. Symptoms of depression and anxiety are elevated in both ADHD (Kessler et al., 2006) and disordered eating (Santos, Richards & Bleckley, 2007; Puccio et al., 2017), and disordered eating may be used as a coping strategy to deal with negative affect (El Archi et al. 2020). In support of this suggestion, Kaisari and colleagues (2018) analysed self-report data on ADHD symptoms, disordered eating and several related variables from two large non-clinical independent samples and found that negative mood mediated the relationship between both inattentive and impulsive symptoms of ADHD and disordered eating (both binge-type and restrictive eating). Similarly in another cross-sectional study of bariatric surgery patients, probable ADHD diagnosis was associated with significant binge eating and this relationship was mediated by problems with emotional regulation (El Archi et al. 2021). Negative mood has also been found to mediate the relationship between ADHD symptoms and disordered eating longitudinally in a large cohort of young adults (Martin et al., 2020).

Another potential mediator is interoceptive ability. Kaisari et al. (2018) found that a reduced reliance on hunger and satiety cues to guide eating (as measured by the intuitive eating scale) specifically mediated the relationship between inattentive symptoms of ADHD and disordered eating. Reliance on hunger and satiety cues may reflect the interpretation and

use of gastric interoceptive information to guide eating, which is altered in individuals with eating disorders and with disordered eating (e.g. Van Dyck et al., 2016; Nyman-Carlsson et al., 2015; Pollatos et al., 2008, Martin et al., 2019). The results of Kaisari et al. (2018) suggest that trait inattention may negatively impact interoceptive processing, which in turn could contribute towards disordered eating. However, longitudinal evidence is lacking. In addition, recent research has identified different facets of interoception: interoceptive attention (herein referred to as interoceptive sensibility: the trait tendency to attend to interoceptive signals) and interoceptive accuracy (how accurately one detects internal state) (Murphy et al. 2019; Garfinkel et al., 2015). Using measures to specifically target different facets of interoception may enable determination of whether any interoceptive deficits associated with ADHD occur specifically in one facet (e.g. sensibility *or* accuracy), or in both facets. Initial evidence for dissociable effects of different facets of interoception on eating behaviours is mixed. For example, Young et al. (2017) found that external eating (eating in response to the sight and smell of food) was associated with lower interoceptive accuracy, and emotional eating tendencies were associated with higher interoceptive accuracy. In contrast, it has been suggested that emotional eating is associated with poorer interoceptive accuracy, but is unrelated to interoceptive sensibility (Robinson et al., 2021). It is therefore unclear how specific facets of interoception may contribute to disordered eating. Similarly, the potential influence of inattention on different facets of interoception and how this may contribute towards disordered eating has yet to be assessed.

The current study aimed to address the gaps in the literature regarding the potential mediating mechanisms between inattention and impulsivity/hyperactivity symptoms of ADHD and disordered eating (binge-type and restrictive eating). The longitudinal relationship between self-reported ADHD symptoms and disordered eating over six months was assessed using mediation models testing the mediating influence of negative mood,

reliance on hunger and satiety cues, interoceptive accuracy and interoceptive sensibility. We hypothesised that ADHD symptoms would predict binge-type and restrictive eating at 6-month follow-up. Further, we hypothesised that the data would confirm previous evidence of a mediating influence of negative mood on the relationship between ADHD symptoms and both types of disordered eating and a mediating influence of reliance on cues of hunger and satiety between ADHD inattentive symptoms and binge-type and restrictive eating. We also predicted that the mediating influence of cues of hunger and satiety could be explained by one or more facet of interoception: self-reported interoceptive accuracy as measured by the Interoceptive Accuracy Scale, Murphy et al., 2020) and/or interoceptive sensibility, as measured by the Body Perception Questionnaire (Porges, 1993).

2. Methods

2.1 Participants

504 participants were recruited at baseline using Prolific (https://prolific.co/). To detect a mediated effect (power = 0.8), a sample size of between 398 and 412 was required, assuming a small effect on the predictor-to-mediator pathway (Fritz & MacKinnon, 2007), as was apparent in previous similar research (Kaisari et al., 2018). To account for potential data loss due to incomplete responding, poor quality data, and participant attrition, we aimed to recruit 500 participants at baseline. Inclusion criteria were: a minimum age of 18 years and a maximum age of 60 years, and English as a first language.

2.2 Procedure

Two data collection rounds took place in November 2020 and May 2021. In the study consent form completed at baseline, participants agreed to be re-contacted through Prolific 6 months after initial participation. The study was advertised under the title 'Cognitive Factors Influencing Eating Behaviours' to conceal details of the study aims. Questionnaires were presented in the order in which they are described below and took around 30 minutes to

complete. Three attention check questions were inserted between true questionnaire items to assess if participants were reading questions, to ensure data quality. Attention check questions asked participants to select a specific response, for example 'Please Select 'Never' for this question'. Ethical approval was granted by the University of Birmingham Ethical Review Committee (reference number ERN_19-1237).

2.3 Measures

Demographic information including age, sex and ethnicity were recorded to characterise the sample. Height and weight were self-reported by participants to calculate body mass index (BMI, kg/m^2).

2.4 Measurement of interoception

2.4.1 The Intuitive eating scale (IES)

The IES (Tylka, 2006) comprises 23 items measuring trait tendency to use cues of hunger and satiety to guide eating, scored on a 5-point scale ranging from Strongly disagree to Strongly agree. There are four subscales: Unconditional permission to eat; Eating for physical rather than emotional reasons; Reliance on hunger and satiety cues; body-food choice congruence scale. The 'reliance on internal cues of hunger/satiety' subscale of the IES has good reliability and validity (e.g. Tylka and Kroon Van Diest, 2013; Duarte, Gouveia & Mendes, 2016) and previously been found to mediate the relationship between ADHD and disordered eating behaviour (Kaisari et al., 2018).

2.4.2 The interoceptive accuracy scale (IAS)

The IAS (Murphy et al., 2020) is a 21-item questionnaire measuring self-reported interoceptive accuracy across a range of interoceptive domains including hunger, thirst, heartbeat and itch. Items consist of the stem questions 'I can always accurately perceive when', followed by a bodily sensation e.g. hunger, breathing rate. Items are scored on a 5-

point scale ranging from 1 = Disagree Strongly to 5 = Strongly Agree. The IAS shows good reliability and validity (Murphy et al., 2020). Self-reported interoceptive accuracy as measured by the IAS has been shown to correlate with objective measurement (heartbeat counting) of interoceptive accuracy (Murphy et al., 2020).

2.4.3 Body Perception Questionnaire – Very Short Form (BPQ-VSF)

The BPQ-VSF (Porges, 1993) is a 12-item questionnaire used to measure body awareness, thought to reflect interoceptive sensibility as opposed to interoceptive accuracy. Respondents are asked 'During most situations I am aware of:' followed by 12 bodily sensations e.g. bloating and heartbeat. Items are scored on a 5-point scale ranging from 1 = Never to 5 = Always. It has been shown to have good validity and reliability (Cabrera, et al. 2018).

2.5 Measurement of ADHD symptoms

The Conners' Adult ADHD Rating Scale: Short Version (CAARS:SV) (Conners, Erdhart & Sparrow, 1999) was used to measure ADHD symptoms. The CAARS:SV comprises 30 items, which can be used to score participants on a continuous measurement of ADHD symptoms (inattention, impulsive/hyperactive, and combined). It can also be used to determine a possible diagnosis of ADHD, based on age and sex of the respondent. Standardised scores (T-scores) > 60 indicate elevated levels of any symptom subscale and indicate an at-risk ADHD index score. Responses are scored on a 4-point scale ranging from Not at all/Never to Very much/Very frequently. The CAARS-S:SV shows good validity and reliability (Sadeghi-Bazargani, Amiri, Hamraz, Malek, Abdi & Shahrokhi, 2014).

2.6 Measurement of Disordered Eating

2.6.1 The Eating Attitudes Test (EAT-26)

The EAT-26 (Garner et al., 1982) is a 26-item questionnaire consisting of three subscales: dieting, bulimia and oral control. Items are scored on a 6-point scale ranging from Always to

Never. Acceptable to good reliability has been reported for the EAT-26 (Ocker, Lam, Jensen & Zhang, 2007; Siervo, Boschi, Papa, Bellini & Falconi, 2005).

2.6.2 The Binge Eating Scale (BES)

The BES (Gormally et al., 1982) consists of 16 questions relating to frequency and severity of binge eating behaviours. Each question includes 3 - 4 statements on behaviours and thoughts associated with binge eating, increasing in severity. Participants are asked to select the statement that best describes themselves. Each response is assigned a numerical value from 0 (least severe) to 4 (most severe). Good reliability and validity have been reported for the BES (Duarte, Pinto-Gouveia & Ferreira, 2015).

2.6.3 The SCOFF questionnaire

The SCOFF (Morgan, Reid & Lacey, 1999) is a screening tool for detecting eating disorders. It comprises 5 yes/no questions asking whether in the past year the participant 1) has lost more than one stone in 3 months (1 stone = 6.3 kg) (weight loss); 2) had made him/herself be sick because he/she felt uncomfortably full (self-sick for feeling full); 3) worried that he/she had lost control over how much he/she eats (uncontrolled eating); 4) believed him/herself to be fat when others said that he/she was too thin (self-perceived fatness); and 5) thought that food dominated his/her life (food dominance). Endorsement of ≥2 items suggests a possible eating disorder. Good reliability and validity have been reported for the SCOFF (Garcia, Grigioni, Allais, Houy-Durand, Thubaut, Déchelotte, 2011; Kutz, Marsh, Gunderson, Maguen & Masheb, 2020).

2.6.4 The Dutch Eating Behaviour Questionnaire (DEBQ)

The DEBQ (Van Strien, Frijters, Bergers, & Defares, 1986) consists of 33-items which relate to three dimensions of eating behaviour: restrained, emotional and external eating. Items are

scored on a 5-point scale ranging from Never to Very Often. The DEBQ has been reported to have good reliability and validity (e.g. Ohara et al., 2020; Malesza & Kaczmarek, 2021).

2.7 Measurement of Negative Mood

2.7.1 The Hospital Anxiety and Depression Scale (HADS)

The HADS (Zigmond & Snaith, 1983) consists of 14 questions relating to anxiety and depression symptoms (7 depression, 7 anxiety). Responses are scored from 0 (least severe/frequent symptoms) - 3 (most severe/frequent symptoms) to give a total score for anxiety and depression ranging from 0 – 21. The HADS has good reliability and validity (Bjelland, Dahl, Haug & Neckelmann, 2002).

2.7.2 The Perceived Stress Scale (PSS)

The PSS (Cohen et al., 1983) is a 10-item questionnaire to measure how frequently the respondent has experienced feelings of stress in the last month. Items are scored on a 5-point scale ranging from Never to Very Often. The PSS is a reliable and valid measurement of perceived stress (Roberti, Harrington & Storch, 2006).

2.8 Covariate Measures

The Fast Alcohol Screening Test (FAST) (Hodgson, Alwyn, John, Thom, and Smith, 2002) and The Drug Abuse Screening Test (DAST) (Skinner, 1982) were used to measure drug and alcohol use.

2.9 Data processing and Analysis

2.9.1 Composite Scores

Using scores from the EAT-26, DEBQ and BES, composite scores were calculated for binge/disinhibited eating and restrictive eating, based on factor loadings from Kaisari et al. (2018).

2.9.2 Mediation models

Mediation was analysed using PROCESS for SPSS (Hayes, 2017). Age, sex, BMI, alcohol and drug use were covariates in the mediation models. Three models for both disordered eating type (binge/disinhibited and restrictive) were defined. The first included IES-RHSC as the mediating variable, to test the relationship reported in Kaisari et al. (2018). The second model included both BPQ and IAS scores as mediators to assess specific contributions of interoceptive sensibility and self-reported interoceptive accuracy. The final model included negative mood as the mediating variable. Predictor and mediator variables were from baseline measurement. Two outcome variables for each disordered eating type were tested: change in disordered eating score between baseline and follow-up, and disordered eating score at follow-up only.

2.10. Sensitivity Analysis

Sensitivity analyses were conducted to address the potential impact of participant attrition on results. Mediation models were replicated on datasets in which follow-up data missing due to participant attrition was replaced using multiple imputation (nImp = 5). Analyses were completed in R version 4.2.1. using the lavaan (Rosseel, 2012) and mitml (Grund et al., 2016) packages.

3. Results

3.1 Baseline Participant Characteristics

At baseline, 493 participants were included after removing participants with incomplete datasets, and participants who did not pass the attention checks (n = 11). At follow-up 70% of participants completed the second data round, resulting in a final sample size of 345 participants (*M* age = 33.9 ± 10.9), *M* BMI = 26.3, 72.5% women). See Table 1

for baseline characteristics of the sample. Forty-two participants (12% of total sample) scored ≥ 2 on the SCOFF screening tool, suggesting possible risk of eating disorder in those participants. Eight participants (2%) reported having previously been treated for an eating disorder. Seventy-eight participants reported inattentive ADHD symptoms within a clinically significant range (26% of total sample). Thirty-three participants reported hyperactive symptoms of ADHD within a clinically significant range (10% of total sample). Fifty-two participants reported combined symptoms of ADHD within a clinically significant range (15% of total sample). Fifty-seven participants reported symptoms indicating an 'at-risk' ADHD index (17% of total sample). One participant reported currently taking ADHD medication. No participants were excluded due to the above measures.

3.2 Differences between completers and non-completers

T-tests revealed that completers were significantly older (M = 33.9) ($M = 29.9$) $t(491) = 4.0$, $p < 0.001$ and had significantly lower combined ADHD symptoms ($M = 17.2$) than non-completers ($M = 20.1$), $t(491) = 3.7$, $p < 0.001$. Fewer men completed both timepoints than expected, whereas more women completed than expected, $X^2(1) = 4.1$, $p = 0.04$.

3.3 Change in Disordered Eating

There was a significant increase in restrictive eating between baseline ($M = 11.0$) and follow-up ($M = 12.3$), $t(344) = 3.7$, $p < 0.001$. The increase in mean binge/disinhibited eating between baseline ($M = 20.5$) and follow-up ($M = 21.1$) was not significant $t(342) = 1.3$, $p = 0.078$.

3.4 Associations between interoception measures

Bivariate correlations revealed that IES-RHSC was associated with interoceptive accuracy as measured by the IAS ($r = 0.19$, $p < 0.001$), but not interoceptive sensibility as

measured by the BPQ (r = -0.12, p = 0.83). Interoceptive accuracy and sensibility were significantly positively associated (r = 0.33, p < 0.001).

3.5 Mediation Analysis: Follow-up disordered eating

3.5.1 Mediation through Reliance on Hunger and Satiety Cues

Inattentive symptoms predicted binge eating and restrictive eating both directly (Effect = 0.64, S.E. = 0.12, T = 7.3, p < 0.001, CI = 0.42 - 0.86; Effect = 0.35, S.E. = 0.10, T = 3.4, p < 0.001, CI = 0.15 - 0.55) and indirectly through IES-RHSC (Effect = 0.27, Bootstrapped S.E. = 0.07, Bootstrapped CI = 0.15 - 0.41; Effect = 0.09, Bootstrapped S.E. = 0.04, Bootstrapped CI = 0.03 - 0.17).

Hyperactive/Impulsive symptoms predicted binge eating and restrictive eating directly (Effect = 0.30, S.E. = 0.13, T = 2.3, p = 0.025, CI = 0.04 - 0.57; Effect = 0.33, S.E. = 0.12, T = 2.7, p = 0.006, CI = 0.09 - 0.56) but not indirectly through IES-RHSC (Effect = 0.10, Bootstrapped S.E. = 0.09, Bootstrapped CI = -0.08 - 0.27; Effect = 0.003, Bootstrapped S.E. = 0.003, Bootstrapped CI = -0.03 - 0.10).

3.5.2 Mediation through Interoceptive Accuracy and Interoceptive Sensibility

Inattentive symptoms predicted binge eating and restrictive eating directly (Effect = 0.85, S.E. = 0.13, T = 6.7, p < 0.001, CI = 0.60 - 1.09; Effect = 0.30, S.E. = 0.10, T = 2.9, p = 0.006, CI = 0.15 - 0.55) and predicted binge eating but not restrictive eating indirectly through IAS (Effect = 0.57, Bootstrapped S.E. = 0.29, Bootstrapped CI = 0.06 - 1.09; Effect = 0.30, S.E. = 0.10, T = 2.9, p = 0.006, CI = 0.15 - 0.55). BPQ did not mediate the relationship between inattentive symptoms and binge or restrictive eating (Effect = 0.007, Bootstrapped S.E. = 0.01, Bootstrapped CI = -0.016 - 0.03; Effect = 0.008, Bootstrapped S.E. = 0.02, Bootstrapped CI = -0.03 - 0.05) (See Figure 1).

Hyperactive/Impulsive symptoms predicted binge eating and restrictive eating directly (Effect = 0.33, S.E. = 0.16, T = 2.1, p = 0.04, CI = 0.015 - 0.64; Effect = 0.29, S.E. = 0.12, T = 2.4, p = 0.017, CI = 0.052 - 0.53), but did not predict either indirectly through either IAS (Effect = 0.04, Bootstrapped S.E. = 0.032, Bootstrapped CI = -0.01 - 0.12; Effect = 0.025, Bootstrapped S.E. = 0.021, Bootstrapped CI = -0.006 - 0.076) or BPQ (Effect = 0.03, Bootstrapped S.E. = 0.023, Bootstrapped CI = -0.07 - 0.08; Effect = 0.04, Bootstrapped S.E. = 0.024, Bootstrapped CI = -0.0003 - 0.092). (see Figure 1).

3.5.3 Mediation through Negative Mood

Inattentive symptoms predicted binge eating scores, but not restrictive eating scores directly (Effect = 0.49, S.E. = 0.14, T = 3.5, p = 0.0004, CI = 0.22 - 0.76; Effect = 0.12, S.E. = 0.12, T = 1.1, p = 0.29, CI = -0.104 - 0.35) and predicted both indirectly through negative mood (Effect = 0.42, Bootstrapped S.E. = 0.090, Bootstrapped CI = 0.26 - 0.60; Effect = 0.22, Bootstrapped S.E. = 0.07, Bootstrapped CI = 0.089 - 0.37).

Hyperactive/Impulsive ADHD symptoms did not predict binge eating or restrictive eating scores directly (Effect = 0.096, S.E. = 0.15, T =0.65, p = 0.52, CI = -0.19 - 0.39; Effect = 0.22, S.E. = 0.12, T = 1.8, p = 0.069, CI = 0.017 - 0.24) but did predict binge and restrictive eating indirectly through negative mood (Effect = 0.303, Bootstrapped S.E. = 0.08, Bootstrapped CI = 0.16 - 0.47; Effect = 0.13, Bootstrapped S.E. = 0.047, Bootstrapped CI = 0.55 - 0.24).

3.6 Mediation Analysis: Change in disordered eating

Neither the direct nor indirect pathways in any of the assessed mediation models predicted change in disordered eating scores.

3.7 Moderation by sex

The moderating influence of sex on all model pathways was assessed. Sex did not moderate the direct or indirect pathways of any model.

3.8 Sensitivity Analysis

Overall, results for the mediation models followed a similar pattern. Briefly, RHSC maintained a mediating influence between inattentive symptoms and both binge and restrictive eating ($p < 0.001$, $p = 0.01$ respectively), while hyperactive/impulsive symptoms were no longer directly related to binge ($p = 0.8$) or restrictive eating ($p = 0.17$).

The overall effects in the models assessing mediation through the IAS and the BPQ followed the same pattern as in the main analysis, with the exception of the overall indirect effect of inattentive symptoms through IAS, which became only marginally significant ($p = 0.059$). Full mediation model results based on pooled estimates can be found in the supplemental materials.

4 Discussion

This is the first study to examine the potential mediating influence of specific interoceptive facets on the relationship between ADHD symptoms and disordered eating over a 6-month period. We found that hyperactive/impulsive and inattentive symptoms of ADHD at baseline predicted both binge and restrictive eating behaviours 6 months later. Mediation models showed that self-reported interoceptive accuracy, but not interoceptive sensibility mediated the relationship between inattention and binge eating symptoms, but not restrictive eating symptoms. Hyperactive/impulsive symptoms of ADHD predicted restrictive and binge/disinhibited eating only through negative mood, not through interoceptive measures.

To date, it has been unclear how inattentive symptoms of ADHD relate to disordered eating. Previous evidence suggested that disturbed interoception, as reflected in reduced

reliance on hunger sand satiety signals to guide eating, may be one underlying mechanism (Kaisari et al., 2018). Here, we replicate and extend this previous finding by providing evidence that inattention specifically contributes towards disordered eating via reduced interoceptive accuracy, rather than interoceptive sensibility. Taken together, these results suggest that trait attention enables accurate interpretation of interoceptive signals, and that this accurate interpretation may specifically protect against binge eating. On the other hand, attention does not appear to influence the trait tendency to notice interoceptive signals.

Trait inattention could lead to inaccuracy in the processing of interoceptive signals relating to fullness/overeating, contributing towards excessive eating associated with binge eating episodes. In addition, inaccuracy in interoceptive signals may encourage binge/disinhibited eating through contributing towards an overreliance on salient external cues to guide behaviour, rather than interoceptive cues which are perceived as inaccurate (Young et al., 2017). In the context of the modern food environment, this tendency could contribute towards overconsumption of highly palatable foods. The specific association between interoceptive accuracy and binge eating rather than interoceptive sensibility may be explained by the predictive coding framework of interoception, which suggests that interoceptive accuracy reflects the ability to use attention to prioritise interoceptive signals (Ainley, Apps, Fotopoulou & Tsakiris, 2016), leading to increased precision in processing but not necessarily an enhancement in the saliency of signals (Ainley, Apps, Fotopoulou & Tsakiris, 2016). It should be noted however that the robustness of this relationship across populations is unclear, given that the mediating effect of interoceptive accuracy became marginally significant when the model was run using multiple imputation to account for missing data. Future research should replicate the models presented here, to assess the robustness of the mediating effect of interoceptive accuracy.

We also identified a relationship between symptoms of ADHD and restrictive eating. Research into ADHD symptoms and restrictive eating has been limited to date and the results inconsistent (see Kaisari et al., 2017 for a review). The relationship between inattention and restrictive eating was mediated by reliance on hunger and satiety cues as has been reported previously (Kaisari et al., 2018), but not through specific interoception measures. It is plausible that for individuals who engage in restrictive eating, attention to, and accuracy of interoceptive signals, as measured by the BPQ and IAS respectively are intact. However, there may be mistrust in bodily signals that gives rise to a trait tendency to ignore these signals (Martini et al., 2021). Brown et al. (2020) found that mistrust in body sensations was the most relevant facet of interoception to disordered eating and was particularly associated with weight concerns. These results highlight that for individuals who are more prone to restrictive eating, trust in interoceptive signals may be more influential to symptomatology than sensibility or accuracy.

Negative mood mediated the relationship between both symptom subtypes of ADHD and both disordered eating behaviour types. However, unlike inattentive symptoms, hyperactive/impulsive symptoms of ADHD predicted restrictive and binge/disinhibited eating only through negative mood, and not through any interoceptive measures. The relationship between negative mood and eating has been well documented (e.g. Rosenbaum & White, 2015; Haynos, Watts, Loth, Pearson, Neumark-Stzainer, 2016; Schulz & Laessle, 2010), as has the relationship between ADHD symptoms and negative mood (El Archi, et al. 2020; Katzman, Bilkey, Chokka, Fallu, & Klassen, 2017). Thus, the experience of ADHD symptoms may contribute towards negative mood, and disordered eating behaviours may reflect a coping mechanism for this negative mood, for example through emotional eating.

We observed a significant increase in restrictive eating reported over the 6-month period, but no statistically significant change in binge eating. No variables included in the

current study were associated with a change in restrictive eating. This may be because the absolute change was relatively small and the 6-month period was insufficient in duration to capture sufficient variability in responding for us to identify significant predictors of change. Alternatively, it is possible that other variables which were not assessed in this study might have predicted change. For example, changes in restrictive eating over a similar time period in young adults have been associated with variables such as body dissatisfaction and weight-related teasing (Wertheim, Koerner & Paxton, 2001; Haynos et al., 2016). Additionally, the differences in season during which responses were collected may interact with these factors. It is possible that a 'seasonal body image' variation exists (e.g. Griffiths, Austen & Blake, 2021), such that body dissatisfaction increases in warmer months, potentially as a result of factors such as the tendency to wear less clothing during warmer months, and media pressures to alter appearance in preparation for this seasonal change. It is unclear whether this may at least partially explain the increase in reported restrictive eating in our sample. Influences such as body dissatisfaction and weight-related teasing may have contributed to the significant increase in restrictive eating in the current sample but were not variables of interest and were therefore not recorded in this study. Either way, the present data do not shed light on the directionality of the relationship between ADHD symptoms and disordered eating. Although there are plausible pathways through which ADHD could contribute towards disordered eating, the reverse relationship may also be possible. Further research over a longer time period with multiple follow up assessments will be required to determine the direction of any causal relationship between ADHD symptoms and disordered eating.

The findings reported here should be interpreted in the context of the strengths and limitations of our study. Interoceptive accuracy and disordered eating were assessed via self-report and so future research could test whether the same relationships hold using objective measures of interoceptive accuracy (Legrand et al. 2022) as well as lab-based measures of

uncontrolled eating (Hartmann, Rief, & Hilbert, 2012). Results from our sensitivity analysis showed a non-significant mediating effect of interoceptive accuracy on the relationship between inattention and binge eating, while this effect was significant in the main analysis. This result may have implications for the robustness of the mediation model. We estimated that a sample size of between 398 and 412 was required and the sample at follow up was under this number at 346, which meant the study was slightly underpowered for meditation analysis. An advantage of using an online survey is access to a large sample size of volunteers with ADHD and disordered eating scores across a spectrum (Insel et al., 2010). However, future research should also confirm the findings in a clinically diagnosed sample.

The results of this study have implications for the assessment of risk of disordered eating. Given that symptoms of ADHD, deficits in self-reported interoceptive accuracy, and negative mood appear to be associated with disordered eating, screening for negative mood and interoceptive accuracy may be useful in identifying individuals (e.g. those who present with symptoms of ADHD), who are at risk of developing disordered eating.

In summary, we provide the first evidence that self-reported interoceptive accuracy, rather than sensibility, mediates the relationship between inattentive ADHD symptoms and binge-type eating. We also confirm the importance of negative mood as a mediator in the relationship between both ADHD symptom types and restrictive and binge-type eating behaviours. These results have implications for the development of screening tools with a focus on negative mood and interoceptive accuracy for individuals with ADHD and individuals at-risk of eating disorders.

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Conflicts of interest

Author Colin T Dourish is a Director and shareholder of P1vital Limited and a Director and shareholder of P1vital Products Limited.

Ethical statement

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. Ethical approval was granted by University of Birmingham Research Ethics Committee.

Data availability

Data for this study will be made available in a public archive following publication of this study. In the interim, data are available upon request.

441 References

442 Ainley, V., Apps, M. A., Fotopoulou, A., & Tsakiris, M. (2016). 'Bodily precision': a
443 predictive coding account of individual differences in interoceptive accuracy. *Philosophical*
444 *Transactions of the Royal Society B: Biological Sciences*, *371*(1708), 20160003.

445 Bjelland, I., Dahl, A. A., Haug, T. T., & Neckelmann, D. (2002). The validity of the Hospital
446 Anxiety and Depression Scale: an updated literature review. *Journal of psychosomatic*
447 *research*, *52*(2), 69-77.

448 Brown, T. A., Vanzhula, I. A., Reilly, E. E., Levinson, C. A., Berner, L. A., Krueger, A., ... &
449 Wierenga, C. E. (2020). Body mistrust bridges interoceptive awareness and eating disorder
450 symptoms. *Journal of Abnormal Psychology*, *129*(5), 445-456.

451 Cabrera, A., Kolacz, J., Pailhez, G., Bulbena-Cabre, A., Bulbena, A., & Porges, S. W. (2018).
452 Assessing body awareness and autonomic reactivity: Factor structure and psychometric
453 properties of the Body Perception Questionnaire-Short Form (BPQ-SF). *International journal*
454 *of methods in psychiatric research*, 27(2), e1596.

455 Cohen, S., Kamarck, T., & Mermelstein, R. (1983). A global measure of perceived stress. *J*
456 *Health Soc Beh*, *24*, 386-396.

457 Conners, C. K., Erhardt, D., & Sparrow, E. P. (1999). *Conners' adult ADHD rating scales*
458 *(CAARS): technical manual*. North Tonawanda, NY: Multi-Health Systems.

459 El Archi, S., Cortese, S., Ballon, N., Réveillère, C., De Luca, A., Barrault, S., & Brunault, P.
460 (2020). Negative affectivity and emotion dysregulation as mediators between ADHD and
461 disordered eating: a systematic review. *Nutrients*, *12*(11), 3292.

462 El Archi, S., Brunault, P., De Luca, A., Cortese, S., Hankard, R., Bourbao-Tournois, C., ... &
463 Barrault, S. (2021). Do Emotion Dysregulation, Alexithymia and Personality Dimensions
464 Explain the Association Between Attention-Deficit/Hyperactivity Disorder and Binge Eating
465 Among Bariatric Surgery Candidates?. *Frontiers in Psychology*, 5400.

466 Duarte, C., Gouveia, J. P., & Mendes, A. (2016). Psychometric properties of the Intuitive
467 Eating Scale-2 and association with binge eating symptoms in a Portuguese community
468 sample. *International Journal of Psychology and Psychological Therapy*, *16*(3), 329-341.

469 Duarte, C., Pinto-Gouveia, J., & Ferreira, C. (2015). Expanding binge eating assessment:
470 Validity and screening value of the Binge Eating Scale in women from the general
471 population. *Eating behaviors*, 18, 41-47.

472 Fritz, M. S., & MacKinnon, D. P. (2007). Required sample size to detect the mediated
473 effect. *Psychological science*, *18*(3), 233-239.

474 Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing
475 your own heart: distinguishing interoceptive accuracy from interoceptive
476 awareness. *Biological psychology*, *104*, 65-74.

Garcia, F. D., Grigioni, S., Allais, E., Houy-Durand, E., Thibaut, F., & Déchelotte, P. (2011). Detection of eating disorders in patients: validity and reliability of the French version of the SCOFF questionnaire. *Clinical Nutrition*, *30*(2), 178-181.

Garner, D. M., Olmsted, M. P., Bohr, Y., & Garfinkel, P. E. (1982). The eating attitudes test: psychometric features and clinical correlates. *Psychological medicine*, *12*(4), 871-878.

Gormally, J. I. M., Black, S., Daston, S., & Rardin, D. (1982). The assessment of binge eating severity among obese persons. *Addictive behaviors*, *7*(1), 47-55.

Griffiths, S., Austen, E., Krug, I., & Blake, K. (2021). Beach body ready? Shredding for summer? A first look at "seasonal body image". Body Image, 37, 269-281.

Grund, S., Lüdtke, O., & Robitzsch, A. (2016). Multiple imputation of multilevel missing data: An introduction to the R package pan. Sage Open, 6(4), 2158244016668220.

Hartmann, A. S., Rief, W., & Hilbert, A. (2012). Laboratory snack food intake, negative mood, and impulsivity in youth with ADHD symptoms and episodes of loss of control eating. Where is the missing link?. *Appetite*, *58*(2), 672-678.

Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford publications.

Haynos, A. F., Watts, A. W., Loth, K. A., Pearson, C. M., & Neumark-Stzainer, D. (2016). Factors predicting an escalation of restrictive eating during adolescence. *Journal of Adolescent Health*, *59*(4), 391-396.

Hodgson, R., Alwyn, T., John, B., Thom, B., & Smith, A. (2002). The FAST alcohol screening test. *Alcohol and alcoholism*, *37*(1), 61-66.

Insel, T., Cuthbert, B., Garvey, M., Heinssen, R., Pine, D. S., Quinn, K., ... & Wang, P. (2010). Research domain criteria (RDoC): toward a new classification framework for research on mental disorders. *American Journal of psychiatry*, *167*(7), 748-751.

Kaisari, P., Dourish, C. T., & Higgs, S. (2017). Attention Deficit Hyperactivity Disorder (ADHD) and disordered eating behaviour: A systematic review and a framework for future research. *Clinical psychology review*, *53*, 109-121.

Kaisari, P., Dourish, C. T., Rotshtein, P., & Higgs, S. (2018). Associations between core symptoms of attention deficit hyperactivity disorder and both binge and restrictive eating. *Frontiers in psychiatry*, *9*, 103.

Katzman, M. A., Bilkey, T. S., Chokka, P. R., Fallu, A., & Klassen, L. J. (2017). Adult ADHD and comorbid disorders: clinical implications of a dimensional approach. *BMC psychiatry*, *17*(1), 1-15.

Kessler, R. C., Adler, L., Barkley, R., Biederman, J., Conners, C. K., Demler, O., ... & Zaslavsky, A. M. (2006). The prevalence and correlates of adult ADHD in the United States: results from the National Comorbidity Survey Replication. *American Journal of psychiatry*, *163*(4), 716-723.

514 Kutz, A. M., Marsh, A. G., Gunderson, C. G., Maguen, S., & Masheb, R. M. (2020). Eating
515 disorder screening: a systematic review and meta-analysis of diagnostic test characteristics of
516 the SCOFF. *Journal of general internal medicine*, *35*(3), 885-893.

517 Legrand, N., Nikolova, N., Correa, C., Brændholt, M., Stuckert, A., Kildahl, N., ... & Allen,
518 M. (2022). The heart rate discrimination task: a psychophysical method to estimate the
519 accuracy and precision of interoceptive beliefs. *Biological psychology*, *168*, 108239.

520 Malesza, M., & Kaczmarek, M. C. (2021). One year reliability of the Dutch eating behavior
521 questionnaire: an extension into clinical population. *Journal of Public Health*, *29*(2), 463-
522 469.

523 Martin, E., Dourish, C. T., Rotshtein, P., Spetter, M. S., & Higgs, S. (2019). Interoception
524 and disordered eating: A systematic review. *Neuroscience & Biobehavioral Reviews*, *107*,
525 166-191.

526 Martin, E., Dourish, C. T., Hook, R., Chamberlain, S. R., & Higgs, S. (2020). Associations
527 between inattention and impulsivity ADHD symptoms and disordered eating risk in a
528 community sample of young adults. *Psychological Medicine*, 1-10.

529 Martini, M., Marzola, E., Brustolin, A., & Abbate-Daga, G. (2021). Feeling imperfect and
530 imperfectly feeling: A network analysis on perfectionism, interoceptive sensibility, and eating
531 symptomatology in anorexia nervosa. *European Eating Disorders Review*. 29:893–909.

532 Morgan, J. F., Reid, F., & Lacey, J. H. (1999). The SCOFF questionnaire: assessment of a
533 new screening tool for eating disorders. *Bmj*, *319*(7223), 1467-1468.

534 Murphy, J., Catmur, C., & Bird, G. (2019). Classifying individual differences in
535 interoception: Implications for the measurement of interoceptive awareness. *Psychonomic*
536 *bulletin & review*, *26*(5), 1467-1471.

537 Murphy, J., Brewer, R., Plans, D., Khalsa, S. S., Catmur, C., & Bird, G. (2020). Testing the
538 independence of self-reported interoceptive accuracy and attention. *Quarterly Journal of*
539 *Experimental Psychology*, *73*(1), 115-133.

540 Nyman-Carlsson, E., Engström, I., Norring, C., & Nevonen, L. (2015). Eating Disorder
541 Inventory-3, validation in Swedish patients with eating disorders, psychiatric outpatients and
542 a normal control sample. *Nordic Journal of Psychiatry*, *69*(2), 142-151.

543 Ocker, L. B., Lam, E. T., Jensen, B. E., & Zhang, J. J. (2007). Psychometric properties of the
544 eating attitudes test. *Measurement in physical education and exercise science*, *11*(1), 25-48.

545 Ohara, K., Nakamura, H., Kouda, K., Fujita, Y., Momoi, K., Mase, T., ... & Iki, M. (2020).
546 Psychometric properties of the Japanese version of the Dutch Eating Behavior Questionnaire
547 for Children. *Appetite*, *151*, 104690.

548 Pollatos, O., Kurz, A. L., Albrecht, J., Schreder, T., Kleemann, A. M., Schöpf, V., ... &
549 Schandry, R. (2008). Reduced perception of bodily signals in anorexia nervosa. *Eating*
550 *behaviors*, *9*(4), 381-388.

551 Porges, S. W. (1993). Body Perception Questionnaire (BPQ) Manual. Stress: The
552 International Journal on the Biology of Stress, 15, 1-7.

553 Puccio, F., Fuller-Tyszkiewicz, M., Youssef, G., Mitchell, S., Byrne, M., Allen, N., & Krug,
554 I. (2017). Longitudinal bi-directional effects of disordered eating, depression and
555 anxiety. *European Eating Disorders Review*, *25*(5), 351-358.

556 Roberti, J. W., Harrington, L. N., & Storch, E. A. (2006). Further psychometric support for
557 the 10-item version of the perceived stress scale. Journal of College Counseling, 9(2), 135-
558 147.

559 Robinson, E., Marty, L., Higgs, S., & Jones, A. (2021). Interoception, eating behaviour and
560 body weight. *Physiology & behavior*, *237*, 113434.

561 Rosenbaum, D. L., & White, K. S. (2015). The relation of anxiety, depression, and stress to
562 binge eating behavior. *Journal of Health Psychology*, *20*(6), 887-898.

563 Rosseel, Y. (2012). lavaan: An R package for structural equation modeling. *Journal of*
564 *statistical software*, 48, 1-36.

565 Sadeghi-Bazargani, H., Amiri, S., Hamraz, S., Malek, A., Abdi, S., & Shahrokhi, H. (2014).
566 Validity and reliability of the Persian version of Conner's adult ADHD rating scales:
567 observer and self-report screening versions. *Journal of Clinical Research &*
568 *Governance*, *3*(1), 42-47.

569 Santos, M., Richards, C. S., & Bleckley, M. K. (2007). Comorbidity between depression and
570 disordered eating in adolescents. *Eating behaviors*, *8*(4), 440-449.

571 Schulz, S., & Laessle, R. G. (2010). Associations of negative affect and eating behaviour in
572 obese women with and without binge eating disorder. *Eating and Weight Disorders-Studies*
573 *on Anorexia, Bulimia and Obesity*, *15*(4), e287-e293.

574 Siervo, M., Boschi, V., Papa, A., Bellini, O., & Falconi, C. (2005). Application of the
575 SCOFF, Eating Attitude Test 26 (EAT 26) and Eating Inventory (TFEQ) questionnaires in
576 young women seeking diet-therapy. *Eating and Weight Disorders-Studies on Anorexia,*
577 *Bulimia and Obesity*, *10*(2), 76-82.

578 Skinner, H. A. (1982). The drug abuse screening test. *Addictive behaviors*, *7*(4), 363-371.

579 Tylka, T. L. (2006). Development and psychometric evaluation of a measure of intuitive
580 eating. *Journal of Counseling Psychology*, *53*(2), 226-240.

581 Tylka, T. L., & Kroon Van Diest, A. M. (2013). The Intuitive Eating Scale–2: Item
582 refinement and psychometric evaluation with college women and men. *Journal of counseling*
583 *psychology*, *60*(1), 137-153.

584 Van Dyck, Z., Herbert, B. M., Happ, C., Kleveman, G. V., & Vögele, C. (2016). German
585 version of the intuitive eating scale: Psychometric evaluation and application to an eating
586 disordered population. *Appetite*, *105*, 798-807

Van Strien, T., Frijters, J. E., Bergers, G. P., & Defares, P. B. (1986). The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *International journal of eating disorders*, *5*(2), 295-315.

Wertheim, E. H., Koerner, J., & Paxton, S. J. (2001). Longitudinal predictors of restrictive eating and bulimic tendencies in three different age groups of adolescent girls. *Journal of Youth and Adolescence*, *30*(1), 69-81.

Young, H. A., Williams, C., Pink, A. E., Freegard, G., Owens, A., & Benton, D. (2017). Getting to the heart of the matter: Does aberrant interoceptive processing contribute towards emotional eating?. *PLoS One*, *12*(10), e0186312.

Zigmond, A. S., & Snaith, R. P. (1983). The hospital anxiety and depression scale. *Acta psychiatrica scandinavica*, *67*(6), 361-370.

Table 1. Baseline participant characteristics.

	Mean (±SD)	Range
Age	33.9 (±10.9)	18 - 60
BMI	26.3 (±6.6)	15.8 - 56.3
BES (0-46)	12.7 (±9.2)	0 - 42
DEBQ (1-5)		
Restrained Eating	2.7 (±0.9)	0.8 - 5.0
External Eating	3.2 (±0.6)	1.5 - 4.8
Emotional Eating	2.4 (±1.0)	0.2 - 5.0
EAT-26		
Dieting (0-39)	5.7 (±6.3)	0 - 34
Bulimia and Food Preoccupation (0-18)	1.6 (±2.6)	0 - 12
Oral Control (0-21)	2.1 (±2.8)	0 - 21
SCOFF (0-5)	0.9 (±1.1)	0 - 5
CAARS		
Impulsive/Hyperactive (0-27)	8.0 (±4.2)	0 - 25
Inattentive (0-27)	9.2 (±5.0)	0 - 25
Combined (0-54)	17.2 (±7.8)	0 - 49
IES RHSC (1-5)	3.3 (±0.9)	1 - 5
IAS (21-105)	76.5 (±10.5)	34 - 100
BPQ-VSF (12-60)	40.8 (±9.6)	14 - 60

BES = Binge Eating Scale; DEBQ = Dutch Eating Behaviour Questionnaire; EAT-26 = Eating Attitudes Test; CAARS = Conners' Adult ADHD Rating Scale (short screening version; IES RHSC = Intuitive Eating Scale; Reliance on Hunger and Satiety Cues subscale; IAS = Interoceptive Accuracy Scale; BPQ-VSF = Body Perception Questionnaire-Very Short Form.

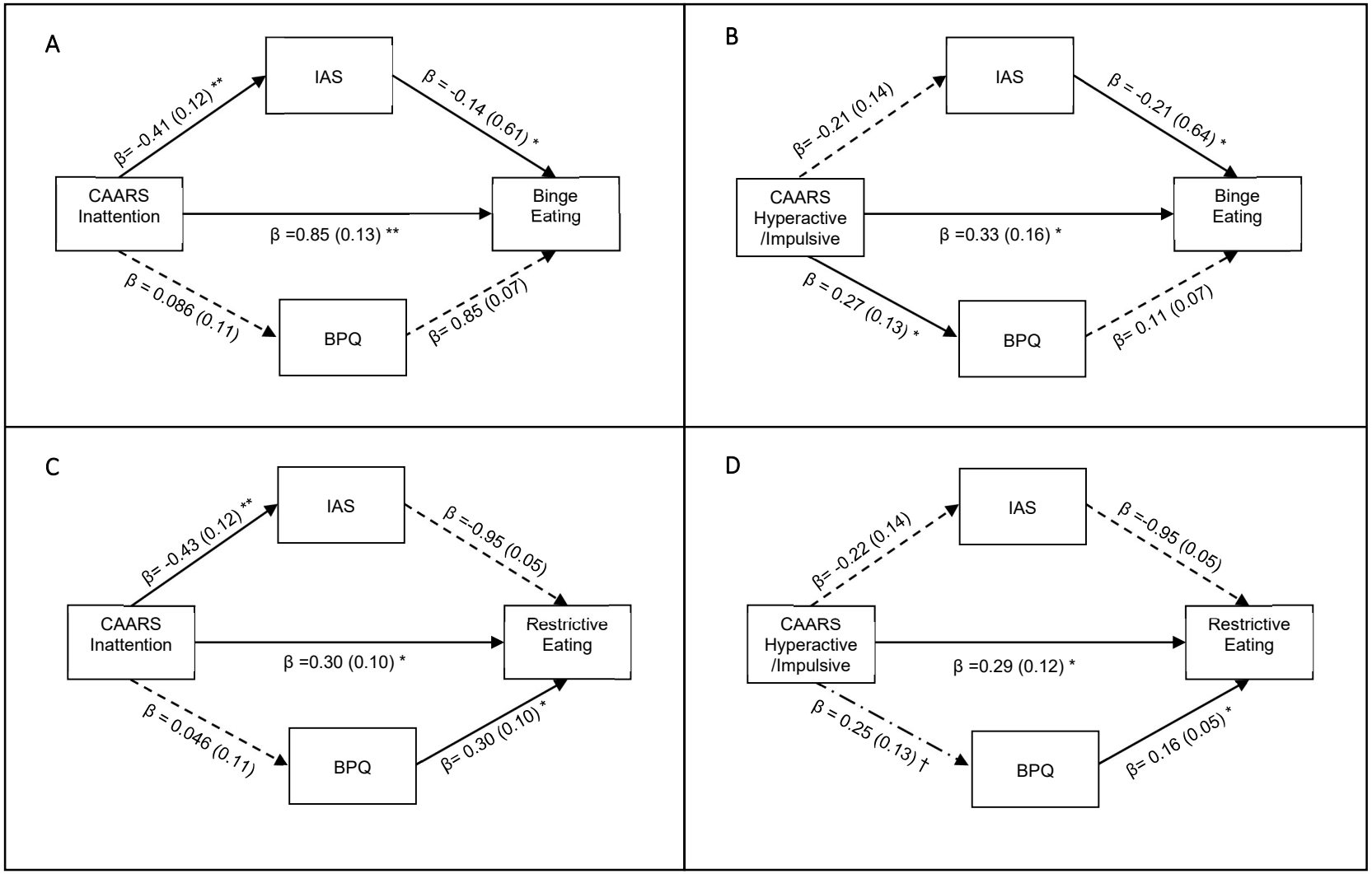

Figure 1. Mediation model showing the mediated relationship between inattentive symptoms and **A:** binge/disinhibited eating, **B:** restrictive eating. Solid lines reflect significant pathways. IAS = Interoceptive Accuracy Scale. BPQ = Body Perception Questionnaire

Estimates (β) are unstandardized regression coefficients, numbers in parentheses show error (direct effects) and bootstrapped error (indirect effects). All analyses controlled for sex, age, BMI, alcohol use and illicit drug use. * = $p < 0.05$, ** = $p < 0.001$, † = $p = 0.05$