University of Southampton

Faculty of Environmental and Life Sciences

School of Psychology

Interoception and Emotion in Autistic and Non-autistic Children and Adolescents

by

Lauren Jane Craik

ORCID ID 0000-0002-2094-2738

Thesis for the degree of Doctorate in Educational Psychology

August 2024

University of Southampton

Abstract

Faculty of Environmental and Life Sciences

School of Psychology

Doctor of Educational Psychology

Interoception and Emotion in Autistic and Non-autistic Children and Adolescents

by

Lauren Jane Craik

This thesis focuses on interoception and emotion in children and adolescents. Whilst the origin of emotion has been an area of debate for many decades, it is widely agreed that interoception, a term that encompasses the processes by which individuals sense, interpret, and regulate signals from inside the body (Chen et al., 2021), plays a key role in emotional experience. Interoception is arguably vital for identifying and interpreting emotion in oneself and in others (Critchley & Garfinkel, 2017; Herbert et al., 2011). The thesis consists of an introduction to the wider context and current research, a systematic literature review, and an empirical report, with the overarching purpose of adding to the growing body of literature that aims to increase understanding of the contribution of interoception to emotional processes in children and adolescents.

Childhood and adolescence are critical periods of time for the development of emotion regulation skills (Silvers, 2022). Given the role of interoception in emotion, the systematic literature review included in this thesis aims to explore the association between interoception and emotion regulation in children and adolescents. The review examines the results of five quantitative papers exploring the relationship between the different dimensions of interoception and varying emotion regulation strategies and outcomes. Though limited, the evidence available is beginning to demonstrate a relationship between the two facets in middle childhood and adolescence.

Sensory differences, including interoceptive differences, are often present for autistic individuals and it is well-established that anxiety is a common occurrence for autistic adolescents. There is an increasing understanding of the role interoception plays in experiences of anxiety, and research is beginning to explore this relationship with autistic groups. Given the role it plays in emotional processing, alexithymia is also theorised to be involved in the interaction between interoception and anxiety in autistic adolescents. Therefore, the empirical portion of this thesis aims to contribute to our understanding of anxiety in autistic adolescents by exploring the relationships between interoception, alexithymia, and anxiety in a sample of autistic adolescents.

Implications for practice are discussed further within each of the respective chapters. It is hoped that further understanding the relationship between interoception and emotion could help those working with children and adolescents to support the development of their emotion regulation skills, and autistic adolescents with anxiety management and reduction.

Table of Contents

Table of Tables

Table of Figures

Research Thesis: Declaration of Authorship

Print name: Lauren Craik

Title of thesis: Interoception and Emotion in Autistic and Non-Autistic Adolescents

I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signature: ..... Date: 31/05/2024

Acknowledgements

First and foremost, I extend my gratitude to my supervisory team. To Dr Gaby Pfeifer and Dr Lisa Quadt, for their invaluable expertise, advice, and guidance throughout this process, and to Professor Matt Garner, for helping me to realise my ideas. I would like to thank my participants, those that took part in the Lived Experience Advisory Panel and therefore helped to ensure my research was relevant and accessible, and those that participated in the study itself, without whom this research would not have been possible. I would also like to thank my fellow Trainee Educational Psychologists who have made the doctorate journey fun, and for their moral support and guidance along the way. Finally, I would like to express my heartfelt gratitude to my partner Jamie for his patience, support and understanding, whilst enduring my late nights and repeated requests for proofreading. Your constant encouragement and belief help me to persevere and has made the journey I have been on possible.

Definitions and Abbreviations

ASSERT ..... The Autism Symptom SElf-ReporT for adolescents and adults

AQC-DDF ..... The Alexithymia Questionnaire for Children – Difficulty Describing Feelings subscale

AQC-DIF ..... Alexithymia Questionnaire for Children – Difficulty Identifying Feelings subscale

BPQ-ANSR ..... Body Perception Questionnaire - Autonomic Nervous System Reactivity subscale

BPQ-BA..... Body Perception Questionnaire - Body Awareness subscale

BPQ-SF ..... Body Perception Questionnaire – Short Form

BRIEF2 ..... The Behavior Rating Inventory of Executive Function, Second Edition

CERQ-k..... The Cognitive Emotion Regulation Questionnaire for children

ER..... Emotion Regulation

GAD-7 ..... General Anxiety Disorder-7

ITPE ..... Interoceptive Trait Prediction Error

JJP ..... Jumping Jack Paradigm

MAIA-Y..... Multidimensional Assessment of Interoceptive Awareness in Youth

Chapter 1 Introduction

1.1 Wider context

This thesis focuses on two key areas, interoception and emotion, both of which are evolving and highly debated fields. Whilst there is not the scope to cover these two areas in substantial detail in this chapter, an overview has been provided to give context for the subsequent chapters.

Our understanding of emotion has developed substantially since the 19th century when 'emotion' emerged fully as a theoretical term (Dixon, 2012), and yet there is little agreement as to what emotion actually is, with much of the debate revolving around whether physiological change or cognitive appraisal comes first in emotional experience. William James is posited as one of the first psychologists to try and answer the question, *what is emotion?* James (1884) theorised that the perception of changes in our physiological state in response to external stimuli is what evokes an emotion, and that, when processed alongside context, enables individuals to interpret their emotional state. He further theorised that specific emotions have specific physiological signatures that facilitate our identification of emotion. Carl Lange proposed a similar theory; thus, it was later termed the James-Lange theory of emotion (Dewey, 1894), and was arguably a theory that laid the foundation for many of the theories of emotion that followed.

Walter Cannon and Philip Bard later presented a contrasting theory for how we experience emotion. They posited that changes in physiological state occur simultaneously but independently of our subjective feeling of emotion, and that both occur upon receipt of signals from the thalamus in response to an external stimulus. They therefore argued that changes in physiological state are a response to, not a cause of, emotion, and that it is not possible to interpret emotional state from physiological state alone (Canon, 1931). Other theorists have argued that cognitive appraisal comes before physiological changes. Richard Lazarus, for example, posited that cognitive processes are the most important aspect of emotional experience. He argued that when experiencing an emotion, physiological change follows cognitive processing and appraisal of a stimulus (Lazarus et al., 1970).

Presenting a different view, Antonio Damasio (1999), influenced by James and Lange, also proposed that emotion is an outcome of physiological changes in the body that result from interactions with the environment. However, he also posited that experiences of physiological changes during emotional experiences create somatic markers that influence individual's later actions at the occurrence of similar experiences (Bechara et al., 1994). This theory is further

built upon in a more recent theory of emotion, presented by Lisa Feldman Barrett termed the Theory of Constructed Emotion (Feldman Barrett, 2017a). This theory posits that the brain constantly draws upon previous experience to predict and categorise physiological signals in order to provide meaning regarding our emotional state.

These are several of many theorists that have contributed to the ongoing debate within the field of emotion. Despite the lack of consensus, a common factor across all theories is the acknowledgement that changes in physiological state are involved in emotional experience. Specifically, peripheral theories of emotion (e.g., James-Lange theory of emotion, Dewey, 1894), arguing that the perception of physiological changes evokes emotion, is often cited as forming the foundation of the relationship between interoception and emotion. Recent accounts acknowledge that the processes by which an individual senses and interprets internal bodily signals is called interoception, (Chen et al., 2021). There is some disagreement regarding the source of the bodily signals encompassed by the term interoception. Whilst not a common view, some interoception theorists, such as Dworkin (2007), argue that the term should only be used to refer to the perception of signals from the viscera of the body. However, a more commonly held view is that interoception encompasses the experience and perception of bodily signals across multiple systems on both a conscious and unconscious level (Suksasilp & Garfinkel, 2022). Given that interoception occurs across multiple systems, this contemporary view arguably warrants a multifaceted framework for understanding and measuring interoception.

Interoception plays a vital role in identifying and interpreting emotion in oneself and in others (Herbert et al., 2011). It is, however, also an ever-evolving construct for which consensus regarding definitions and operationalisation has not yet been reached, which presents conceptual and methodological challenges. Development of a multifaceted framework for interoception has progressed in recent years to include numerous dimensions of interoception with varied terminology and definitions. An influential, recently developed framework outlining the multidimensional nature of interoception was put forward by Suksasilp and Garfinkel (2022) to incorporate preconscious, lower, and higher-order levels of processing within a widely accepted earlier version of the framework (Garfinkel et al., 2016). Suksasilp and Garfinkel outline higher-order levels of processing of interoceptive signals including interoceptive accuracy (an individual's accuracy at detecting their internal bodily signals), interoceptive beliefs (an individual's self-reported experiences of their interoceptive sensations in relation to different interoceptive dimensions e.g., how accurately individuals believe they perceive interoceptive signals or individuals' reports of their attention to interoceptive signals), and interoceptive insight (metacognitive awareness of interoceptive accuracy). Neural representation (central nervous system activity); strength of afferent signals (signals from the

peripheral nervous system); preconscious impact of afferent signals (the impact of changes in afferent signals); interoceptive attention (purposeful attention to interoceptive signals); and attribution of interoceptive sensations (interpretation of the cause of internal bodily sensations) are also included in the framework to reflect lower-order and preconscious levels of interoceptive processing.

Suksasilp and Garfinkel's (2022) framework has developed and evolved from previous multi-dimensional frameworks presenting different terms (e.g., Garfinkel et al., 2015; Khalsa et al., 2018). In addition, the aforementioned framework is not utilised by all, and varying terminology is used by different authors when referring to different dimensions of interoception. For example, interoceptive accuracy is referred to elsewhere as interoceptive sensitivity (e.g., Mikkelsen et al., 2019; Lyyra & Parviainen, 2018; DeWitte et al., 2016) and interoceptive belief is referred to elsewhere as metacognitive interoception (e.g., Yoris et al., 2015), interoceptive sensitivity (e.g. De Berardis et al., 2007), and interoceptive awareness (e.g., Bishop et al., 2023). This highlights just some of the discrepancies in the use of terminology related to interoception and its measurement in the literature, emphasising the difficulty faced with conceptualising and gaining an empirical understanding of the different facets of interoception. For the purpose of this thesis, the terminology outlined in Suksasilp and Garfinkel (2022) will be utilised, as this is a framework that has developed over time based on research and theory and is frequently used within the literature.

1.2 Research aims and rationale

The overarching aim of my thesis is to add to the body of evidence aimed at better understanding the contribution of interoception to emotion in children and adolescents. It is well established that internal bodily signals are influential in emotional experience (Critchley & Garfinkel, 2017) and yet there remain gaps in the literature, and in our understanding, in relation to the specific association between interoception and emotion in children and adolescents.

Emotion regulation, defined as an individual's ability to effectively manage, modify and respond to emotion (Gross, 2015), is an important area of consideration when thinking about emotion in children and adolescents. Effective emotion regulation skills can be a protective factor for mental health problems (Daniel et al., 2020), whilst difficulties with emotion regulation can impact negatively upon educational (Blair, 2002), social (Kim & Cicchetti, 2010), and health outcomes (Aparicio et al., 2016). Given that childhood and adolescence are critical times for the development of effective emotion regulation skills (Silvers, 2022), further empirical understanding of the relationship between interoception and emotion regulation could help to support practitioners such as psychologists, occupational therapists, mental health

practitioners, and school staff to be better equipped to support children and young people with their emotion regulation and mental health.

Subsequently, in my systematic literature review I explored the question, 'are dimensions of interoception associated with emotion regulation outcomes in children and adolescent populations?' Through understanding the relationship between interoception and emotion regulation, this can help to further clarify the importance of interoception in the process of emotion regulation as well as offer insight into the potential ways of supporting children and young people with the development of emotion regulation skills. My systematic literature review draws on evidence from relevant literature to explore the aforementioned research question, highlighting the potential implications for practice but also bringing attention to an area that would benefit from further research.

Further to this, my thesis aims to explore interoception and emotion more specifically in autistic adolescents. Anxiety is prevalent amongst autistic adolescents (Joshi et al., 2010). Research suggests that anxiety persists across autistic individuals' lifespans, with anxiety severity being shown to increase with age from pre-school to adolescence (Vasa et al., 2013; Mayes et al., 2011). Anxiety may increase from childhood to adolescence for autistic individuals as social interactions become more complex, and awareness of differences increases during this time (White et al., 2009). Research suggests that autistic individuals can experience a negative view of their differences which they perceive as impacting upon their desire to 'fit in' (Humphrey & Lewis, 2008). In addition to this, anxiety may be exacerbated by environmental factors associated with reaching adolescence, such as the greater demand for independence both socially and academically (Mandy et al., 2016), the increase in the demand to work in areas that are not of interest to the individual (Jacobsen, 2005), an increase in unstructured social time (Ashburner et al., 2010), and more complex environments in secondary schools that may impact upon sensory sensitivities (Costley et al., 2021; Bogdashina, 2016).

My empirical paper aimed to explore other relevant factors related to anxiety in autistic adolescents. Interoception has been closely linked with mental health difficulties including anxiety (Khalsa et al., 2018), and sensory difficulties are commonly experienced by autistic individuals (Schaaf & Lane, 2015). This was therefore deemed to be an appropriate relationship to explore further. With this in mind, my empirical paper focused on exploring the association between interoception and anxiety in autistic adolescents, with consideration to the role that alexithymia, a difficulty in identifying and describing emotions (Nemiah et al., 1976), plays in this relationship. As a non-autistic researcher, it was highly important to me that this research was of relevance to autistic adolescents and was conducted in a way that reflected and supported the needs of my participants. I therefore engaged a group of autistic adolescents prior to

commencing my data collection, to explore their thoughts on the research topic and process and provide them with the opportunity to contribute their views. The panel indicated that this was a project that they believed was of high relevance to them and to other autistic adolescents, a sentiment that seemed to be shared as I communicated with the teachers and parents of my participants, and the participants themselves, throughout the research process. Additionally, given the difficulty faced by many in accessing an autism assessment, and the increased recognition that many women and girls face additional barriers to assessment and diagnosis (Estrin et al., 2021), those self-identifying as autistic were not excluded from the study.

The findings from both of my papers will add to the field of research exploring the important role that interoception plays within the realm of emotion and anxiety, facilitating a better understanding of how we can support children and young people with their emotion regulation, and autistic adolescents with their anxiety.

1.3 Research paradigm

The approach to this thesis was grounded in a post-positivist research paradigm. Post-positivism emerged as a critique of positivism. Positivism is influenced by a realist ontology and takes the stance that a full understanding of a phenomenon - an objective reality - can be gained through observation and experimentation, and subsequent interpretation using logical inference. Moreover, it separates knowledge from the person constructing it; knowledge is discovered not produced (Holton, 1993).

Post-positivism on the other hand posits that there is no absolute truth, and that all knowledge is fallible and evolving. Moreover, this stance advocates for research methods being selected based on the research question being asked (Wildemuth, 1993). My adoption of a post-positivist paradigm was influenced by a critical realist ontology. Critical realism assumes that we can gain knowledge through experimentation but that it is influenced by those who construct it. Moreover, causal mechanisms, that is, the factors that cause events to occur, must be considered tendencies rather than universal law, as they are dependent on both theoretical framework and context (Gorski, 2013).

By adopting a post-positivist, critical realist position, I hold the view that knowledge can be gained through my choice of quantitative methodology. I endeavoured to identify tendencies that would help me to understand how the different facets of interoception relate to emotion in children and adolescents. I aimed to utilise reliable and validated methods to gain this knowledge based on prior theory. Through my systematic literature review I synthesised the

existing evidence on the relationship between interoception and emotion regulation adhering to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines. Moreover, in my empirical paper I incorporated valid objective and subjective measures of interoception to explore the relationship between interoception and anxiety in an autistic group. As the researcher I recognise that I am involved in the construction of knowledge through retroduction. Whilst I sought to find regularities through my research process, I recognise that these identified regularities are influenced by theory and context. My conclusions are fallible, they may differ from prior research, and research that follows may draw different conclusions.

1.4 Dissemination plan

These two research papers have been written with the intention to submit them for publishing in peer-reviewed journals and they have therefore been written to the specifications of these journals, including format and word count. I intend to submit my systematic literature review for consideration to the British Journal of Developmental Psychology. Alongside other areas of developmental psychology, this journal focuses on understanding issues related to emotional development across the lifespan. As my systematic literature review aims to support further understanding of factors related to the development of emotion regulation skills in childhood and adolescence, this makes this a suitable journal for my review.

For my empirical paper, I intend to submit this for consideration to the peer reviewed journal Neurodiversity. This is a relatively new journal with only one issue currently published. The scope of this journal is to publish open-access research on neurodiversity and neurodevelopmental conditions from a number of disciplines, including psychology and education. It was of high importance to me that my empirical paper covered a topic that was of relevance to the group it is aimed at supporting, i.e. autistic adolescents. In line with this it is also of high importance to me that the research is accessible to this group of people and to those working to implement effective policy and practice for this group. Therefore, I feel publishing in an open-access journal to be imperative. Moreover, this journal is published in association with the Institute of Neurodiversity, a neurominority led organisation that advocates for awareness, acceptance and appreciation of neurodiversity. Subsequently I feel confident that this journal aligns with my own views and values around neurodiversity.

Chapter 2 Interoception and emotion regulation in children and adolescents: A systematic literature review

2.1 Abstract

Background: Interoception plays a significant role in shaping emotional experiences and research suggests that interoception is involved specifically in emotion regulation. Childhood and adolescence are key periods of time for the development of emotion regulation skills.

Objectives: This systematic review aimed to explore the association between interoception and emotion regulation strategies and outcomes in a child and adolescent population.

Methods: A systematic literature search was carried out following PRISMA guidelines. Key search terms were identified using the PICO framework and pre-specified inclusion and exclusion criteria were utilised to screen papers. Papers underwent quality appraisal using the STROBE checklist. A narrative synthesis was carried out to review the findings from the included studies.

Results: 345 papers were identified through database searches. Following screening and quality appraisal, five of these were included in the review. All included studies utilised a cross-sectional design. Two studies measured the relationship between interoceptive beliefs and emotion regulation, whilst the remaining three explored the association between interoceptive accuracy and emotion regulation. For children in middle childhood and adolescence, results showed a significant relationship between areas of interoceptive beliefs and the use of specific emotion regulation strategies. Furthermore, participants with higher interoceptive accuracy tended to employ fewer maladaptive emotion regulation strategies. Studies involving children in early childhood (ages 4-6) reported that interoceptive accuracy predicted emotion regulation skills, though these findings were not statistically significant.

Conclusions: The available evidence is beginning to reflect a relationship between interoception and the use of adaptive emotion regulation strategies in children and adolescents. However, additional research is needed to explore this further.

2.2 Introduction

Our current understanding of emotion is rooted in the century-old but influential theory that our emotional experiences are formed by changes in our physiological state (e.g. James, 1884). Our awareness of the physiological state of our body, termed interoception (Craig 2014), therefore plays a vital role in emotional awareness and emotion regulation (ER). Emotions are experienced by every individual; they play a fundamental role in influencing and motivating our actions (Harmon-Jones et al., 2012). The degree to which we can regulate our emotions can act as a risk or protective factor for physical (e.g., DeSteno et al., 2013), behavioural (e.g., Daniel et al., 2020), social, and cognitive outcomes (e.g. Gross, 2002).

Childhood and adolescence are a critical time for the development of ER skills (Silvers, 2022). For many young people, their ER skills develop substantially during this period of time, but for those who continue to find regulating their emotions to be a challenge, this can result in negative outcomes and additional challenges in other areas of development (e.g., Kim & Cicchetti, 2010; Aparicio et al., 2016; Schneider et al., 2018). Given the importance of ER in everyday life, and the important role ER plays within childhood and adolescence, there is a growing body of research exploring ER related outcomes, interventions, and contributing factors within this age group (e.g., Eadeh et al., 2021; Schlesier et al., 2019; Zeman et al., 2006). However, despite the connection between interoception and emotion, a gap exists in the form of a systematic review focusing on the association between interoception and ER in children and adolescents.

2.2.1 Emotion

Whilst the construct of emotion has been conceptualised in many different ways (Gross & Feldman Barrett, 2011), the current body of research suggests that emotion relates to coherent changes across multiple systems (Mauss et al., 2005; Levenson, 2014; Dan-Glausser & Gross, 2013; Kreibig, 2010), including subjective experience (individual perception and understanding of the world around us), behaviour (facial expressions, posture, and specific actions), and physiology (in the autonomic and neuroendocrine systems). When an individual attends to and evaluates an internal or external situation, it is this that is attributed to the experiential, behavioural, and physiological changes that make up emotion (Moors et al., 2013).

Many theorists support an evolutionary understanding of emotion in which a set of universal, basic emotions are genetically hardwired. These are deemed to facilitate adaptive responses that support the identification of, and response to, threats in the environment (Ekman, 1999). Conversely, proponents of the Theory of Constructed Emotion, originally proposed by Feldman

Barrett (2017a), argue that emotions are not innate, they are learned through experience. This theory posits that from infancy the bodily sensations associated with an experience can be felt, but emotion cannot be perceived until an individual has been given the language to be able to construct their perception of any given emotion (Feldman Barrett, 2017b). Without the necessary experiences to allow an individual to construct an emotion, they simply experience core affect, a combination of affect, on a scale from unpleasant to pleasant, and level of arousal, from low to high activation (Russell, 2003). An individual's ability to construct a perception of an emotion from core affect is called emotional granularity. Someone with low emotional granularity may experience a stomach ache in a given context, where someone with high emotional granularity may experience anger (Feldman Barrett, 2017b).

Irrespective of the origin of emotion, it has also been considered helpful in the realms of decision making (Bechara et al., 2000), memory (Kensinger & Schacter, 2008), and in the formation and maintenance of social relationships (Fischer & Manstead, 2008). Emotion, however, can also be unhelpful in its function when the type, duration, or frequency of a given emotion is maladaptive to a situation (Gross & Jazaieri, 2014). In addition, emotion has been found to play a role in exacerbating preexisting psychological conditions (Keltner & Kring, 1998).

2.2.2 Emotion regulation

Emotion regulation is a term often discussed in conjunction with emotion. Emotion regulation refers to the efforts made "to influence which emotions one has, when one has them, and how one experiences or expresses these emotions" (Gross, 1998 p.275). Emotion regulation is arguably vital for optimal functioning and has been shown to be associated with better cognitive outcomes (Teper et al., 2013) and physical wellbeing (Song et al., 2015; Trindade et al., 2017; Cloitre et al., 2019). Emotion regulation is a goal–driven, motivated process, that can be deliberate or automatic, in which action is taken to move from a current to a desired state (Tamir et al., 2020; Gross & Feldman Barrett, 2011). This goal can be centred around regulating someone else's emotion, referred to as extrinsic ER, or one's own emotion, referred to as intrinsic ER (Cole et al., 2004). Learning to intrinsically regulate emotions is a key milestone within child development. Children as young as preschool age have often accumulated numerous strategies to manage their emotions (Zeman et al., 2006) and as children get older, they continue to accrue a number of strategies for ER. However, there are many children and adolescents that have difficulty regulating their emotions, which can result in negative health, educational, and social outcomes. Research suggests that difficulties with ER is a risk factor for symptoms of anxiety (Schneider et al., 2018), can negatively impact academic attainment (Blair, 2002), can create social challenges (Kim & Cicchetti, 2010; Eisenberg & Fabes, 2006), can result in perceived challenging behaviour (Zeman et al., 2002), and impact upon physical health

(Aparicio et al., 2016) for children and adolescents. Conversely, effective ER skills can act as a protective factor against mental health difficulties, and internalising (e.g., withdrawal) and externalising problems (e.g., aggression) (Daniel et al., 2020).

A frequently utilised model to understand ER is the Process Model of Emotion Regulation (Gross, 1998). In this model, Gross identifies two categories of ER approaches, antecedent-focused and response-focused. Antecedent-focused strategies occur before an emotion is experienced in full, whilst response-focused strategies occur once an emotion has been fully experienced. Within antecedent-focused regulation, Gross posits that four strategies are utilised to regulate emotion. Firstly, two event modification strategies, situation selection and situation modification, can be utilised early on in an emotional experience to regulate emotion. Situation selection refers to the process of either seeking, avoiding, or changing a situation based on the emotions we predict are going to be experienced and the emotions we want to experience. Once situation selection has taken place, we can then try to modify the situation to change our emotional experience (i.e. situation modification). Research suggests that children can modify the source of a negative emotion from around 18 months of age (Van Lieshout, 1975) but are more likely to utilise event modification strategies when they reach middle childhood (López-Pérez et al., 2017). Following on from this, cognitive modification strategies can be utilised whilst an emotion is being experienced. Cognitive modification strategies include distraction (or redirection) and reappraisal (changing our thoughts about a situation). Between the age of one to three, children begin to develop the cognitive skills necessary to intentionally redirect their attention away from an emotionally distressing experience (Rothbart et al., 2006; Theurel & Gentaz, 2018). Cognitive reappraisal strategies are more advanced, but research suggests they can be utilised, with support, by children as young as four, and independently during middle childhood (Willner et al., 2022).

Response-focused ER on the other hand, is utilised in response to an emotion being fully experienced in order to amplify or suppress the emotion. Gross' model proposes that this can be done through changing our behaviour (e.g., facial expressions, tone of voice), changing our thoughts (e.g., increasing or decreasing attention to an emotion or event), or by changing our physiological arousal (e.g., using food, alcohol, breathing activities, and exercise). Children aged two and three begin using response focused strategies such as controlling their facial expressions (Cole, 1986; Calkins, 2004), whilst older children and adolescents are reportedly more likely than younger groups to utilise maladaptive response-focused strategies to manage their emotions (Cisler et al., 2010).

Understanding why some people are able to use the aforementioned ER strategies more successfully than others may help to identify ways in which to support the development of ER

skills. Gross (2015) proposes an extended model of ER as a framework to enhance comprehension in this area. This model breaks ER down into three stages. Firstly, the identification stage involves perception of the emotion, evaluation as to whether regulation is required, and a goal to regulate being activated. This is followed by the selection stage in which the ER strategy is selected based on the available cognitive and physiological resources. Finally, an implementation stage involves applying the selected strategy to a specific situation in order to regulate an emotion.

This review will further explore the role of interoception as a contributing factor in the ER process in children and adolescents. Interoception is closely linked with our emotional experience, therefore, exploring the influence of various interoceptive processes on ER could elucidate their effects on the different stages of the extended model of ER.

2.2.3 Interoception and emotion regulation

The term interoception encompasses the processes by which individuals sense, interpret, and regulate signals from inside the body (Chen et al., 2021). Suksasilp and Garfinkel (2022) propose a multi-dimensional framework for delineating the different facets of interoception, ranging from preconscious and lower-level processing to higher-order levels of processing. Dimensions in the preconscious and lower levels of processing include neural representation (activity in the central nervous system), strength of afferent signals to the central nervous system influencing interoceptive processing, and the preconscious impact of afferent signals on processing of external stimuli and central nervous system activity. Beyond this, they outline interoceptive measures such as interoceptive accuracy (performance on behavioural tests of interoception), interoceptive beliefs (an individual's self-reported account of their interoceptive experiences in relation to different interoceptive dimensions e.g., how accurately individuals believe they perceive interoceptive signals or individuals' reports of their attention to interoceptive signals), interoceptive insight (correspondence between interoceptive accuracy and perceived accuracy), interoceptive attention (purposeful attention to interoceptive signals), and attribution of interoceptive signals (the interpretation of bodily signals and their causes).

In line with theories of emotion that posit that emotion is experienced as a result of physiological changes in our body (Craig, 2016), or that emotion stems from an interpretation of these physiological changes (Feldman Barrett, 2017b), interoception significantly contributes to emotional experience. Research suggests that individual differences in ER are underpinned by differences in interoceptive accuracy (Herbert et al., 2007). Moreover, interoceptive beliefs have been shown to influence ER ability through an increase in emotional awareness (Tan et al., 2023). These findings are further supported by research that explores areas of the brain and

nervous system involved in interoception and emotional processes. Limbic brain regions that are active during emotional experiences, namely the anterior insula and cingulate cortices, have been shown to also receive interoceptive signals from physiological systems within the body (Craig, 2014), suggesting that afferent interoceptive signals are involved in the determination of regulatory responses based on physiological information.

One recent systematic review currently exists that explores the association between interoceptive accuracy and ER in an adult population (Pinna & Edwards, 2020). Results of the review revealed that individuals that performed better on measures of interoceptive accuracy also had better ER skills according to self-report measures of ER. Despite the limited number of studies and the scope of only one dimension of interoception included, these findings suggest a potential link between interoception and ER that supports the underlying physiological and psychological theoretical basis for this connection.

2.2.4 Aim

Given the important and protective role that ER plays, and the theoretical and empirical links between interoception and ER, this review aims to address a gap in the literature by exploring this association specifically for children and adolescents. As interoception is multi-faceted in nature, this review aims to explore the different constructs outlined by Suksasilp and Garfinkel (2022) to answer the question: are different dimensions of interoception associated with ER outcomes in children and adolescent populations? Given the challenge that many children and adolescents face regulating their emotions and the impact this has on academic, social, and mental health outcomes, this review can contribute to better understanding how these young people can best be supported to develop their ER skills.

2.3 Method

A systematic literature search for original research articles was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2020) (see Figure 1). The review was registered on Prospero (registration number: CRD42023470953). The PICO framework (Richardson et al., 1995) was utilised to develop a search strategy, with the exclusion of the comparison category, (see Table 1) and key terms were entered into CINAHL, ERIC, Medline, PsychInfo, Web of Science, and ProQuest Dissertations & Theses Global databases. The decision was made to not exclude non-peer-reviewed literature as this can facilitate the inclusion of a greater number of relevant studies, enabling a more comprehensive review of the evidence (Mahood et al., 2014). Searches were

limited to only abstracts. Duplicates were removed using the remove duplicates function in Endnote 21 (Clarivate, 2023) and checked via visual inspection.

Table 1. *Key search terms identified using the PICO systematic search framework*.

P (Population)	child* OR adolescen* OR teen* OR primary-age* OR primary age* OR secondary-age* OR secondary age* OR preschool* OR pre-school* OR pupil* OR student*
I (Intervention)	interocept*
C (Comparison)	N/A
O (Outcome)	emotion* regulation OR "affect" regulation OR emotion* dysregulation OR "affect" dysregulation OR emotion* control OR "affect" control OR mood regulation OR regulation strategies

2.3.1 Inclusion and exclusion criteria

Three reviewers screened each abstract in Endnote and the results of screening were discussed until a consensus was reached. The lead author then reviewed the full-text articles for each study to identify if they were suitable for the review. Review articles and articles in which the full text was not available or was not available in English were excluded. Only studies with human participants were included and studies were required to include child or adolescent (3-18 years of age) participants. Papers that included both adult and child or adolescent participants were retained with a focus on reviewing the results for the child or adolescent participants. Studies that included populations with a physical or mental health condition were excluded, though papers including a control group were retained with a focus on reviewing control group performance. Studies were required to include a measure of interoception including: (a) Interoception accuracy measures including the heartbeat counting task (Schandry, 1981), the heartbeat detection task (Whitehead et al., 1977) or both; (b) interoceptive belief measures (e.g. Multidimensional Assessment of Interoceptive Awareness in Youth, [MAIA-Y; Jones et al., 2021]; The Body Perception Questionnaire [BPQ; Porges, 1993] etc.); (c) interoceptive insight including confidence ratings in response to interoceptive accuracy measures; (d) preconscious impact of afferent signals (e.g., cardiac signals; see Suksasilp & Garfinkel, 2022) or; (e) studies using a new interoceptive measure that systematically investigates interoception through one of the dimensions described in Suksasilp & Garfinkel (2022). Studies were also required to include a direct measure of ER, for example, The Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) and The Cognitive Emotion Regulation Questionnaire for children (CERQ-k; Garnefski et

al., 2007). Finally, studies were required to analyse the association between a measure of interoception and a measure of ER.

2.3.2 Data extraction and quality assessment

Full-text articles were extracted by the lead author and tabulated (see Appendix A). When deciding what data to extract, the PICO framework was referred to, to ensure that all useful data were extracted. This included population characteristics (age, sex, ethnicity), measure of interoception, measure of ER, and results related to the association between interoception and ER. Additional information that was considered to be relevant to answering the research question was also extracted including country, study aims, sample size, and confounding variables considered.

The STROBE checklist (von Elm et al., 2014) was used by the lead author to assess the quality of each study. This checklist was chosen as it allows for the comprehensive quality appraisal of cross-sectional studies.

2.4 Results

A total of 345 papers were initially identified from the six databases utilised. A breakdown of how many were found from each database can be seen in Figure 1. After duplicates were removed, 155 papers remained. Initial screening of titles and abstracts resulted in the exclusion of 147 additional papers, leaving eight papers remaining for full text examination. After a full screening and critical appraisal was carried out, five studies were selected for inclusion in the review.

2.4.1 Study characteristics

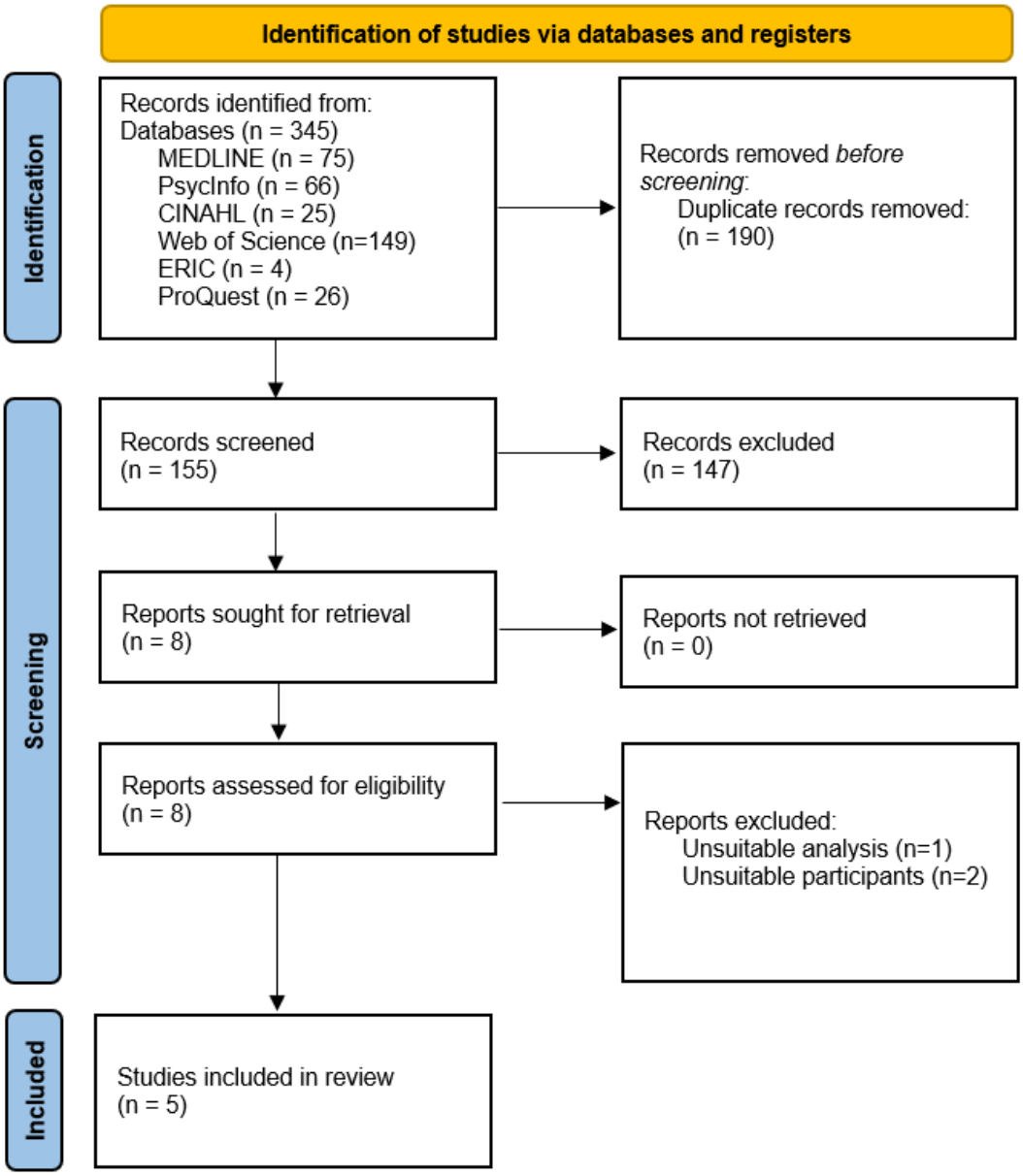
The articles included in the study were published between 2016 and 2023 in peer-reviewed journals. Participant ages ranged from four (Schaan et al., 2019; Opdensteinen et al., 2021) to sixteen years (De Witte et al., 2016). The percentage of female participants ranged from 32% (Cheung et al., 2023) to 67% (Bishop et al., 2023). The majority of studies did not report the ethnicity of participants. The single study that did report ethnicity (De Witte et al., 2016) indicated that ethnicity of participants was ‘mostly Caucasian’. Sample sizes ranged from 25 (Cheung et al., 2023) to 49 (Schaan et al., 2019).

All studies utilised a cross-sectional design. Two of the studies utilised the MAIA-Y to measure interoceptive beliefs (Bishop et al., 2023; Cheung et al., 2023), whilst the others utilised measures of interoceptive accuracy, namely the heartbeat counting task (De Witte et al., 2016)

or an adapted version of this (Schaan et al., 2019; Opdensteinen et al., 2021). All studies utilised questionnaires to capture information regarding ER.

For consistency and ease of understanding, the language used to describe dimensions of interoception in the included studies has been taken from the definitions outlined in Suksasilp and Garfinkel (2022), even if this is not the language used in the articles.

Figure 1. *Prisma Flow Diagram*



2.4.2 Interoception and emotion regulation

Two of the included studies explored the relationship between interoceptive accuracy and the use of ER strategies in early childhood. Firstly, Schaan et al., (2019) explored this relationship in 49 children aged between four and six years of age, using a researcher adapted version of the

heartbeat counting task, named the Jumping Jack Paradigm (JJP). This required participants to perform jumping jacks for 10 seconds to increase heart rate and then indicate, using a magnitude estimation task with four different sized felt circles, how fast their heart was beating before and after the jumping jacks. Participants heart rates were measured using an ECG device and interoceptive accuracy was derived from comparing actual heart rate with self-reported heart rate (via the magnitude estimation task). To measure participants' use of ER strategies, participants were asked to complete the Emotion Regulation subscale of the Emotional Competence Inventory for Children (MeKKi; In-Albon et al., 2022). This involved participants being presented with six vignettes depicting a negative emotional experience and being asked what they would do in each situation to help them to feel better. Answers were coded to ten different ER strategies, which were split into adaptive and maladaptive strategies. Higher scores were indicative of greater use of adaptive strategies. Findings from the JJP task indicated that children were able to successfully identify an increase in heart rate when an increase in heart rate occurred. Correlation analysis showed that interoceptive accuracy was not significantly associated with ER. A multiple linear regression was carried out with sex, age, and interoceptive accuracy entered into the model as predictor variables and emotion regulation as the outcome variable. Interoceptive accuracy was reported as accounting for some of the variance in ER, with more accurate performance on the JJP task predicting higher ER scores, however, the model did not reach statistical significance (p>0.05, R^2=0.154).

Similar methodology was utilised by Opdensteinen et al., (2021) with changes made to the JJP task to address limitations identified in the aforementioned study, namely an increase in the number and length of the JJP trials. Forty participants aged between four and six years of age completed three trials of jumping jacks for 15, 20, and 25 seconds. In addition, the magnitude estimation task included five instead of four felt circles. The authors found a significant multiple regression effect with age, sex, and interoceptive accuracy included as predictor variables and ER as the outcome variable (R^2 = 0.227). However, the authors report a 'trend level' significant effect of interoceptive accuracy on ER given that the significance value was greater than 0.05 but less than 0.10. There was no significant association between age, sex and ER.

The study carried out by De Witte et al., (2016) similarly explored the relationship between interoceptive accuracy and use of adaptive and maladaptive ER strategies, but in an older age group of 46 participants aged 9-16 years. A heartbeat counting task (Schandry, 1981) was used as a measure of interoceptive accuracy. This involved participants counting their heartbeats (without touching their body) for six trials of different durations (25, 35, or 45 seconds). Their responses were compared to their actual number of heartbeats, measured via ECG. They were also asked to rate how confident they were that their responses were correct, on a scale from one to nine, to measure interoceptive insight. The FEEL-KJ (Grob & Smolenski, 2005), a 90-item

self-report questionnaire was utilised to measure the extent to which participants habitually used a range of adaptive and maladaptive ER strategies. Analyses revealed a significant small to moderate partial correlation (r = -0.31) between performance on the heartbeat counting task and use of maladaptive ER strategies, indicating that better interoceptive accuracy was associated with less use of maladaptive strategies for ER. Interoceptive accuracy was not associated with use of adaptive ER strategies and interoceptive insight was not associated with ER.

Cheung et al., (2023) utilised the MAIA-Y and the CERQ-k to explore the association between 25 nine to twelve-year-old children's interoceptive beliefs and their use of ER strategies. The MAIA-Y is a self-report questionnaire with 32-items across 8 subscales, on a 6-point Likert scale. It captures individuals' self-reported interoceptive experiences (e.g., noticing interoceptive signals and responses to interoceptive signals) in different contexts (e.g., when in a conversation and when upset about something). The CERQ-k includes 36 self-report items within nine subscales, on a 5-point Likert scale, relating to different types of cognitive ER strategies. The questionnaire aims to identify which cognitive ER strategies individuals use the most. Correlational analyses and linear regression analyses with bootstrapping were conducted to analyse the data. A negative predictive relationship was found between the 'not-distracting' (not ignoring uncomfortable and painful body sensations) subscale of the MAIA-Y and the cognitive ER strategy 'planning' (considering the actions to take to manage unpleasant emotions) (r=-0.598). This indicated that those with a tendency to not ignore their uncomfortable bodily sensations were less likely to think about and plan their actions in response to negative emotions. 'Not-distracting' was also a significant negative predictor of use of positive reappraisal (r=-0.615). In addition, the MAIA-Y subscale 'self-regulation' (being able to sustain attention and respond to internal bodily sensations) was found to predict positive reappraisal (r=0.5). These findings indicated that participants that were more focused on their uncomfortable and painful internal bodily signals were less likely to use planning and positive reappraisal to manage difficult emotions, but those that had a tendency to focus their attention on and respond to neutral internal bodily signals were more likely to use positive reappraisal to regulate their emotions.

Similarly, in the final study, Bishop et al., (2023) utilised the MAIA-Y to measure interoceptive beliefs in 30 participants of a similar age group (8–12-year-olds), to explore the association between interoception and ER ability, measured using the ER subscales of the Behaviour Rating Inventory of Executive Functioning, Second Edition (BRIEF-2; Gioia et al., 2015). Again, data were bootstrapped, artificially increasing the sample size to 1000. A significant association was found between the 'emotional awareness' subscale of the MAIA-Y, which indicates how aware a child is of the bodily signals that are associated with their emotions, and the 'emotion control'

subscales of the BRIEF-2 (r=0.394). This suggests that children that had greater awareness of the bodily signals associated with their emotions reported a greater ability to moderate and regulate their emotional responses.

2.5 Discussion

The aim of this systematic review was to examine the available literature exploring the association between interoception and ER in children and adolescents. A previous systematic review explored this relationship in adults and found that interoceptive accuracy is associated with ER in this age group (Pinna & Edwards, 2020). However, there is currently no systematic review exploring this association in childhood or adolescence. Given the importance of this period for the emergence and development of ER skills (Silvers, 2022), and the impact of ER on academic, social, and mental health outcomes, this was considered to be an important area for review. There were mixed findings in relation to this association, dependent on age group.

2.5.1 Interoceptive accuracy and emotion regulation

Studies exploring interoceptive accuracy and ER revealed mixed findings. A significant association was found by De Witte et al., (2016), in participants aged 9-16 years, between performance on a measure of interoceptive accuracy and the use of less maladaptive ER strategies, irrespective of interoceptive insight. Evidence suggests that there is an association between maladaptive ER strategies and symptoms of anxiety and depression in adolescents (Schäfer et al., 2017). The findings from De Witte et al.'s (2016) study highlight that increased accuracy in the perception of emotional states at the 'identification' stage of the extended model of emotion regulation (Gross, 2015) may contribute to the way in which children and adolescents select strategies for ER at the 'selection' stage. This suggests that interoceptive accuracy may act as a protective factor in mental health through the use of less maladaptive ER strategies. The robustness of the findings of this study is bolstered by the consideration given by the authors to a number of confounding variables and the utilisation of a reliable measure of interoception (Santos et al., 2023). However, the study participants listened to their heartbeats prior to completing the heartbeat counting task which will have offered insight into their heart rate prior to starting the task and therefore may have contributed to their performance. This should therefore be considered when interpreting the findings.

The included studies that explored interoceptive accuracy in a younger age group, four- to six-year-olds (Schaan et al., 2019; Opdensteinen et al., 2021), found that whilst performance on an interoceptive accuracy task was shown to account for some of the variance in ER scores, this finding was not statistically significant at a 0.05 level in either study. It was not clear in these

articles what value the significance level had been set to. Emotion regulation skills develop rapidly within this age group (Eisenberg et al., 2010) as a result of key advances in executive functions that facilitate attention and inhibition (Blankson et al., 2017), consequently providing more ways of navigating emotional experiences. At this age caregivers act as a key resource for the development of ER skills, including supporting a developing understanding of strategies for ER (Eisenberg et al., 2010). It may therefore be the case that caregiver influence plays more of a role in strategy selection at this age than perception of internal signals. Yang et al., (2022) conducted a study with four- to six-year-olds, in which a curvilinear relationship was found between age and interoceptive accuracy. Their findings suggested that younger children may have poorer interoceptive accuracy than young adults. This may further highlight the importance of caregiver influence at this age over interoceptive accuracy in ER strategy selection.

There are a limited number of studies exploring interoceptive accuracy in this age group. This is likely a result of the methodological difficulties with exploring interoceptive accuracy in such a young sample, hence the development of an adapted paradigm for measuring this dimension of interoception in Schaan et al., (2019) and Opdensteinen et al.'s (2021) studies. Whilst the development of the methodology within these studies was theoretically underpinned, capturing additional data may have been useful to increase the validity of the data collected. For example, the task requires children to have developed the skill of sensing magnitude. Whilst this skill theoretically should have developed by the age that the participants were (von Baeyer et al., 2017), there is variance in the development of numerical skills in this age group (e.g. Passolunghi et al., 2015) and magnitude estimation tasks arguably require a certain level of numerical skill (Durghin, 2016). Therefore, it would likely have been prudent to assess whether participants had developed this skill before requiring them to use it. The interoceptive accuracy measure utilised by Yang et al., (2022), a child-friendly eye-tracking task not requiring speech and motor skills or a level of numerical competency, could be considered as a valid alternative to this task in future research involving young children. Moreover, whilst the tool used to measure ER in these studies has been found to be reliable (In-Albon et al., 2022), the questionnaire requires children to be able to express what action they would take in a given situation. A child's ability to do this is dependent on several skills, for example expressive language, and it may therefore have also been beneficial to capture information relating to this. Nevertheless, this study provides a useful basis for exploring interoceptive accuracy in a younger population moving forward, though more research into the reliability and validity of the paradigm would be helpful. Triangulation from different data sources for ER may also help to offer additional insight into this relationship in future research.

2.5.2 Interoceptive beliefs and emotion regulation

The findings from studies exploring interoceptive beliefs and ER reflected that different facets of interoceptive beliefs may influence the use of ER strategies in different ways, dependent on the type of bodily signals that are given attention. Of particular note, Cheung et al., (2023) found that scores on the 'not-distracting' subscale of the MAIA-Y were negatively associated with the antecedent focused cognitive ER strategies, 'planning' and 'positive reappraisal'. When considering Gross' (2015) extended model of ER, this suggests that participants who did not ignore their uncomfortable body sensations, which would sit within the 'identification' stage of the model, were subsequently less likely to select and implement the adaptive regulation strategies planning and positive reappraisal at the 'selection' and 'implementation stages of the process. On the other hand, those that scored higher on the 'self-regulation' subscale of the MAIA-Y were more likely to use positive reappraisal. The 'self-regulation' subscale assesses attention to neutral bodily sensations whilst the 'not-distracting' subscale focuses on painful and uncomfortable sensations. This suggests that when uncomfortable bodily sensations were given more attention this impacted participants' ability to utilise adaptive ER strategies, whereas, when more neutral bodily sensations were given attention and responded to, reappraisal was more likely to be selected and implemented.

Bishop et al.'s (2023) results, showing an association between the MAIA-Y 'emotional awareness' scores and the BRIEF2's 'emotion control' scores, provide further support for the notion that when internal bodily signals linked with emotion are perceived, processed, and understood, children and adolescents are more likely to utilise strategies to help regulate their emotions. It is important to note that there was limited exploration of potential confounding factors, bootstrapping could have potentially introduced bias, and the sampling approaches (snowball sampling and sampling through a sports club) may potentially reduce the reliability and generalisability of the findings in these studies. However, the outcome measures utilised, the MAIA-Y, CERQ-k, and BRIEF2, have all been shown to be valid and reliable measures (Jones et al., 2020; Garnefski et al., 2007; Gioia et al., 2015), and precise details were given surrounding the statistical analyses, which adds credibility to the findings of these studies. Subsequently, these studies provide promising results in respect to the relationship between interoception and ER and therefore the potential avenues for support for children and adolescents that find ER challenging.

2.5.3 Limitations

One limitation of this review is that the included studies did not provide detail in regard to power analysis of sample size and therefore it is not clear for most studies whether or not the sample

sizes were sufficient for the analyses conducted. Several of the studies found near-significant relationships which may suggest that these studies were underpowered. In addition to this, all studies utilised correlational methods and whilst it is possible to interpret the existence and direction of a relationship from this, causal inferences cannot be determined. The small number of studies included in the review, and limited information regarding various participant characteristics (e.g. ethnicity), also indicates that interpretations must be considered cautiously, particularly in relation to generalisability, given that the evidence base is limited.

2.5.4 Conclusions and future research

The available literature, though minimal, indicates that both interoceptive accuracy and interoceptive beliefs may be associated with the increased use of adaptive ER strategies, reduced use of maladaptive ER strategies, and overall ER skills, in children and adolescents. This highlights the potential importance of focusing support for children and adolescents with ER difficulties, on the identification stage of the extended process model of ER (Gross, 2015), given that increased capacity at this stage may be beneficial for the latter stages of the model, selection and implementation. The relationship between interoception and ER in early childhood remains less clear, however, the studies outlined within this review provide a foundation for further research to be carried out with this age group. Given the limited number of studies exploring this association, and the importance of ER skills development during childhood and adolescence, future research should continue to explore the relationship between interoception and ER in this age group. Consideration should also be given to different groups of participants, such as those that are neurodiverse and those from different ethnic backgrounds, to increase generalisability.

Chapter 3 Exploring the association between interoception, alexithymia, and anxiety in autistic adolescents

3.1 Abstract

It is well-established that anxiety is prevalent amongst autistic adolescents and sensory differences are common. Interoception is increasingly being explored in relation to anxiety, and research has begun to investigate the link between interoception and anxiety in autistic groups, with a suggestion that a discrepancy between interoceptive accuracy and beliefs may result in a diminished capacity to regulate, resulting in greater levels of anxiety. Given its role in emotional processing, alexithymia, which is reported to be more prevalent in autistic individuals, may also play a role in the interaction between autism, interoception, and anxiety. This study aims to contribute to an understanding of anxiety in autistic adolescents by exploring the associations between interoception, alexithymia, and anxiety in this population. Questionnaires were utilised to measure autism traits, anxiety, alexithymia and interoceptive beliefs in a sample of 37 autistic adolescents. In addition, behavioural measures of cardiac interoception, with confidence judgements, were used to measure interoceptive accuracy and insight. Correlation, regression, and moderation analyses were utilised to analyse the data. The results revealed a significant relationship between interoceptive beliefs and anxiety. No other variables were associated with anxiety in the present study. The implications of these findings are discussed.

3.2 Introduction

It is well established that anxiety is prevalent amongst autistic children and young people (e.g., Joshi et al., 2010). Estimates of prevalence vary significantly with research indicating that up to 82% of autistic youth experience anxiety (Kerns et al., 2020; Ben-Itzchak et al., 2020; Bougeard et al., 2021). Recent research suggests that approximately 51% of autistic children and adolescents in the UK experience anxiety to a diagnosable level (Hollocks et al., 2023). Anxiety poses challenges for autistic young people, impacting them across home, social, and educational contexts (Simpson et al., 2020). For example, it has been shown to exacerbate restricted and repetitive behaviours (Baribeau et al., 2020) and sensory sensitivities (Mazurek et al., 2013) in autistic children and adolescents, and has been associated with social challenges (McVey et al., 2018; Factor et al. 2017), reduced school engagement (Wood, 2006), difficulty completing schoolwork (Adams & Emerson, 2020), depression, self-harming behaviours (Kerns

et al., 2015), physical health issues and sleep problems (Williams et al., 2015) in this population. Given the prevalence of anxiety in autistic adolescents and the impact this has on them across multiple contexts, a greater understanding of factors contributing to anxiety in this population could help to inform appropriate avenues for support.

One domain that is being increasingly explored in relation to anxiety is interoception. The term interoception encompasses the processes by which individuals sense, interpret, and regulate signals from inside the body (Chen et al., 2021). The multidimensional nature of interoception involves both unconscious and conscious processes that determine how bodily states are experienced and measured (Suksasilp & Garfinkel, 2022; Garfinkel et al., 2015). For example, interoceptive accuracy refers to an individual's accuracy at detecting their internal bodily signals and is frequently measured by behavioural heartbeat perception tasks (e.g., Schandry, 1981; Whitehead et al., 1977). Conversely, interoceptive beliefs reflect an individual's account of their interoceptive experiences in relation to different interoceptive dimensions (e.g., how accurately individuals believe they perceive interoceptive signals or individuals' reports of their attention to interoceptive signals) and are commonly assessed using self-report questionnaires (e.g., Cabrera et al., 2017), or through assessing participants' confidence in their performance on interoceptive accuracy measures. Finally, interoceptive insight refers to how well an individual's interoceptive beliefs and accuracy correspond with each other.

Prominent emotion theorists have long argued that emotion is closely linked with our bodily experiences (James, 1890) and is shaped by the signals from our internal systems (Craig, 2014; Feldman Barrett, 2017). Interoception is therefore believed to play a vital role in our emotional experience, and impaired interoception across different dimensions has been shown to significantly impact on 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, which contributes to individual differences in maintaining homeostasis, and affects physical and mental wellbeing (Tsakiris & Critchley, 2016). Differences in interoceptive beliefs have been argued to play a role in the development of anxiety symptoms. Interoceptive beliefs have been linked with anxiety, with reports of greater internal focus on interoceptive signals being associated with greater anxiety, in adolescents (De Berardis et al., 2007) and adults (Olatunji et al., 2007). Anxiety disorders are associated with an increased focus on autonomic bodily processes (Mumford et al., 1991) which may explain the link between interoceptive beliefs and anxiety. Research conducted by Ehlers (1993) suggests that individuals that experience anxiety may present with a tendency to catastrophize their interpretations of their bodily signals, a response which may become conditioned over time,

and play a subsequent role in maintaining anxiety symptoms (Bouton et al., 2001; Paulus & Stein, 2006; 2010).

The link between interoceptive accuracy and anxiety has also been explored. Performance on interceptive accuracy measures has been shown to be positively correlated with scores on measures of anxiety in adults with (Van der Does et al., 2000; Zoellner et al., 1999; Pollatas 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). Whilst the aforementioned studies reflect the notion that better interoceptive accuracy results in greater anxiety, other research has found a converse relationship (De Pascalis et al., 1984) or no relationship at all (Ehlers et al., 1988). Mixed findings in the research could be indicative of other factors playing a role in this relationship.

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 adults, with autistic adults scoring lower on measures of interoceptive accuracy (Garfinkel et al., 2016; Mul et al., 2018) and interoceptive beliefs (Fiene & Brownlow, 2015; Fiene et al., 2018; Hassen et al., 2023; Bonete et al., 2023). Randomised control trials of interventions aimed at improving interoception have also shown reductions in anxiety in autistic adults (Quadt et al., 2021). This has been supported by qualitative studies such as that conducted by Trevisan et al., (2021), that demonstrated that many autistic individuals describe limited awareness of, or difficulty understanding, their internal bodily signals. Other researchers have found no differences in measures of interoceptive accuracy between autistic adults and non-autistic groups (Nicholson et al., 2018; 2019; Mash et al., 2017; Shah et al., 2016; Failla et al., 2020). Furthermore, some research indicates that autistic individuals score higher on measures of interoceptive beliefs than non-autistic groups, indicating that the autistic participants reported being more aware of their internal bodily signals (Garfinkel et al., 2016; Zdankiewicz-Ścigała et al., 2021). There is less research exploring this association in samples of autistic children and adolescents with research findings also varying. Some research has indicated that interoceptive accuracy (Schauder et al., 2015; Mash et al., 2017; Failla et al., 2020) and beliefs (Butera et al., 2023) do not differ between autistic and non-autistic children and adolescents. Other researchers have found significant differences between the two groups, with autistic children and adolescents scoring lower on measures of interoceptive accuracy (Nicholson et al., 2019; Palser et al., 2018a, Yang et al., 2021). Research has also suggested that interoceptive accuracy may increase until middle-age in autistic individuals (Ulus & Aisenberg-Shafran, 2022; Nicholson et al., 2019; Yang 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. Specifically, their study with autistic adults showed that differences between interoceptive accuracy and beliefs were associated with anxiety. Palser et al., (2018) replicated this finding, demonstrating that ITPE was associated with anxiety in autistic children and adolescents aged 6-17. However, Palser et al., also found interoceptive beliefs alone predicted anxiety in their sample. This is in line with the posited theory that anxiety is associated with a failure to predict interoceptive changes (Paulus & Stein, 2010) which can hinder the association between bodily sensations and emotional experiences, leading to reduced identification of emotions and subsequent diminished capacity to regulate (Maisel et al., 2016).

Research further suggests that alexithymia, a difficulty identifying and describing emotions (Nemiah et al., 1976), may be associated with interoception and anxiety 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., 2018). The discrepancy in findings in relation to autism and interoception has been theorized to be a result of alexithymia, with the suggestion being that interoception is central to alexithymia, not autism (Bird & Cook, 2013; Brewer et al., 2016). Subsequently, it is argued that performance on interoceptive measures may be influenced by the co-occurrence of alexithymia in autistic participants and therefore, differences in levels of alexithymia between studies may explain why there are mixed findings (Shah et al., 2016). Research findings lend support to this hypothesis, revealing significant associations between interoceptive accuracy and alexithymia (Herbert et al., 2011), and interoceptive accuracy and alexithymia but not autism traits (Shah et al., 2016) in non-autistic adults. Furthermore, a meta-analysis conducted by Trevisan et al., (2019) revealed alexithymia to be associated with interoceptive beliefs. However, this meta-analysis highlighted that discrepancies in the operationalization of interoception created inconsistency in the available literature. In addition, some research has shown no relationship between alexithymia and interoception in autistic and non-autistic adults (Nicholson 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; South & Rodgers 2017; Maisel et al., 2016). Alexithymia has been shown to be associated with heightened anxiety in non-autistic adults (Marchesi et al., 2004; Besharat, 2008; Devine et al., 1999) and adolescents (Karukivi et al., 2010) and to mediate the relationship between interoceptive beliefs and anxiety in a non-autistic sample (Palser et al., 2018).

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).

Given the high prevalence of anxiety in autistic adolescents and the limited evidence available, the relationship between interoception, anxiety, and alexithymia in this group warrants further investigation. The current study therefore aims to explore the relationship between interoception, alexithymia, and anxiety in autistic adolescents. Specifically, we examine whether interoceptive accuracy, interoceptive beliefs, interoceptive insight, 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.

3.2.1 Research questions and hypotheses

This study aims to answer the following research questions: (a) Are interoceptive accuracy, beliefs, and insight associated with anxiety in autistic adolescents? It was predicted that interoceptive accuracy, beliefs and insight would be associated with anxiety in this population; (b) are interoceptive accuracy and beliefs associated with alexithymia in autistic adolescents? Specifically, we hypothesised that both interoceptive accuracy and alexithymia would be associated with anxiety 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; (d) does alexithymia moderate the relationship between interoception and anxiety in autistic adolescents? It was predicted that alexithymia would moderate the relationship between interoception and anxiety.

3.3 Method

3.3.1 Ethics

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

3.3.2 Participants

A power analysis was conducted using G*Power (Faul et al., 2007), based on effect sizes from Palser et al., (2018a), as this study included a similar age group, and Garfinkel et al., (2016), which had a similar design. This indicated that a minimum sample size of 31 was required for a correlational analysis to detect a significant effect with 80% power, at a significance level of

$p<0.05$. 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, leaving a total of 37 participants. 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. To facilitate the inclusion of self-identifying participants, 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). Of the 37 participants recruited, two (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. 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.

3.3.3 Measures

3.3.3.1 Screening questionnaire

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

3.3.3.2 Interoceptive accuracy – heartbeat perception tasks

Two behavioural measures of cardiac interoception, the Heartbeat Counting Task (Schandry, 1981) and the Heartbeat Discrimination Task (Whitehead et al., 1977) were used to measure interoceptive accuracy. A pulse oximeter was used in both tasks to monitor participants' heart rate.

In the Heartbeat Counting Task participants were asked to silently count their heartbeat over six different, randomly presented, time intervals (25, 30, 35, 40, 45, and 50 seconds) without putting their hands on their body. At the end of each trial, they were asked to report the number of heartbeats they had counted. This task has been shown to have good reliability (Santos et al., 2022) 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, 10cm 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 Heartbeat Discrimination Task participants were played a series of tones through headphones, which were either in sync or slightly delayed by 300ms relative to their heartbeat. After hearing the tones, participants were asked to indicate to the researcher 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. As with the heartbeat counting task, participants were asked to rate their confidence after each trial on a 10cm visual analogue scale.

3.3.3.3 Interoceptive beliefs

The Body Perception Questionnaire Short Form (BPQ-SF; Porges, 2015) 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., 'muscle tension in my arms and legs' and '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' and 'I have indigestion'). The mean was calculated for each subscale by dividing the total score for the subscale by the number of items in that scale. Cabrera et al., (2018) demonstrated that BPQ-SF has good internal consistency (α =.92), convergent validity, and test-retest reliability (α =.99).

3.3.3.4 Interoceptive insight

Interoceptive insight was calculated for each of the interoceptive accuracy tasks by evaluating the relationship between accuracy and confidence judgements. As outlined in (Garfinkel et al., 2015), due to data from the heartbeat discrimination task being binary, 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 heartbeat counting task, a Pearson correlation was carried out between accuracy scores and confidence judgements for each participant, to establish an additional measure of interoceptive insight.

3.3.3.5 Interoceptive Trait Prediction Error (ITPE)

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

3.3.3.6 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., 1994) 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, as suggested by Loas and colleagues.

3.3.3.7 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.

3.3.4 Procedure

3.3.4.1 Lived Experience Advisory Panel

Prior to data collection a Lived Experience Advisory Panel (LEAP) of four autistic adolescents was conducted in a school in the South East of England. This consisted of a one-hour session in which the researcher (LC) sought to gain the views of participants on the accessibility of the research materials and procedures as well as the relevance of the topic. Research materials were provided to participants one week before the panel and participants were paid £25 each for their time with the option of receiving this as a voucher or in cash. Overall, participants were satisfied with the proposed research and methods, but offered some suggestions in relation to the procedure to help ensure participants were comfortable, for example, checking that participants were happy with the volume of the tones being presented to them in the Heartbeat Discrimination Task. These suggestions were then taken forward into the main study.

3.3.4.2 Main study

Study details were sent out to secondary school, sixth form, and college headteachers in South East England inviting them to support the research. Eight schools agreed to be involved and sent out information sheets and consent forms to the parents of autistic pupils or to the pupils themselves in post-16 institutions. 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. Participants had the alternate option to complete the questionnaires at their school or college on the day they were visited by the researcher (LC).

Participants met with the researcher in a quiet room at their school or college during the school day to complete the Heartbeat Discrimination Task, Heartbeat Counting Task, and the GAD-7, taking approximately 25-30 minutes 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.

Based on the practical guidelines for conducting research with the autistic community outlined by Gowen et al., (2019), the following steps were taken, in addition to those already mentioned, to ensure that the project reflected the needs of the participants:

- The information sheet included clear information about why the study was being conducted, and exactly what it involved.
- Relevant pictures were included in the information sheet (e.g., example photo of a pulse oximeter).

- Participants were informed that they could take a break at any time during their participation and a pre-planned break could be arranged for those who wanted or needed it.
- Participants were informed they could bring someone with them during their participation.
- Participants were made fully aware of what will be happening with the research findings.
- A clear summary of the findings will be passed on to schools so that participants can access this if they wish.

3.3.5 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, sex, ethnicity, 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. In addition, a multiple regression analysis was carried out to explore the contributions of interoceptive accuracy, interoceptive beliefs, and alexithymia to anxiety. Finally, a moderation analysis was conducted to evaluate whether an increase in alexithymia would impact upon the relationship between the different dimensions of interoception and anxiety.

3.4 Results

3.4.1 Data screening

Independent t-tests and bivariate correlations were conducted to identify any between-group differences in age, sex, ethnicity, 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 (F=1.75, p=0.71).

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 (see Appendix B). 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.

3.4.2 Descriptive statistics

Descriptive statistics for each of the dependent variables can be found in Table 2.

3.4.3 Correlational analyses

Correlational analyses revealed significant relationships between ASSERT scores and scores on the AQC subscales, DIF (p=.003) and DDF (p=.003). A significant relationship was also found between scores for the BPQ-ANSR and GAD-7 scores (p=0.015). For correlation coefficients, see Table 3.

Table 2. *Means and standard deviations for dependent variables*.

Variable	M	SD
GAD7	8.24	3.57
Heartbeat counting average	0.46	0.31
Heartbeat discrimination average	0.51	0.11
BPQ – BA	2.63	0.62
BPQ – ANSR	1.67	0.52
AQC – DIF	0.99	0.48
AQC – DDF	1.17	0.49
ASSERT	10	1.91

Table 3. *Correlation coefficients for dependent variables*

	GAD	Heartbeat counting average	Heartbeat discrimination average	BPQ – BA	BPQ – ANSR	AQC – DIF	AQC – DDF	ASSERT
GAD								
Heartbeat counting average	-.143							
Heartbeat discrimination average	-.154	.205						
BPQ – BA	.161	-0.84	-.184					
BPQ – ANSR	.398*	.055	-.093					
AQC – DIF	.218	.308	-.117	.136	.308			
AQC – DDF	.131	.236	.125	.128	.302			
ASSERT	-.020	.232	-.046	.225	.042	.470**	.473**	

*<0.05

** <0.01

3.4.4 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)=0.657, p=0.516). Individuals with high (N=18) and low (N=19) interoceptive accuracy scores as determined by a median split (Median = 0.5) did not differ significantly on their heartbeat counting accuracy-confidence correlations (t(35)=0.344, p=0.733).

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 heartbeat discrimination task 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=-382, p=0.02) suggesting that those that performed better on the heartbeat discrimination task had lower confidence in their performance.

Interoceptive insight did not correlate with anxiety scores for heartbeat counting accuracy-confidence correlations (r=0.101, p=0.554) 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=-0.056, p=0.741).

3.4.5 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=0.206, p=0.220).

3.4.6 Regression analysis

A multiple regression analysis was carried out to explore the contributions of interoceptive accuracy, interoceptive beliefs, and alexithymia to anxiety. Data screening confirmed that the data met the assumptions required for a multiple regression analysis. The outcome variable for the multiple regression was anxiety. Scores for BPQ-ANSR, AQC-DIF, and heartbeat counting scores were entered into the model as predictor variables. Results of the multiple regression revealed that the overall model was significant (F(3,33)=2.935, p=0.048, R square=0.211), with 21% of variance in anxiety scores explained by the predictor variables, indicative of a medium

effect size. The BPQ-ANSR was the only significant predictor of anxiety in this model, accounting for 11% of the variance in anxiety, indicative of a small to medium effect size. Results are shown in Table 4.

Table 4. *Linear regression model showing predictors of anxiety (GAD-7)*

Variable	***β***	SE ***β***	t	*p*	sr^2
BPQ-ANSR	2.449	1.121	2.185	0.036	0.11
AQC-DIF	1.289	1.258	1.025	0.313	0.03
Counting Accuracy	-2.514	1.888	-1.332	0.192	0.05

3.4.7 Moderation analysis

A moderation analysis was carried out using PROCESS v4.2, model 1 (Hayes, 2022) to explore whether alexithymia moderates the relationship between interoception and anxiety. Interoceptive beliefs (BPQ-ANSR), interceptive accuracy (Heartbeat Counting Task scores) and Interoceptive insight (heartbeat counting accuracy-confidence correlations) were entered into the model as independent variables. Anxiety (GAD-7) was entered as the dependent variable and alexithymia (AQC-DIF) was entered as the moderator variable. Alexithymia was found to not moderate the relationship between interoceptive beliefs and anxiety (*B*=1.031, *SE*=2.055, *p*=0.619), interoceptive accuracy and anxiety (*B*=-4.061, *SE*=3.563, *p*=0.262), or interoceptive insight and anxiety (*B*=0.962, *SE*=2.454, *p*=0.698).

3.5 Discussion

This study aimed to explore the relationship between the 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.

Contrary to our hypothesis, findings revealed no significant relationship between interoception (behavioural and self-report measures) and alexithymia in our autistic adolescent sample. Previous research using adult samples has revealed mixed findings in relation to alexithymia and interoception. Whilst some previous research has found a significant association between interoceptive accuracy and alexithymia in non-autistic (Herbert et al., 2011) and autistic (Shah et al., 2016) adults, in their meta-analysis of the relationship between interoception and alexithymia, Trevisan et al., (2019) found interoceptive accuracy, as measured by heartbeat perception tasks, to not be associated with alexithymia in the general population. On the other hand, research utilising the BPQ to measure interoceptive beliefs reveals a significant association between this dimension of interoception and alexithymia (Trevisan et al., 2019). As

far as the authors are aware, the present study is the first study to explore the association between alexithymia and interoception in autistic adolescents. The findings from the current study therefore both support and contradict previous findings, with results finding both interoceptive beliefs and accuracy to be statistically unrelated to alexithymia. Given the novel nature of this analysis, this highlights a need to explore this relationship further in this population as it poses a challenge to the argument that interoception and alexithymia are inextricably linked.

It is theorised that sensory difficulties and alexithymia both contribute to anxiety in autistic adults through their influence on intolerance of uncertainty (Riedelbauch et al., 2023). It may be the case that this association looks different for autistic adolescents as the nature of this relationship and the interaction between these dimensions is not yet fully understood in this group. As intolerance of uncertainty was not measured in the present study, it is not possible to establish whether it contributed to the lack of a significant association between interoception and alexithymia. Another possible explanation for the lack of statistically significant relationship between interoception and alexithymia could be that previous research has indicated that children and adolescents have been shown to have poorer interoceptive accuracy than adults (Yang et al., 2022). In the current sample, whilst a median split suggested that some participants had high interoceptive accuracy relative to the mean, the vast majority of scores classified as high on interoceptive accuracy measures fell within one standard deviation of the mean and those with high and low scores did not differ significantly from each other. It may be the case that participants in the present study had overall lower interoceptive accuracy than adult samples in studies that have found an association between interoceptive accuracy and alexithymia (e.g. Mash et al., 2017), potentially weakening the relationship between the two constructs in the present study. Finally, research indicates that early language proficiency is a contributor to the occurrence of alexithymia in children and adolescents (Lee et al., 2024). Subsequently, the language skills of participants in the current study may also have contributed to their likelihood of experiencing alexithymia.

The one variable that was shown to have a significant relationship with alexithymia in the current study was autism traits, as measured by the ASSERT. This finding provides further evidence for the prevalence of alexithymia in an autistic population (Kinnaird et al., 2018), highlighting this as an area that warrants continued exploration and that autistic adolescents may benefit from additional support with.

Addressing our third research question, ITPE was not associated with anxiety which is inconsistent with previous findings (Garfinkel et al., 2016; Palser et al., 2018). However, in Palser et al.'s (2018) study, when ITPE was entered into a regression with interoceptive beliefs,

ITPE was not a significant predictor of anxiety, whereas interoceptive beliefs were. Similarly, interoceptive beliefs, as measured by BPQ-ANSR, were found in the current study to be positively correlated with anxiety and to independently explain 11% of the variance in anxiety scores within the sample. It has been suggested that the BPQ measures an individual's self-reported beliefs about their attention to interoceptive signals (Suksasilp & Garfinkel, 2022). This suggests that participants that self-reported a greater attention to changes in their internal states experienced greater anxiety, supporting previous research that has found the same association in non-autistic adolescents (De Berardis et al., 2007). Given that interoceptive accuracy was not associated with anxiety in the current sample, the finding that interoceptive beliefs predicted anxiety, could be a result of the way in which the participants interpret their bodily signals. Anxiety has previously been linked with a tendency to catastrophise perception of bodily signals (Bouton et al., 2001), which might explain the relationship between anxiety and the interoceptive beliefs in the present study.

In prior research, autistic individuals have reported difficulty interpreting the meaning of their bodily signals (Trevisan et al., 2021). When taking this into consideration, the findings in the present study suggest that for some autistic adolescents, greater attention to, and perhaps a subsequent difficulty interpreting, changes in their physiological state may play a key role in their experiences of anxiety. Analysis of the relationship between performance on interoceptive accuracy measures and confidence judgements, revealed that participants in the present study were in fact not interoceptively aware, that is they were not aware of the extent of their interoceptive ability. It may therefore be the case that for those individuals that cannot accurately perceive changes in their physiological state, and therefore would not know what to expect in regard to this, may experience anxiety as a result. This highlights the importance of supporting autistic adolescents to accurately identify and interpret their bodily signals to enable them to use these interpretations to support with the management of anxiety.

It is also possible, that the nature of the relationship between participants self-reported findings from the BPQ-ANSR and the GAD-7 can be understood through considering the potential impact of anxiety on the autonomic nervous system. Children experiencing anxiety tend to present with physical symptoms, such as increased heart rate, that are believed to be a result of activity in the autonomic nervous system caused by anxiety (Thayer et al., 1996; Sharma et al., 2011). It is therefore possible in the present study that participants reporting increased autonomic nervous system reactivity on the BPQ-ANSR have increased activity in this system as a result of their anxiety.

Also contrary to our initial hypothesis, we found that alexithymia did not moderate the relationship between interoception and anxiety. Given that we found no significant associations

between alexithymia and interoception or alexithymia and anxiety, this is not an entirely unexpected result. This further highlights that in the present sample, interoceptive beliefs were a key factor in predicting anxiety, irrespective of the other variables investigated. This finding has implications for understanding what may be the most effective avenues for supporting autistic adolescents to manage their anxiety, through a focus on interoceptive beliefs. Studies measuring interoceptive beliefs have shown that reported variations in attention and response to interoceptive signals influences the use of adaptive emotion regulation strategies (Cheung et al., 2023; Bishop et al., 2023), and the Theory of Constructed Emotion highlights the need for appropriate language and understanding of physiological states in order to understand emotion (Feldman Barrett, 2017). It is perhaps a combination of these two things, awareness of changes to internal physiological states and an understanding of what these changes are indicative of, that could support effective management of anxiety in an autistic adolescent population. It is important to note, however, that language skills continue to develop during adolescence (Fuhrman et al., 2015) and, in particular, the language of emotion is not yet fully developed during this time (OKearney & Dadds, 2004). This should therefore be taken into account in relation to support being provided for young people.

3.5.1 Limitations

It is important to consider the results of this study in light of its limitations. First, there are several 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 required to sufficiently power the multiple regression and moderation analyses, and therefore the findings from these analyses should be interpreted with caution. It is also important to note the limited nature of the sample demographically. The sample comprised mostly of white, British participants and the majority identified as male. Socioeconomic data was also not collected from the sample, so any influence on the results could not be explored. Secondly, methodological limitations should be taken into consideration. Whilst the heartbeat perception tasks utilised in this study have been shown to be reliable and valid and are widely used within the field, it is important to consider the limitations with using them as a single measure of interoceptive accuracy. As has been found with several studies, heartbeat counting and discrimination results did not correlate in the present study. This suggests that whilst both tasks undoubtedly involve the perception of an individuals' heartbeat, they may place demands on different cognitive processes (Garfinkel et al., 2015). This also indicates that performance on these tasks may be influenced by separate factors, for example resting heart rate beliefs (Brener & Ring, 2016) and time estimation skills (Murphy et al., 2018). It may have been advantageous therefore to utilise additional control tasks such as a counting control task like that used by Shah et al., (2016) to control for these

factors. Moreover, these tasks can only measure interoceptive accuracy for one element of the body's physiological state and therefore may not be a reflection of overall interoceptive accuracy. Nevertheless, the majority of current research exploring interoceptive accuracy with autistic participants does so by utilising heartbeat perception tasks (Proff et al., 2022) making the current study more comparable with previous research. Moreover, our study has shown that interoceptive belief might be an appropriate measure to include in research with autistic adolescent samples in order to elucidate relationships with alexithymia and anxiety. Future research could utilise additional tasks measuring interoceptive accuracy for different sensory pathways such as respiratory or gastric sensations.

3.5.2 Conclusion

In summary, the findings from the present study suggest that self-reported beliefs in relation to perception of physiological changes in the autonomic nervous system were associated with increased anxiety in autistic adolescents, whilst interoceptive accuracy and ITPE were not. Interoception and anxiety were not associated with alexithymia and alexithymia did not moderate the relationship between interoception and anxiety. This adds to the current body of literature exploring the relationship between interoception and anxiety by further exploring this in relation to autistic adolescents. Moreover, it highlights the importance of focusing on individuals reported awareness of or attention to interoceptive signals when considering the support given to autistic adolescents experiencing anxiety. A focus on supporting autistic adolescents to better understand changes in their physiological states and how to regulate interoceptive signals associated with anxiety (e.g., raised heart rate), may be an effective avenue for supporting them to manage their anxiety.

List of References

Adams, D., & Emerson, L. M. (2021). The impact of anxiety in children on the autism spectrum. *Journal of Autism and Developmental Disorders*, *51*, 1909-1920. https://doi.org/10.1007/s10803-020-04673-3

Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. Clinical psychology review, 30(2), 217 – 237.

Aparicio, E., Canals, J., Arija, V., De Henauw, S., & Michels, N. (2016). The role of emotion regulation in childhood obesity: implications for prevention and treatment. *Nutrition research reviews*, *29*(1), 17-29. https://doi.org/10.1017/S0954422415000153

Bagby, R. M., Taylor, G. J., Parker, J. D., & Dickens, S. E. (2005). The development of the Toronto Structured Interview for Alexithymia: item selection, factor structure, reliability and concurrent validity. *Psychotherapy and psychosomatics*, *75*(1), 25-39. https://doi.org/10.1159/000089224

Baribeau, D. A., Vigod, S., Pullenayegum, E., Kerns, C. M., Mirenda, P., Smith, I. M., ... & Szatmari, P. (2020). Repetitive behavior severity as an early indicator of risk for elevated anxiety symptoms in autism spectrum disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *59*(7), 890-899. https://doi.org/10.1016/j.jaac.2019.08.478

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*(1-3), 7-15. https://doi.org/ 10.1016/0010-0277(94)90018-3

Bechara, A., Damasio, H., & Damasio, A.R. (2000). Emotion, decision making, and the orbitofrontal cortex. *Cerebral Cortex, 10*(3), 295-307. https://doi.org/10.1093/cercor/10.3.295

Ben-Itzchak, E., Koller, J., & Zachor, D. A. (2020). Characterization and prediction of anxiety in adolescents with autism spectrum disorder: A longitudinal study. *Journal of abnormal child psychology*, *48*(9), 1239-1249. https://doi.org/10.1007/s10802-020-00673-0

Besharat, M. (2008). Relations between alexithymia, anxiety, depression, psychological distress, and psychological well-being. *Journal of Modern Psychological Researches*, *3*(10), 17-40.

Bird, G., & Cook, R. (2013). Mixed emotions: the contribution of alexithymia to the emotional symptoms of autism. *Translational psychiatry*, *3*(7), e285. https://doi.org/10.1038/tp.2013.61

Bishop, C., Brown, T., & Yu, M. L. (2023). The relationship between school-age children's interoceptive awareness and executive functioning: An exploratory study. *British Journal of Occupational Therapy, 86*(2), 116-129. https://doi.org/10.1177/03080226221128184

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist*, *57*(2), 111–127. https://psycnet.apa.org/doi/10.1037/0003-066X.57.2.111

Blankson, A. N., Weaver, J. M., Leerkes, E. M., O'Brien, M., Calkins, S. D., & Marcovitch, S. (2017). Cognitive and emotional processes as predictors of a successful transition into school. *Early Education and Development, 28*(1), 1–20. http://dx.doi.org/10.1080/10409289.2016.1183434

Bonete, S., Molinero, C., & Ruisanchez, D. (2023). Emotional dysfunction and interoceptive challenges in adults with autism spectrum disorders. *Behavioral Sciences*, *13*(4), 312. https://doi.org/10.3390/bs13040312

Bougeard, C., Picarel-Blanchot, F., Schmid, R., Campbell, R., & Buitelaar, J. (2021). Prevalence of autism spectrum disorder and co-morbidities in children and adolescents: a systematic literature review. *Frontiers in psychiatry*, *12*, 744709. https://doi.org/10.3389/fpsyt.2021.744709

Boulter, C., Freeston, M., South, M., & Rodgers, J. (2013). Intolerance of Uncertainty as a Framework for Understanding Anxiety in Children and Adolescents with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders, 44*(6), 1391–1402. https://doi.org/10.1007/s10803-013-2001-x

Bouton, M. E., Mineka, S., & Barlow, D. H. (2018). *The Neurotic Paradox, Vol 2*. Routledge.

Brener, J., & Ring, C. (2016). Towards a psychophysics of interoceptive processes: the measurement of heartbeat detection. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1708). https://doi.org/10.1098/rstb.2016.0015

Brewer, R., Cook, R., & Bird, G. (2016). Alexithymia: a general deficit of interoception. *Royal Society open science*, *3*(10), 150664. https://doi.org/10.1098/rsos.150664

Butera, C., Kaplan, J., Kilroy, E., Harrison, L., Jayashankar, A., Loureiro, F., & Aziz-Zadeh, L. (2023). The relationship between alexithymia, interoception, and neural functional connectivity during facial expression processing in autism spectrum disorder. *Neuropsychologia*, *180*, 108469. https://doi.org/10.1016/j.neuropsychologia.2023.108469

Cabrera, A., Kolacz, J., Pailhez, G., Bulbena-Cabre, A., Bulbena, A., & Porges, S. W. (2017). Assessing body awareness and autonomic reactivity: Factor structure and psychometric properties of the Body Perception Questionnaire-Short Form (BPQ-SF). *International journal of methods in psychiatric research*, *27*(2). https://doi.org/10.1002/mpr.1596

Calkins S. (2004). Temperament and emotion regulation: Multiple models of early development. In M. Beuregard, (Eds.), *Consciousness, emotional self-regulation and the brain (pp.35-59)*. John Benjamins.

Canon, W.B. (1931). Again the James-Lange and the thalamic theories of emotion. *Psychological Review, 38*(4), 281-295. https://doi.org/10.1037/h0072957

Chen, W. G., Schloesser, D., Arensdorf, A. M., Simmons, J. M., Cui, C., Valentino, R., ... & Langevin, H. M. (2021). The emerging science of interoception: sensing, integrating, interpreting, and regulating signals within the self. *Trends in neurosciences*, *44*(1), 3-16. https://doi.org/10.1016/j.tins.2020.10.007

Cheung, H. Y. L., Brown, T., Yu, M. L., & Cheung, P. P. (2023). The relationship between school-age children's self-reported perceptions of their interoceptive awareness and emotional regulation: An exploratory study. *Journal of Occupational Therapy, Schools, & Early Intervention,* 1-27. https://doi.org/10.1080/19411243.2023.2215764

Cisler, J. M., Olatunji, B. O., Feldner, M. T., & Forsyth, J. P. (2010). Emotion regulation and the anxiety disorders: an integrative review. *Journal of Psychopathology and Behavioral Assessment*, *32*(1), 68–82. https://doi.org/10.1007/s10862-009-9161-1

Clarivate (2023). *Endnote* (Version 21.2) [Computer software]. Clarivate.

Cloitre, M., Khan, C., Mackintosh, M. A., Garvert, D. W., Henn-Haase, C. M., Falvey, E. C., & Saito, J. (2019). Emotion regulation mediates the relationship between ACES and physical and mental health. *Psychological Trauma: Theory, Research, Practice, and Policy*, *11*(1), 82. https://psycnet.apa.org/doi/10.1037/tra0000374

Cole, P. M. (1986). Children's spontaneous control of facial expression. *Child development*, 57(6), 1309-1321. https://doi.org/10.2307/1130411

Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child development*, *75*(2), 317-333. https://doi.org/10.1111/j.1467-8624.2004.00673.x

Craig, A. D. (2014). *How do you feel? An interoceptive moment with your neurobiological self*. Princeton University Press.

Craig, A.D. (2016). Interoception and emotion: A neuroanitomical perspective. In L.F. Barrett, M. Lewis, & J. M. Haviland-Jones (Eds.), *Handbook of emotions (pp.215-219)*. Guilford Publications.

Critchley, H. D., & Garfinkel, S. N. (2017). Interoception and emotion. *Current opinion in psychology*, *17*, 7-14. https://doi.org/10.1016/j.copsyc.2017.04.020

Critchley, H. D., Wiens, S., Rotshtein, P., Öhman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature neuroscience*, *7*(2), 189-195. https://doi.org/10.1038/nn1176

Damasio, A. (2000). *The feeling of what happens: Body and emotion in the making of consciousness*. Mariner Books.

Dan-Glauser, E. S., & Gross, J. J. (2013). Emotion regulation and emotion coherence: evidence for strategy-specific effects. *Emotion*, *13*(5), 832–842. https://doi.org/10.1037/a0032672

Daniel, S. K., Abdel-Baki, R., & Hall, G. B. (2020). The protective effect of emotion regulation on child and adolescent wellbeing. *Journal of Child and Family Studies*, *29*, 2010-2027. https://doi.org/10.1007/s10826-020-01731-3

De Berardis, D., Campanella, D., Gambi, F., La Rovere, R., Sepede, G., Core, L., ... & Ferro, F. M. (2007). Alexithymia, fear of bodily sensations, and somatosensory amplification in young outpatients with panic disorder. *Psychosomatics*, *48*(3), 239-246. https://doi.org/10.1176/appi.psy.48.3.239

De Pascalis, V., Alberti, M. L., & Pandolfo, R. (1984). Anxiety, perception, and control of heart rate. *Perceptual and motor skills*, *59*(1), 203-211. https://doi.org/10.2466/pms.1984.59.1.203

De Witte, N. A., Sütterlin, S., Braet, C., & Mueller, S. C. (2016). Getting to the heart of emotion regulation in youth: the role of interoceptive sensitivity, heart rate variability, and parental psychopathology. *PloS one, 11*(10), e0164615. https://doi.org/10.1371/journal.pone.0164615

DeSteno, D., Gross, J. J., & Kubzansky, L. (2013). Affective science and health: the importance of emotion and emotion regulation. *Health Psychology*, *32*(5), 474-486. https://doi.org/10.1037/a0030259

Devine, H., Stewart, S. H., & Watt, M. C. (1999). Relations between anxiety sensitivity and dimensions of alexithymia in a young adult sample. *Journal of Psychosomatic Research*, *47*(2), 145-158. https://doi.org/10.1016/S0022-3999(99)00033-1

Dewey, J. (1894). The theory of emotion: I: Emotional attitudes. *Psychological Review, 1*(6), 553–569. https://doi.org/10.1037/h0069054

Dixon, T. (2012). "Emotion": The history of a keyword in crisis. *Emotion Review*, *4*(4), 338-344. https://doi.org/10.1177/1754073912445814

Durgin, F. H. (2016). Magnitudes in the coding of visual multitudes: Evidence from adaptation. In A. Henik (Ed.), *Continuous issues in numerical cognition: How many or how much* (pp. 245–270). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-801637-4.00011-1

Eadeh, H. M., Breaux, R., & Nikolas, M. A. (2021). A meta-analytic review of emotion regulation focused psychosocial interventions for adolescents. *Clinical child and family psychology review*, *24*, 684-706. https://doi.org/10.1007/s10567-021-00362-4

Ehlers, A. (1993). Somatic symptoms and panic attacks: A retrospective study of learning experiences. *Behaviour Research and Therapy*, *31*(3), 269-278. https://doi.org/10.1016/0005-7967(93)90025-P

Ehlers, A., Margraf, J., Roth, W. T., Taylor, C. B., & Birbaumer, N. (1988). Anxiety induced by false heart rate feedback in patients with panic disorder. *Behaviour research and therapy*, *26*(1), 1-11. https://doi.org/10.1016/0005-7967(88)90028-9

Eisenberg, N., Spinrad, T. L., & Eggum, N. D. (2010). Emotion-related self-regulation and its relation to children's maladjustment. *Annual Review of Clinical Psychology, 6*, 495–525. http://dx.doi.org/10.1146annurev.clinpsy.121208.131208

Eisenburg, N., & Fabes, R.A. (2006). Emotion regulation and children's socioemotional competence. In L. Balter., & C.S. Tamis-LeMonda (Eds.), *Child psychology: A handbook of contemporary issues*. Psychology Press.

Ekman, P. (1999). Basic emotions. In T. Dalgleish, & M. Power (Eds.), *Handbook of Cognition and Emotion (pp.45-60)*. John Wiley & Sons Ltd.

Eley, T. C., Stirling, L., Ehlers, A., Gregory, A. M., & Clark, D. M. (2004). Heart-beat perception, panic/somatic symptoms and anxiety sensitivity in children. *Behaviour research and therapy*, *42*(4), 439-448. https://doi.org/10.1016/S0005-7967(03)00152-9

Factor, R. S., Ryan, S. M., Farley, J. P., Ollendick, T. H., & Scarpa, A. (2017). Does the presence of anxiety and ADHD symptoms add to social impairment in children with autism spectrum disorder?. *Journal of Autism and Developmental Disorders*, *47*, 1122-1134. https://doi.org/10.1007/s10803-016-3025-9

Failla, M. D., Bryant, L. K., Heflin, B. H., Mash, L. E., Schauder, K., Davis, S., ... & Cascio, C. J. (2020). Neural correlates of cardiac interoceptive focus across development: Implications for social symptoms in autism spectrum disorder. *Autism Research*, *13*(6), 908-920. https://doi.org/10.1002/aur.2289

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146

Feldman Barrett, L. (2017a). The theory of constructed emotion: an active inference account of interoception and categorization. *Social cognitive and affective neuroscience*, *12*(1), 1-23. https://doi.org/10.1093/scan/nsw154

Feldman Barrett, L. (2017b). *How emotions are made: The secret life of the brain*. Pan Macmillan.

Fiene, L., & Brownlow, C. (2015). Investigating interoception and body awareness in adults with and without autism spectrum disorder. *Autism Research*, *8*(6), 709-716. https://doi.org/10.1002/aur.1486

Fiene, L., Ireland, M. J., & Brownlow, C. (2018). The Interoception Sensory Questionnaire (ISQ): A scale to measure interoceptive challenges in adults. *Journal of Autism and Developmental Disorders*, *48*(10), 3354-3366. https://doi.org/10.1007/s10803-018-3600-3

Fischer, A. H., & Manstead, A. S. (2008). Social functions of emotion. In M. Lewis, J.M. Haviland-Jones, & L. Feldman Barrett (Eds.), *Handbook of emotions (pp.456-468)*. The Guildford Press.

Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. *Biological psychology*, *104*, 65-74. https://doi.org/10.1016/j.biopsycho.2014.11.004

Garfinkel, S. N., Tiley, C., O'Keeffe, S., Harrison, N. A., Seth, A. K., & Critchley, H. D. (2016). Discrepancies between dimensions of interoception in autism: Implications for emotion and anxiety. *Biological psychology*, *114*, 117-126. https://doi.org/10.1016/j.biopsycho.2015.12.003

Garnefski, N., Kraaij, V., & Spinhoven, P. (2007). Negative life events, cognitive emotion regulation and emotional problems. *Personality and Individual differences*, *30*(8), 1311-1327. https://doi.org/10.1016/S0191-8869(00)00113-6

Gioia, G.A., Isquith, P.K., Guy, S.C., & Kenworthy, L. (2015). *Behaviour Rating Inventory of Executive Function, Second Edition*. PAR.

Gioia, G. A., Isquith, P. K., Retzlaff, P. D., & Espy, K. A. (2002). Confirmatory factor analysis of the Behavior Rating Inventory of Executive Function (BRIEF) in a clinical sample. *Child neuropsychology, 8*(4), 249-257. https://doi.org/10.1076/chin.8.4.249.13513

Gorski, P. S. (2013). What is critical realism? And why should you care? *Contemporary Sociology, 42*(5), 658-670. https://doi.org/10.1177/0094306113499533

Grob, A., & Smolenski, C. (2005). *Fragebogen zur erhebung der emotionsregulation bei kindern und jugendlichen: FEEL-KJ*. Verlag Hans Huber.

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of general psychology*, *2*(3), 271-299. https://doi.org/10.1037/1089-2680.2.3.271

Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, *39*(3), 281-291. https://doi.org/10.1017/S0048577201393198

Gross, J. J. (2015). Emotion regulation: Current status and future prospects. *Psychological inquiry*, *26*(1), 1-26. https://doi.org/10.1080/1047840X.2014.940781

Gross, J. J., & Feldman Barrett, L. (2011). Emotion generation and emotion regulation: One or two depends on your point of view. *Emotion review*, *3*(1), 8-16. https://doi.org/10.1177/1754073910380974

Gross, J. J., & Jazaieri, H. (2014). Emotion, emotion regulation, and psychopathology: An affective science perspective. *Clinical psychological science*, *2*(4), 387-401. https://doi.org/10.1177/2167702614536164

Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *Journal of personality and social psychology*, *85*(2), 348-362. https://psycnet.apa.org/doi/10.1037/0022-3514.85.2.348

Harmon-Jones, E., Gable, P. A., & Price, T. F. (2012). The influence of affective states varying in motivational intensity on cognitive scope. *Frontiers in integrative neuroscience*, *6*. https://doi.org/10.3389/fnint.2012.00073

Hassen, N. B., Molins, F., Garrote-Petisco, D., & Serrano, M. A. (2023). Emotional regulation deficits in autism spectrum disorder: The role of alexithymia and interoception. *Research in Developmental Disabilities*, *132*, 104378. https://doi.org/10.1016/j.ridd.2022.104378

Herbert, B. M., Herbert, C., & Pollatos, O. (2011). On the relationship between interoceptive awareness and alexithymia: is interoceptive awareness related to emotional awareness?. *Journal of personality*, *79*(5), 1149-1175. https://doi.org/10.1111/j.1467-6494.2011.00717.x

Herbert, B. M., Pollatos, O., & Schandry, R. (2007). Interoceptive sensitivity and emotion processing: an EEG study. *International Journal of Psychophysiology*, *65*(3), 214-227. https://doi.org/10.1016/j.ijpsycho.2007.04.007

Hollocks, M. J., Leno, V. C., Chandler, S., White, P., Yorke, I., Charman, T., ... & Simonoff, E. (2023). Psychiatric conditions in autistic adolescents: longitudinal stability from

childhood and associated risk factors. *European child & adolescent psychiatry*, *32*(11), 2197-2208. https://doi.org/10.1007/s00787-022-02065-9

In-Albon, T., Shafiei, M., Christiansen, H., Könen, T., Gutzweiler, R., & Schmitz, J. (2022). Development and psychometric properties of a computer-based standardized emotional competence inventory (MeKKi) for preschoolers and school-aged children. *Child Psychiatry & Human Development*, *53*(6), 1207-1220. https://doi.org/10.1007/s10578-021-01206-6

James, W. (1884). What is an Emotion? *Mind*, *9*(34), 188–205. https://doi.org/10.1093/mind/os-IX.34.188

Jones, A., Silas, J., Todd, J., Stewart, A., Acree, M., Coulson, M., & Mehling, W. E. (2020). Exploring the multidimensional assessment of interoceptive awareness in youth aged 7–17 years. *Journal of Clinical Psychology, 77*(3), 661–682. https://doi.org/10.1002/jclp.23067

Joshi, G., Petty, C., Wozniak, J., Henin, A., Fried, R., Galdo, M., ... & Biederman, J. (2010). The heavy burden of psychiatric comorbidity in youth with autism spectrum disorders: A large comparative study of a psychiatrically referred population. *Journal of autism and developmental disorders*, *40*, 1361-1370. https://doi.org/10.1007/s10803-010-0996-9

Karukivi, M., Hautala, L., Kaleva, O., Haapasalo-Pesu, K. M., Liuksila, P. R., Joukamaa, M., & Saarijärvi, S. (2010). Alexithymia is associated with anxiety among adolescents. *Journal of affective disorders*, *125*(1-3), 383-387. https://doi.org/10.1016/j.jad.2010.02.126

Keltner, D., & Kring, A. M. (1998). Emotion, social function, and psychopathology. *Review of General Psychology*, *2*(3), 320-342. https://doi.org/10.1037/1089-2680.2.3.320

Kensinger, E. A., & Schacter, D. L. (2008). Neural processes supporting young and older adults' emotional memories. *Journal of cognitive neuroscience*, *20*(7), 1161-1173. https://doi.org/10.1162/jocn.2008.20080

Kerns, C. M., Kendall, P. C., Zickgraf, H., Franklin, M. E., Miller, J., & Herrington, J. (2015). Not to be overshadowed or overlooked: Functional impairments associated with comorbid anxiety disorders in youth with ASD. Behavior Therapy, 46(1), 29–39. https://doi.org/10.1016/j.beth.2014.03.005

Kerns, C. M., Rast, J. E., & Shattuck, P. T. (2020). Prevalence and correlates of caregiver-reported mental health conditions in youth with autism spectrum disorder in the United States. *The journal of clinical psychiatry*, *82*(1), 11637. https://doi.org/10.4088/JCP.20m13242

Khalsa, S. S., Adolphs, R., Cameron, O. G., Critchley, H. D., Davenport, P. W., Feinstein, J. S., ... & Zucker, N. (2018). Interoception and mental health: a roadmap. *Biological psychiatry: cognitive neuroscience and neuroimaging*, *3*(6), 501-513. https://doi.org/10.1016/j.bpsc.2017.12.004

Khalsa, S. S., Rudrauf, D., Damasio, A. R., Davidson, R. J., Lutz, A., & Tranel, D. (2008). Interoceptive awareness in experienced meditators. *Psychophysiology*, *45*(4), 671-677. https://doi.org/10.1111/j.1469-8986.2008.00666.x

Kim, J., & Cicchetti, D. (2010). Longitudinal pathways linking child maltreatment, emotion regulation, peer relations, and psychopathology. *Journal of child psychology and psychiatry*, *51*(6), 706-716. https://doi.org/10.1111/j.1469-7610.2009.02202.x

Kinnaird, E., Stewart, C., & Tchanturia, K. (2019). Investigating alexithymia in autism: A systematic review and meta-analysis. *European Psychiatry*, *55*, 80-89. https://doi.org/10.1016/j.eurpsy.2018.09.004

Kreibig S. D. (2010). Autonomic nervous system activity in emotion: a review. *Biological psychology*, *84*(3), 394–421. https://doi.org/10.1016/j.biopsycho.2010.03.010

Lazarus, R. S., Averill, J. R., & Opton, E. M. (1970). *Toward a cognitive theory of emotions*. In M. Arnold (Ed.), Feelings and emotions (pp. 207-232). Academic Press.

LeDoux, J. E. (1998). *The emotional brain: The mysterious underpinnings of emotional life*. Simon and Schuster.

Lee, K. S., Catmur, C., & Bird, G. (2024). Childhood language development and alexithymia in adolescence: an eight-year longitudinal study. *Development and Psychopathology*.

Levenson, R. W. (2014). The Autonomic Nervous System and Emotion. *Emotion Review*, *6*(2), 100-112. https://doi.org/10.1177/1754073913512003

Loas, G., Braun, S., Delhaye, M., & Linkowski, P. (2017). The measurement of alexithymia in children and adolescents: Psychometric properties of the Alexithymia Questionnaire for Children and the twenty-item Toronto Alexithymia Scale in different non-clinical and clinical samples of children and adolescents. *PloS one*, *12*(5), e0177982. https://doi.org/10.1371/journal.pone.0177982

Lockwood Estrin, G., Milner, V., Spain, D., Happé, F., & Colvert, E. (2021). Barriers to autism spectrum disorder diagnosis for young women and girls: A systematic review. *Review Journal of Autism and Developmental Disorders*, *8*(4), 454-470. https://doi.org/10.1007/s40489-020-00225-8

López-Pérez, B., Gummerum, M., Wilson, E., & Dellaria, G. (2017). Studying children's intrapersonal emotion regulation strategies from the process model of emotion regulation. *The Journal of Genetic Psychology*, *178*(2), 73-88. https://doi.org/10.1080/00221325.2016.1230085

Lyyra, P., & Parviainen, T. (2018). Behavioral inhibition underlies the link between interoceptive sensitivity and anxiety-related temperamental traits. *Frontiers in psychology*, *9*, 344607. https://doi.org/10.3389/fpsyg.2018.01026

Mahood, Q., Van Eerd, D., & Irvin, E. (2014). Searching for grey literature for systematic reviews: challenges and benefits. *Research synthesis methods*, *5*(3), 221-234. https://doi.org/10.1002/jrsm.1106

Maisel, M. E., Stephenson, K. G., South, M., Rodgers, J., Freeston, M. H., & Gaigg, S. B. (2016). Modeling the Cognitive Mechanisms Linking Autism Symptoms and Anxiety in Adults. *Journal of Abnormal Psychology, 125*(5), 692-703. https://doi.org/10.1037/abn0000168

Marchesi, C., Fontò, S., Balista, C., Cimmino, C., & Maggini, C. (2004). Relationship between alexithymia and panic disorder: a longitudinal study to answer an open question. *Psychotherapy and psychosomatics*, *74*(1), 56-60. https://doi.org/10.1159/000082028

Mash, L. E., Schauder, K. B., Cochran, C., Park, S., & Cascio, C. J. (2017). Associations between interoceptive cognition and age in autism spectrum disorder and typical development. *Journal of Cognitive Education and Psychology*, *16*(1), 23-37. https://doi.org/10.1891/1945-8959.16.1.23

Mauss, I. B., Levenson, R. W., McCarter, L., Wilhelm, F. H., & Gross, J. J. (2005). The tie that binds? Coherence among emotion experience, behavior, and physiology. *Emotion, 5*(2), 175-190. https://doi.org/10.1037/1528-3542.5.2.175

Mazurek, M. O., Vasa, R. A., Kalb, L. G., Kanne, S. M., Rosenberg, D., Keefer, A., ... & Lowery, L. A. (2013). Anxiety, sensory over-responsivity, and gastrointestinal problems in children with autism spectrum disorders. *Journal of abnormal child psychology*, *41*, 165-176. https://doi.org/10.1007/s10802-012-9668-x

McVey, A. J., Schiltz, H. K., Haendel, A. D., Dolan, B. K., Willar, K. S., Pleiss, S. S., ... & Van Hecke, A. V. (2018). Social difficulties in youth with autism with and without anxiety and ADHD symptoms. *Autism Research*, *11*(12), 1679-1689. https://doi.org/10.1002/aur.2039

Mikkelsen, M. B., O'Toole, M. S., Lyby, M. S., Wallot, S., & Mehlsen, M. (2019). Emotional reactivity and interoceptive sensitivity: Exploring the role of age. *Psychonomic bulletin & review*, *26*, 1440-1448. https://doi.org/10.3758/s13423-019-01603-y

Milosavljevic, B., Carter Leno, V., Simonoff, E., Baird, G., Pickles, A., Jones, C. R., ... & Happé, F. (2016). Alexithymia in adolescents with autism spectrum disorder: Its relationship to internalising difficulties, sensory modulation and social cognition. *Journal of autism and developmental disorders*, *46*, 1354-1367. https://doi.org/10.1007/s10803-015-2670-8

Moors, A., Ellsworth, P. C., Scherer, K. R., & Frijda, N. H. (2013). Appraisal theories of emotion: State of the art and future development. *Emotion Review, 5*(2), 119-124. https://doi.org/10.1177/1754073912468165

Mul, C. L., Stagg, S. D., Herbelin, B., & Aspell, J. E. (2018). The feeling of me feeling for you: Interoception, alexithymia and empathy in autism. *Journal of autism and developmental disorders*, *48*, 2953-2967. https://doi.org/10.1007/s10803-018-3564-3

Mumford, D. B., Bavington, J. T., Bhatnagar, K. S., Hussain, Y., Mirza, S., & Naraghi, M. M. (1991). The Bradford Somatic Inventory: A multi-ethnic inventory of somatic symptoms reported by anxious and depressed patients in Britain and the Indo-Pakistan subcontinent. *The British Journal of Psychiatry*, *158*(3), 379-386. https://doi.org/10.1192/bjp.158.3.379

Murphy, J., Catmur, C., & Bird, G. (2019). Classifying individual differences in interoception: Implications for the measurement of interoceptive awareness. *Psychonomic Bulletin & Review*, *26*, 1467-1471. https://doi.org/10.3758/s13423-019-01632-7

Nemiah,J.C., Freyberger, H., & Sifneos, P.E. (1976). Alexithymia: A view of the psychosomatic process. In O. W. Hill (Ed.), *Modern Trends in Psychosomatic Medicine*, (3rd ed., pp. 430-439). Butterworths

Nicholson, T. M., Williams, D. M., Grainger, C., Christensen, J. F., Calvo-Merino, B., & Gaigg, S. B. (2018). Interoceptive impairments do not lie at the heart of autism or alexithymia. *Journal of abnormal psychology*, *127*(6), 612-622. https://doi.org/10.1037/abn0000370

Nicholson, T., Williams, D., Carpenter, K., & Kallitsounaki, A. (2019). Interoception is impaired in children, but not adults, with autism spectrum disorder. *Journal of autism and developmental disorders*, *49*, 3625-3637. https://doi.org/10.1007/s10803-019-04079-w

O'Kearney, R., & Dadds, M. (2004). Developmental and gender differences in the language for emotions across the adolescent years. *Cognition and emotion, 18*(7), 913-938.

Olatunji, B. O., Deacon, B. J., Abramowitz, J. S., & Valentiner, D. P. (2007). Body vigilance in nonclinical and anxiety disorder samples: structure, correlates, and prediction of health concerns. *Behavior Therapy*, *38*(4), 392-401. https://doi.org/10.1016/j.beth.2006.09.002

Opdensteinen, K. D., Schaan, L., Pohl, A., Schulz, A., Domes, G., & Hechler, T. (2021). Interoception in preschoolers: New insights into its assessment and relations to emotion regulation and stress. *Biological Psychology, 165*, 108166. https://doi.org/10.1016/j.biopsycho.2021.108166

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*. https://doi.org/10.1136/bmj.n71

Palser, E. R., Fotopoulou, A., Pellicano, E., & Kilner, J. M. (2018a). The link between interoceptive processing and anxiety in children diagnosed with autism spectrum disorder: Extending adult findings into a developmental sample. *Biological Psychology*, *136*, 13-21. https://doi.org/10.1016/j.biopsycho.2018.05.003

Palser, E. R., Palmer, C. E., Galvez-Pol, A., Hannah, R., Fotopoulou, A., & Kilner, J. M. (2018b). Alexithymia mediates the relationship between interoceptive sensibility and anxiety. *PloS one*, *13*(9), e0203212. https://doi.org/10.1371%2Fjournal.pone.0203212

Paulus, M. P., & Stein, M. B. (2006). An insular view of anxiety. *Biological psychiatry*, *60*(4), 383-387. https://doi.org/10.1016/j.biopsych.2006.03.042

Paulus, M. P., & Stein, M. B. (2010). Interoception in anxiety and depression. *Brain structure and Function*, *214*, 451-463. https://doi.org/10.1007/s00429-010-0258-9

Pinna, T., & Edwards, D. J. (2020). A systematic review of associations between interoception, vagal tone, and emotional regulation: Potential applications for mental health, wellbeing, psychological flexibility, and chronic conditions. *Frontiers in psychology*, *11*, 1792. https://doi.org/10.3389/fpsyg.2020.01792

Pollatos, O., Traut-Mattausch, E., Schroeder, H., & Schandry, R. (2007). Interoceptive awareness mediates the relationship between anxiety and the intensity of unpleasant feelings. *Journal of anxiety disorders*, *21*(7), 931-943. https://doi.org/10.1016/j.janxdis.2006.12.004

Porges S. W. (1993). *Body Perception Questionnaire*. Laboratory of Developmental Assessment, University of Maryland.

Posserud, M. B., Breivik, K., Gillberg, C., & Lundervold, A. J. (2013). ASSERT–the autism symptom SElf-ReporT for adolescents and adults: bifactor analysis and validation in a large adolescent population. *Research in Developmental Disabilities*, *34*(12), 4495-4503. https://doi.org/10.1016/j.ridd.2013.09.032

Proff, I., Williams, G. L., Quadt, L., & Garfinkel, S. N. (2022). Sensory processing in autism across exteroceptive and interoceptive domains. *Psychology & Neuroscience, 15*(2), 105–130. https://doi.org/10.1037/pne0000262

Quadt, L., Garfinkel, S. N., Mulcahy, J. S., Larsson, D. E., Silva, M., Jones, A. M., ... & Critchley, H. D. (2021). Interoceptive training to target anxiety in autistic adults (ADIE): A single-center, superiority randomized controlled trial. *EClinicalMedicine*, *39*, 101042. https://doi.org/10.1016/j.eclinm.2021.101042

Richardson, W. S., Wilson, M. C., Nishikawa, J., & Hayward, R. S. (1995). The well-built clinical question: a key to evidence-based decisions. *ACP Journal Club*, *123*(3), 12-13. https://doi.org/10.7326/ACPJC-1995-123-3-A12

Riedelbauch, S., Gaigg, S. B., Thiel, T., Roessner, V., & Ring, M. (2023). Examining a model of anxiety in autistic adults. *Autism*, *28*(3), 565-579. https://doi.org/10.1177/13623613231177777

Rieffe, C., Oosterveld, P., & Terwogt, M. M. (2006). An alexithymia questionnaire for children: Factorial and concurrent validation results. *Personality and individual differences*, *40*(1), 123-133. https://doi.org/10.1016/j.paid.2005.05.013

Rothbart, M. K., Posner, M. I., & Kieras, J. (2006). Temperament, Attention, and the Development of Self-Regulation. In K. McCartney & D. Phillips (Eds.), *Blackwell handbook of early childhood development* (pp. 338–357). Blackwell Publishing. https://doi.org/10.1002/9780470757703.ch17

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review*, *110*(1), 145-172. https://doi.org/10.1037/0033-295X.110.1.145

Santos, L. E. R., Elsangedy, H. M., de Souza, C. F. C. X. M., da Silva Mesquita, B. M., Brietzke, C., Vinícius, Í., ... & Santos, T. M. (2023). Reliability of the heartbeat tracking task to assess Interoception. *Applied Psychophysiology and Biofeedback*, *48*(2), 171-178. https://doi.org/10.1007/s10484-022-09574-y

Schaaf, R. C., & Lane, A. E. (2015). Toward a best-practice protocol for assessment of sensory features in ASD. *Journal of Autism and Development Disorders, 45*(5), 1380–1395. https://doi.org/10.1007/s10803-014-2299-z.

Schaan, L., Schulz, A., Nuraydin, S., Bergert, C., Hilger, A., Rach, H., & Hechler, T. (2019). Interoceptive accuracy, emotion recognition, and emotion regulation in preschool children. *International Journal of Psychophysiology*, *138*, 47-56. https://doi.org/10.1016/j.ijpsycho.2019.02.001

Schäfer, J. Ö., Naumann, E., Holmes, E. A., Tuschen-Caffier, B., & Samson, A. C. (2017). Emotion regulation strategies in depressive and anxiety symptoms in youth: A meta-analytic review. *Journal of youth and adolescence, 46*, 261-276. https://doi.org/10.1007/s10964-016-0585-0

Schandry, R. (1981). Heart beat perception and emotional experience. *Psychophysiology, 18*(4), 483–488. https://doi.org/10.1111/j.1469-8986.1981.tb02486.x

Schauder, K. B., Mash, L. E., Bryant, L. K., & Cascio, C. J. (2015). Interoceptive ability and body awareness in autism spectrum disorder. *Journal of experimental child psychology*, *131*, 193-200. https://doi.org/10.1016/j.jecp.2014.11.002

Schlesier, J., Roden, I., & Moschner, B. (2019). Emotion regulation in primary school children: A systematic review. *Children and Youth Services Review*, *100*, 239-257. https://doi.org/10.1016/j.childyouth.2019.02.044

Schneider, R. L., Arch, J. J., Landy, L. N., & Hankin, B. L. (2018). The longitudinal effect of emotion regulation strategies on anxiety levels in children and adolescents. *Journal of Clinical Child & Adolescent Psychology*, *47*(6), 978-991. https://doi.org/10.1080/15374416.2016.1157757

Schwartzman, J. M., & Bettis, A. H. (2024). Autistic traits in adolescents in psychiatric inpatient care: Clinical and demographic characteristics and correlates. *Research in Autism Spectrum Disorders*, *112*, 102339. https://doi.org/10.1016/j.rasd.2024.102339

Shah, P., Hall, R., Catmur, C., & Bird, G. (2016). Alexithymia, not autism, is associated with impaired interoception. *cortex*, *81*, 215-220. https://doi.org/10.1016/j.cortex.2016.03.021

Sharma, R. K., Sagar, R., Deepak, K. K., Mehta, M., & Balhara, Y. P. S. (2011). Clinical and autonomic functions: A study of childhood anxiety disorders. *Annals of Saudi Medicine*, *31*(3), 250-257. https://doi.org/10.4103/0256-4947.81533

Silvers, J. A. (2022). Adolescence as a pivotal period for emotion regulation development. *Current opinion in psychology*, *44*, 258-263. https://doi.org/10.1016/j.copsyc.2021.09.023

Simpson, K., Adams, D., Wheeley, E., & Keen, D. (2020). Parent perspectives on the presentation, triggers, impact, and support of anxiety in young children on the autism spectrum. *Journal of Child and Family Studies, 29*, 572–582. https://doi.org/10.1007/s10826-019-01576-5.

Song, Y., Lu, H., Hu, S., Xu, M., Li, X., & Liu, J. (2015). Regulating emotion to improve physical health through the amygdala. *Social cognitive and affective neuroscience*, *10*(4), 523-530. https://doi.org/10.1093/scan/nsu083

South, M., & Rodgers, J. (2017). Sensory, Emotional and Cognitive Contributions to Anxiety in Autism Spectrum Disorders. *Frontiers in Human Neuroscience, 11*, 1–7. https://doi.Org/10.3389/fnhum.2017.00020

Suksasilp, C., & Garfinkel, S. N. (2022). Towards a comprehensive assessment of interoception in a multi-dimensional framework. *Biological Psychology*, *168*, 108262. https://doi.org/10.1016/j.biopsycho.2022.108262

Tamir, M., Vishkin, A., & Gutentag, T. (2020). Emotion regulation is motivated. *Emotion*, *20*(1), 115-119. https://doi.org/10.1037/emo0000635

Tan, Y., Wang, X., Blain, S. D., Jia, L., & Qiu, J. (2023). Interoceptive attention facilitates emotion regulation strategy use. *International Journal of Clinical and Health Psychology*, *23*(1), 100336. https://doi.org/10.1016/j.ijchp.2022.100336

Teper, R., Segal, Z. V., & Inzlicht, M. (2013). Inside the mindful mind: How mindfulness enhances emotion regulation through improvements in executive control. *Current Directions in Psychological Science*, *22*(6), 449-454. https://doi.org/10.1177/0963721413495869

Thayer, J. F., Friedman, B. H., & Borkovec, T. D. (1996). Autonomic characteristics of generalized anxiety disorder and worry. *Biological psychiatry*, *39*(4), 255-266. https://doi.org/10.1016/0006-3223(95)00136-0

Theurel, A., & Gentaz, E. (2018). The regulation of emotions in adolescents: Age differences and emotion-specific patterns. *PloS one*, *13*(6). https://doi.org/10.1371/journal.pone.0195501

Thompson, R. A. (2011). Emotion and emotion regulation: Two sides of the developing coin. *Emotion Review, 3*(1), 53– 61. http://dx.doi.org/10.1177/1754073910380969

Tiirikainen, K., Haravuori, H., Ranta, K., Kaltiala-Heino, R., & Marttunen, M. (2019). Psychometric properties of the 7-item Generalized Anxiety Disorder Scale (GAD-7) in a large representative sample of Finnish adolescents. *Psychiatry research*, *272*, 30-35. https://doi.org/10.1016/j.psychres.2018.12.004

Trevisan, D. A., Altschuler, M. R., Bagdasarov, A., Carlos, C., Duan, S., Hamo, E., ... & McPartland, J. C. (2019). A meta-analysis on the relationship between interoceptive awareness and alexithymia: Distinguishing interoceptive accuracy and sensibility. *Journal of Abnormal Psychology*, *128*(8), 765-776. https://psycnet.apa.org/doi/10.1037/abn0000454

Trevisan, D. A., Parker, T., & McPartland, J. C. (2021). First-hand accounts of interoceptive difficulties in autistic adults. *Journal of Autism and Developmental Disorders*, *51*(10), 3483-3491. https://doi.org/10.1007/s10803-020-04811-x

Trindade, I. A., Ferreira, C., & Pinto-Gouveia, J. (2018). The longitudinal effects of emotion regulation on physical and psychological health: A latent growth analysis exploring the role of cognitive fusion in inflammatory bowel disease. *British journal of health psychology*, *23*(1), 171-185. https://doi.org/10.1111/bjhp.12280

Tsakiris, M., & Critchley, H. (2016). Interoception beyond homeostasis: affect, cognition and mental health. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1708). https://doi.org/10.1098/rstb.2016.0002

Ulus, G., & Aisenberg-Shafran, D. (2022). *Interoception in Old Age*. *Brain Sciences, 12*(10), 1398. https://doi.org/10.3390/brainsci12101398

Van der Does, A. W., Antony, M. M., Ehlers, A., & Barsky, A. J. (2000). Heartbeat perception in panic disorder: a reanalysis. *Behaviour research and therapy*, *38*(1), 47-62. https://doi.org/10.1016/S0005-7967(98)00184-3

Van Lieshout, C. F. (1975). Young children's reactions to barriers placed by their mothers. *Child Development*, *46*(4), 879-886. https://doi.org/10.2307/1128393

von Baeyer, C. L., Jaaniste, T., Vo, H. L., Brunsdon, G., Lao, H. C., & Champion, G. D. (2017). Systematic review of self-report measures of pain intensity in 3-and 4-year-old children: bridging a period of rapid cognitive development. *The Journal of Pain, 18*(9), 1017-1026. https://doi.org/10.1016/j.jpain.2017.03.005

Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *The lancet*, *370*(9596), 1453-1457. https://doi.org/10.1016/S0140-6736(07)61602-X

Whitehead, W. E., Drescher, V. M., Heiman, P., & Blackwell, B. (1977). Relation of heart rate control to heartbeat perception. *Biofeedback and Self-Regulation, 2*(4), 371–392. https://doi.org/10.1007/BF00998623

Whitehead, W. E., Drescher, V. M., Heiman, P., & Blackwell, B. (1977). Relation of heart rate control to heartbeat perception. *Biofeedback and Self-Regulation, 2*(4), 371–392. https://doi.org/10.1007/BF00998623

Wildemuth, B. M. (1993). Post-positivist research: two examples of methodological pluralism. *The Library Quarterly*, *63*(4), 450-468. https://doi.org/10.1086/602621

Williams, S., Leader, G., Mannion, A., & Chen, J. (2015). An investigation of anxiety in children and adolescents with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *10*, 30-40. https://doi.org/10.1016/j.rasd.2014.10.017

Willner, C. J., Hoffmann, J. D., Bailey, C. S., Harrison, A. P., Garcia, B., Ng, Z. J., ... & Brackett, M. A. (2022). The development of cognitive reappraisal from early childhood through adolescence: A systematic review and methodological recommendations. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.875964

Wood, J. (2006). Effect of anxiety reduction on children's school performance and social adjustment. *Developmental Psychology, 42*(2), 345–349. https://doi.org/10.1037/0012-1649.42.2.345

Yang, H. X., Zhou, H. Y., Li, Y., Cui, Y. H., Xiang, Y., Yuan, R. M., ... & Chan, R. C. (2022). Decreased interoceptive accuracy in children with autism spectrum disorder and with comorbid attention deficit/hyperactivity disorder. *Autism Research*, *15*(4), 729-739. https://doi.org/10.1002/aur.2679

Yang, H. X., Zhou, H. Y., Wei, Z., Wan, G. B., Wang, Y., Wang, Y. Y., ... & Chan, R. C. (2021). Multidimensional interoception and autistic traits across life stages: Evidence from a novel eye-tracking task. *Journal of Autism and Developmental Disorders*, 1-12. https://doi.org/10.1007/s10803-021-05155-w

Yoris, A., Esteves, S., Couto, B., Melloni, M., Kichic, R., Cetkovich, M., ... & Sedeño, L. (2015). The roles of interoceptive sensitivity and metacognitive interoception in panic. *Behavioral and Brain Functions*, *11*, 1-6. https://doi.org/10.1186/s12993-015-0058-8

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist, 35*(2), 151–175. https://doi.org/10.1037/0003-066X.35.2.151

Zdankiewicz-Ścigała, E., Ścigała, D., Sikora, J., Kwaterniak, W., & Longobardi, C. (2021). Relationship between interoceptive sensibility and somatoform disorders in adults with autism spectrum traits. The mediating role of alexithymia and emotional dysregulation. *PLoS One*, *16*(8), e0255460. https://doi.org/10.1371/journal.pone.0255460

Zeman, J., Cassano, M., Perry-Parrish, C., & Stegall, S. (2006). Emotion regulation in children and adolescents. *Journal of Developmental & Behavioral Pediatrics*, *27*(2), 155-168.

Zeman, J., Shipman, K., & Suveg, C. (2002). Anger and sadness regulation: Predictions to internalizing and externalizing symptoms in children. *Journal of clinical child and adolescent psychology*, *31*(3), 393-398. https://doi.org/10.1207/S15374424JCCP3103_11

Zoellner, L. A., & Craske, M. G. (1999). Interoceptive accuracy and panic. *Behaviour research and therapy*, *37*(12), 1141-1158. https://doi.org/10.1016/S0005-7967(98)00202-2

Appendix A Data Extraction Table

Table 5. *Systematic Literature Review data extraction table*

Author(s) & Year	Country	Relevant Study Aims	Sample Size	Population characteristics (age, sex, ethnicity)	Measure of Interoception	Measure of Emotional Regulation	Confounding variables considered	Results related to Interoception and Emotional Regulation
Schaan et al. (2019)	Germany	To assess interoceptive accuracy in pre-school aged children using an adapted paradigm. To explore the links between interoceptive accuracy, emotion recognition, and emotion regulation skills.	49	Age: 4 – 6 years (M=4.86) Sex: 22 female; (45%); 27 male Ethnicity: Not reported	Adapted heartbeat tracking task – 'Jumping Jack Paradigm'.	Emotional Competence Inventory for Children (MeKKi; In-Albon et al., 2014) (α = 0.82) [responses coded to 10 different emotional regulation strategies e.g., distraction, withdrawal, and an overall score computed.]	Age; BMI; sex.	Self-reported heart rates were higher when objectively measured heart rates were higher (suggests children of that age are able to self-report heartrate). Interoceptive accuracy scores showed a pattern towards an overestimation of heart rate being associated with lower emotional

								regulation, though this relationship was not statistically significant . Age was related to interoceptive accuracy and emotion regulation, sex was not. A small amount of variance in emotional regulation was accounted for by emotional recognition.
Opdensteinen et al. (2021) [Study 1]	Germany	To investigate the association between interoceptive accuracy and emotional regulation in preschoolers.	40	Age: 4 – 6 years (M=4.93) Sex: Female – 18 (45%); Male – 22 Ethnicity: Not reported	Adapted heartbeat tracking task – 'Jumping Jack Paradigm'. Changes were made following the 2019 study to address limitations.	Emotional Competence Inventory for Children (MeKKi; In-Albon et al., 2014)	Age; sex.	Children with higher interoceptive accuracy scores demonstrated a trend effect towards higher emotional regulation ability i.e. children who detected changes in heart rate more

								accurately, demonstrate higher overall emotional regulation, though this was not statistically significant.
Cheung et al., (2023)	Not provided	To explore the association between school-aged children's self reported interoceptive beliefs and emotional regulation.	25	Age: 9-12 years (M=10.49) Sex: 8 female (32%); 17 male Ethnicity: Not reported	MAIA-Y (Jones et al., 2020)	CERQ-K (Garnefski et al., 2007)	None	A negative predictive relationship was found between MAIA-Y subscale 'not distracting' and emotion regulation strategy 'planning' and 'positive reappraisal'. MAIA-Y subscale 'self-regulation' predicted 'positive reappraisal'.
De Witte et al., (2016)	Belgium	To examine the link between interoceptive accuracy and emotional	46	Age: 9-16 years (M=13) Sex: 22 female (48%); 24 male Ethnicity:	The Heartbe't Tracking Task (Schandry, 1981) with	FEEL-KJ (Braet et al., 2013)	BMI; sex	Higher interoceptive accuracy was associated with less use of

		regulation strategies in children and adolescents.		'mostly caucasian'	confidence judgements.			maladaptive emotion regulation strategies, specifically rumination and self-devaluation. Interoceptive insight was not associated with emotion regulation.
Bishop et al., (2023)	Australia	To explore the association between school-aged children's interoceptive beliefs and emotional regulation.	30	Age: 8-12 years (M= Sex: 20 female (67%); 10 male Ethnicity: not reported	MAIA-Y (Jones et al., 2020)	BRIEF-2 (Gioia et al., 2015)	None	A positive correlation was found between interoceptive awareness and emotional regulation. A statistically significant predictive relationship was determined between the MAIA-Y emotional awareness subscale and emotional control.

Appendix B Normality Tests

Table 6 *Shapiro-Wilks values*

Variable	Shapiro-Wilk significance value
GAD	.583
BPQ – Body Awareness	.819
BPQ – Autonomic Nervous System Reactivity	.004
ASSERT	.057
AQC – Difficulty Identifying Feelings	.471
AQC – Difficulty Describing Feelings	.026
Heartbeat Counting Accuracy	.250
Heartbeat Counting/VAS Correlations	.087
Heartbeat Discrimination Accuracy	.099
Heartbeat Discrimination VAS Area Under the Curve	.804

Figure 2 *Q-Q Plots for BPQ ANSR scores*

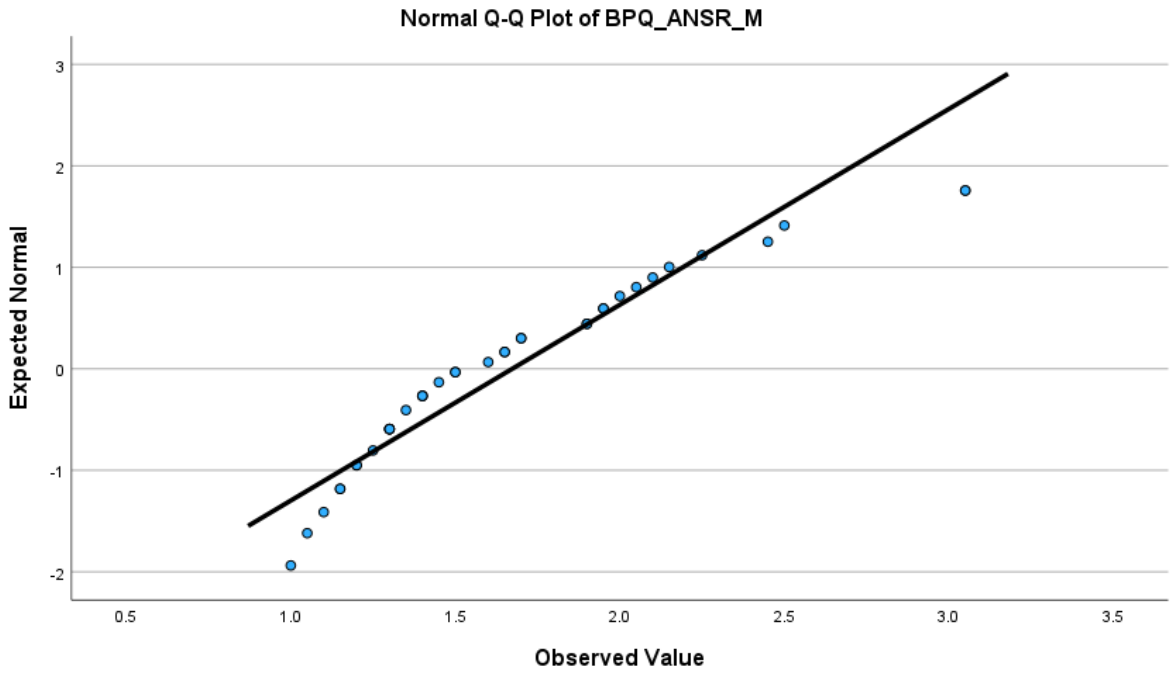


Figure 3 *Q-Q Plot for AQC – Difficulty Identifying Feelings subscale scores.*