

Furthering the Multi-Route Model of Alexithymia:

A Constructionist Perspective



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To the four-year-old me who dreamed of becoming a marine biologist one day.

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Declaration

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Chapter 2 presents two systematic reviews and meta-analyses that have been published as a peer-reviewed journal article in *Neuroscience and Biobehavioural Reviews*. The content has been edited and re-formatted specifically for this thesis. Kenneth Ka-Shu Lee was the first author and contributed to all research duties as mentioned previously. Dr Hannah Hobson at University of York and Dr Jennifer Murphy at Royal Holloway, University of London assisted with the independent screening of articles, provided statistical supervision on the meta-analyses, and revised the manuscript for publication.

Chapter 3 leverages data from the Surrey Communication and Language in Education Study (SCALES), a UK-based cohort study that tracks the language and socioemotional development of children from 161 primary schools in Surrey, England. The data was entirely collected and managed by the SCALES consortium:

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Chapter 4 presents a study on the link between language talents and emotional self-awareness. The Royal Literary Fund kindly supported the recruitment of professional writers

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Note to Reader

Considering the large volume of materials presented in this thesis, references and appendices (labelled **Supplementary Materials** throughout) are placed after each corresponding chapter for the ease of electronic reading. The orientation of certain pages is adjusted horizontally for accommodating larger tables and figures. Page numbers are provided for a few tables and figures that are not placed immediately after the corresponding paragraph due to limited space. Supplementary tables and figures are arranged according to their sequential order as referenced in the main text.

Abstract

Alexithymia – difficulties identifying and describing feelings with an externally-oriented thinking style – is elevated in a range of psychiatric and neurodevelopmental conditions, and may explain co-occurring affective psychopathology. Past research has primarily focused on the role of interoceptive deficits in the development of alexithymia, yet the sole reliance on this interoceptive account may be insufficient to explain the aetiology of alexithymia in a wide array of alexithymic individuals.

Chapter 1 first describes the alexithymia construct and its high co-occurrence with a wide range of mental health conditions. This is followed by an overview of the past literature on the link between interoceptive deficits and alexithymia, and its limitations in explaining the development of alexithymia in different clinical groups. The multi-route model of alexithymia is discussed, which posits that there are multiple psychological pathways underlying alexithymia. In particular, the language hypothesis of alexithymia proposes that language impairments predispose language impaired groups to alexithymia. To enrich the theoretical discussion, the theory of constructed emotion is considered, introducing novel areas for research on the representation and acquisition of emotion concepts in alexithymic individuals.

Chapter 2 presents an integrated systematic review and meta-analysis on the relationships between alexithymia and (i) multi-domain language impairments, and (ii) emotional granularity. A modest association was found between alexithymia and language impairments, and elevated alexithymic traits were evident in language impaired groups relative to those with typical language in a small subset of studies. Alexithymia was associated with less fine-grained perception of emotional experience.

Chapter 3 investigates the prospective relationship between childhood language impairments and alexithymic traits in adolescence using data from the SCALES cohort. Supporting the language hypothesis, boys with low language function at ages 4-5 and those who later met the diagnostic criteria of language disorders at ages 5-6 reported more difficulties differentiating emotions and paying less attention to others' emotions at ages 12-13 than peers with typical language. Early structural language difficulties were consistently associated with elevated alexithymic traits in adolescence.

Chapter 4 adopts a strength-based approach, using professional writers as a model to study the role of language talents in emotional self-awareness. Results showed that writers had very low levels of alexithymic traits when compared to non-writers, and this group difference was related to higher self-reported interoceptive accuracy in writers compared to non-writers. Both writers and non-writers showed similar structural organisation of emotion concepts, which did not significantly predict their alexithymic traits.

Chapter 5 tests the link between alexithymia and emotion concept acquisition. Experiments 1 and 2 found no robust associations between alexithymia and emotion concept learning processes, but an indirect pathway between alexithymia and more stochastic choices through co-occurring anxiety symptoms. Experiment 3 found this same indirect pathway through anxiety when learning abstract non-emotion concepts, suggesting a general choice characteristic.

Chapter 6 investigates the relationships between autistic and alexithymic traits and information gathering. In a sample of typically-developing youths (aged 6-25 years), autistic traits were consistently associated with more information gathering regardless of information type and cost of information gathering. Computational modelling suggested that this was related to later emergence of subjective cost of information gathering, promoting later

guesses in those with higher autistic traits. Alexithymia was uniquely associated with inconsistent reporting of emotional responses to rewards and losses, and reduced gathering of emotional information when analysing parent-report measures, suggesting a novel treatment target.

Finally, **Chapter 7** summarises the key findings and discusses their theoretical and methodological implications with respect to a multi-route model of alexithymia. This is followed by a general discussion of the utility of the theory of constructed emotion. Future directions and clinical implications are also discussed. Together, this collection of work seeks to refine the theoretical framework of the multi-route model of alexithymia and highlights the importance of mechanism-focused research, with the ultimate goal of informing treatments for the wide array of alexithymic individuals.

Chapter 1
General Introduction

CHAPTER 1 GENERAL INTRODUCTION

General Introduction

The awareness of emotion has long been a subject of discussion and debate in the humanities and sciences (Barrett et al., 2007b; Goldie, 2000; Russell & Barrett, 1999). Humans, in particular, seem to have the unique ability to be aware of and experience a wide range of emotions relative to other animals, along with the capacity to communicate, express, and share these internal experiences with others in a sophisticated manner (Smith et al., 2020; Steklis & Lane, 2012). In the psychological sciences, emotional experiences were once considered a subjective matter that should not be scientifically scrutinised, particularly during the heyday of behaviourism (Skinner, 1965). However, the growing recognition of the interplay between emotion, cognition, and behaviour has led to a resurgence of research on the influences (and causal links) between emotion and conventional categories of cognitive processes, such as language, learning, and decision making (Barrett et al., 2007b; Ochsner & Phelps, 2007; see reviews on the neural correlates of emotion-cognitive interactions by Dolcos et al., 2011 and Lindquist et al., 2012). This greater appreciation of the link between emotion and cognition has important clinical implications, as atypicalities in these systems may explain low emotional awareness as commonly seen in psychopathology (Barrett et al., 2007b; Luminet et al., 2021).

Alexithymia refers to a subclinical dimensional trait with which individuals struggle to identify and describe their own feelings (Taylor et al., 1991; see a 25-year review on the 20-item Toronto Alexithymia Scale by Bagby et al., 2020). Alexithymic individuals also adopt an externally-oriented thinking style that focuses more on the operative aspects of reality than their internal states, notably emotional experiences (Bagby et al., 2020; Taylor et al., 1991). Although first discovered and studied in psychosomatic patients who frequently complained about incomprehensible physiological reactions to stress (i.e., patients who appeared to have “no words for feelings”; Nemiah et al., 1976), recent studies have pointed

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out the presence of alexithymia in a wide range of psychiatric and mood disorders, such as anxiety and depression, post-traumatic disorder, and eating disorders (Albantakis et al., 2020; Preece et al., 2022; Spitzer et al., 2007; Westwood et al., 2017). Notably, the prevalence of alexithymia has been found to be significantly elevated in autism (Kinnaird et al., 2019: 49.9% autistic adults; Milosavljevic et al., 2016: 55% autistic adolescents). This has led to the proposal that alexithymia (sometimes termed “low emotional (self-)awareness” in some studies) might be a transdiagnostic factor associated with increased risks of psychopathology (e.g., children and adolescents: Weissman et al., 2020; and in adults; Preece et al., 2017, 2020, 2022).

This thesis aims to test accounts of the development of alexithymia and derive empirical approaches that have the potential to improve the specificity of models of alexithymia, particularly the multi-route model of alexithymia (see section The Multi-Route Model and Language Hypothesis of Alexithymia below). In the following sections, I first describe one of the most prominent theories of alexithymia, the interoceptive hypothesis of alexithymia, and its limitations in considering interoceptive failure as the sole and/or primary contributor of alexithymia across clinical populations. I then introduce the multi-route model of alexithymia, which posits that there are multiple routes and contributing factors to alexithymia, such as the role of language impairments in predisposing individuals with language disorders to develop alexithymia (Hobson et al., 2019). I next present some outstanding empirical questions that would enhance the specificity of the model’s theoretical claims and predictions, as well as raise the possibility of expanding its theoretical framework by incorporating the theory of constructed emotion (Barrett, 2017; Barrett et al., 2007a).

CHAPTER 1 GENERAL INTRODUCTION

The Interoceptive Account of Alexithymia: Current State and Limitations

One prominent theory which attempts to explain the occurrence of alexithymia stems from the James-Lange hypothesis that individuals rely on the perception of internal bodily signals to recognise and understand their current emotional states, such as by sensing and monitoring one's heartbeat and breathing (Fehr & Stern, 1970). Based on this view, it has been suggested that alexithymic individuals struggle to perceive and monitor internal (or 'interoceptive') signals, thereby contributing to difficulties identifying and describing emotions (Brewer et al., 2016; also see a commentary on co-occurring alexithymia in autism by Brewer et al., 2015). This interoceptive hypothesis is generally supported by studies demonstrating an association between alexithymic traits and poorer self-reported interoceptive abilities (e.g., Giulia et al., 2021; Zamariola et al., 2018) and less accurate reporting of interoceptive signals than non-alexithymic individuals in behavioural studies (e.g., counting their heartbeats on the heartbeat counting/perception task; Herbert et al., 2011; Shah et al., 2016b). At the neural level, the anterior insula and anterior cingulate cortex may play a central role in supporting the ability to perceive internal bodily signals (whether in relation to affective experiences or not; Zaki et al., 2012). Atypical structural features and functional activity in this "interoceptive cortex" are commonly associated with alexithymia (e.g., Bird et al., 2010; Goerlich-Dobre et al., 2014; Moriguchi et al., 2007).

Despite the hypothesis's popularity in the field, there have been increasing concerns regarding the conceptualisation and measurement of interoception, which impact upon the strength of the evidence for the interoceptive hypothesis of alexithymia. Some key issues are the need to distinguish what interoceptive ability is measured (accuracy vs. attention) and disagreements about appropriate measures (self-report vs. objective measures) (see the 2 x 2 factorial model of interoceptive abilities by Murphy et al., 2019). There has also been little consideration of potential confounds that might otherwise explain the observed relationship

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between interoception and alexithymia (Murphy et al., 2018). Indeed, a recent meta-analysis has raised a number of questions about these issues, pointing out that untenable operationalisation and invalid measurement of interoception may have contributed to inconsistent findings and conceptual confusion in the literature (Trevisan et al., 2019).

The Multi-Route Model and Language Hypothesis of Alexithymia

Methodological issues notwithstanding, sole reliance on the interoceptive account results in limited success in explaining the vast individual differences in alexithymia. These individual differences are threefold. First, alexithymia is a dimensional trait construct that encompasses very low to exceptional levels of emotional self-awareness (Bagby et al., 2020; Smith et al., 2018; Taylor et al., 1991; see Hoemann et al., 2021 on emotional expertise). Second, it is suggested that alexithymia can arise early in development and impact the odds of future psychopathology (primary alexithymia) (Messina et al., 2014), or be a result of neuropsychological insults such as brain injury and stroke (secondary alexithymia) (e.g., Hobson et al., 2018, but see Hobson et al., 2020). These different origins of alexithymia imply that their underlying psychological pathways are likely different, as may also be the case for alexithymic individuals in other clinical groups with co-occurring alexithymia, such as individuals with language disorder or those with eating disorders (see discussion below). Third, alexithymia could contribute to differential clinical outcomes and impairments. For example, some alexithymic individuals with reward processing deficits might be more susceptible to developing addiction and substance misuse than those without such deficits (Morie et al., 2016; Pinard et al., 1996), while some other alexithymic individuals with a history of abuse and trauma might develop more severe forms of emotion dysregulation and personality disorders as compared to those without such adverse experiences (Preece et al., 2022; Spitzer et al., 2007; Zlotnick et al., 2001).

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In other words, considering the transdiagnostic nature of alexithymia, treating interoceptive failure as the primary contributor of all incidences of alexithymia is likely insufficient. Instead, it is more likely that alexithymia is determined by a complex and diverse range of psychological pathways that interact with, or even function independently of, interoception in some subgroups of individuals. This new proposal for understanding the development of alexithymia is known as the multi-route model of alexithymia (Hobson et al., 2019). A key hypothesis of the model is the language hypothesis of alexithymia, which posits that language impairments predispose individuals with language disorders to elevated levels of alexithymic traits. For instance, it is suggested that children with developmental language disorder (DLD) – those who show early and persistent difficulties in comprehending and using their native language(s) despite formal schooling – would be at heightened risk of developing alexithymia. Those widespread language impairments likely preclude these children from identifying and expressing their own feelings (such as struggling to use specific verbs and emotion vocabulary to communicate their own feelings coherently and extract emotional information in conversations, Hobson et al., 2019; Hobson & van den Bedem, 2021). For other clinical groups, individuals with eating disorders show elevated alexithymic traits (Westwood et al., 2017), but have comparable language abilities for describing their emotional states to healthy individuals (Rommel et al., 2013) and outperform the general population on the National Adult Reading Test by 10.8 units (Lopez et al., 2010). Interoceptive difficulties, rather than language impairments, may be a primary contributor to alexithymia in those with eating disorders.

Refining the Multi-Route Model of Alexithymia: Outstanding Questions

While the multi-route model of alexithymia sets forth a number of opportunities for future research, more empirical work is warranted to help consolidate its theoretical framework and enhance the specificity of its predictions. From an epistemological point of

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view, a critical first step in model building in psychology (or psychopathology in this case) would involve identifying and characterising the empirical phenomena of interest. This would help researchers construct specific and concrete theories that are appropriate for hypothesis testing and subsequent evaluation of the overall explanatory adequacy of the model (Borsboom et al., 2021; Haslbeck et al., 2021). To facilitate discussion of these epistemological issues, the following question words have been used as a guiding framework to reflect on some key knowledge gaps in the literature: *when*, *which*, *what*, *who*, and *how*.

A key limitation of the literature relevant to the language hypothesis of alexithymia is the predominance of cross-sectional studies demonstrating a relationship between language function and alexithymia (Hobson et al., 2019; Luminet et al., 2021), which do not test the prediction that language impairments *predispose* affected individuals to develop alexithymia. In particular, it seems crucial to specify the age and/or developmental stage at which children's language impairment is robustly linked to an elevated risk of developing alexithymia, and when these alexithymic traits are observable in later life. This developmental prediction relates to the *when* aspect of the model, as it suggests the need for longitudinal studies that track the temporal precedence of language impairments in the development of alexithymia, which is the minimal requirement to establish causality (Pearl, 2000).

Moreover, both theoretical work and observational/empirical studies have not yet specified *which* language domains might play a more direct role in the development of alexithymia. It is relevant to note that research on language development and linguistics has generally pointed out at least three domains of language function that serve relatively different linguistic purposes: structural language (the ability to understand and use grammar) (McDonald, 1997; Romberg & Saffran, 2010), pragmatics (the ability to understand and extract underlying social messages in language) (Bishop, 2014; Norbury, 2014), and narrative

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language (the ability to understand and produce speech coherently) (Sharp & Hillenbrand, 2008). Based on this conceptual framework, one might expect that these language domains may contribute to differential language pathways of alexithymia (*how*), such as among individuals with specific impairments in these language domains (*who*). For individuals with profound structural language impairments, their alexithymic traits might be relevant to difficulties extracting and/or expressing emotional information with the use of syntactic features (e.g., verbs denoting emotional states, such as “feel”, and adjectives that describe emotion concepts and feelings). For those who have specific pragmatic impairments, difficulties understanding and using metaphors (which are often used to indirectly describe one’s emotional experiences in most cultures, Emanatian, 1995; Kovecses, 2008), might render emotional state inference less effective and efficient through language, thereby contributing to difficulty describing feelings. For children with DLD, their alexithymic traits might be explained by a complex interplay between their persistent impairments in all three language domains (e.g., general communicative deficits might reduce the opportunity to interact with peers, which would in turn reduce the opportunity to understand and practise the use of emotion vocabulary and related syntaxes to communicate one’s emotional states; Hobson et al., 2019). The relationships between these language domains and alexithymia will be examined in more depth in Chapters 2 and 3.

Incorporating the Theory of Constructionist Emotion and Language

The multi-route model of alexithymia is rooted in the idea that researchers should be open to a variety of theoretical perspectives that show the potential of informing other contributing factors of alexithymia beyond interoception. One such perspective is the theory

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of constructed emotion (hereafter, the constructionist theory)¹ and its view on the role of language in emotional abilities (Barrett, 2017; Barrett et al., 2007a; Hoemann & Barrett, 2019; Lindquist, 2017). On the one hand, both the language hypothesis of alexithymia and the constructionist theory share the idea that language and emotion are two related mental systems; the latter, on the other hand, considers language playing a more fundamental role in the development of emotion concepts than does the language hypothesis of alexithymia. Specifically, the constructionist theory views emotions as concepts applied to rudimentary perceptual information, including internal bodily signals and external facial cues as though they were building blocks of emotional experience (hence the idea of “construction”, Hoemann & Barrett, 2019; Lindquist & Gendron, 2013; Lindquist et al., 2006). Language is one psychological mechanism that can facilitate this conceptualisation process (Lindquist, 2017). This is often illustrated by analogy with a “placeholder”, as language provides convenient access to discrete linguistic labels for making sense of and communicating one’s emotional states (Barrett et al., 2007a; Lindquist et al., 2015; Shablack & Lindquist, 2019). Another analogy would be language as a “concept glue”, which binds “noisy”, ambiguous affective signals (e.g., unpleasant bodily sensations) into discrete and more specific emotion labels (e.g., “frustration”) (Lindquist et al., 2015), fostering the development of emotion concepts (Hoemann et al., 2019, 2020).

Relating to the study of alexithymia, the constructionist theory raises the fundamental question as to *how* (a)lexithymic individuals represent and acquire emotion concepts in the first place. Of relevance are experience-sampling studies where alexithymic individuals tend

¹ Throughout this thesis, the term “constructionist theory” (or “theories” for its subordinate proposals and relevant work where appropriate) refers specifically to the theory of constructed emotion proposed by L. F. Barrett and colleagues, including K. A. Lindquist’s work on the role of language and K. Hoemann’s work on emotion development. It does not imply any links with constructionism in other emotion theories more broadly.

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to use a narrow range of emotion words to label their emotional experiences and rate these emotional experiences at less varied levels of valence (how negative/positive) and arousal (how stimulating/intense) (Erbas et al., 2014, 2019). These findings suggest that the internal representation of emotional experiences and related concepts in alexithymic individuals may be less fine-grained and with more blurred boundaries than those of non-alexithymic individuals. Developmental research has likewise considered the role of language in fostering the acquisition and development of emotion concepts. Such a role can be derived from formal literary activities (such as reading and writing about emotions) (Hoemann et al., 2019) and/or via an instructional curriculum that teaches the usage and valence-arousal mapping of emotion vocabulary (e.g., the RULER programme, see Brackett et al., 2019 and Hoffmann et al., 2020, which also involves basic learning principles such as reinforcement learning). Direct learning experience aside, some have postulated the role of social experience, in that interacting with members of a larger social group may help inform the normative usage of emotion words and concepts that one is not familiar with (Lindquist et al., 2022). This indirect social learning pathway highlights the importance of studying social processes in alexithymic individuals, whereas the multi-route model has focused on interoceptive and language deficits of an individual so far. Indeed, interpersonal difficulties are common in clinical populations with high co-occurring alexithymia (such as autism and mood disorders: Gerber et al., 2019; Radetzki et al., 2021), which may compromise their social learning opportunities to acquire and develop emotion concepts.

Considering the Transdiagnostic Outcome of Alexithymia: Decision Making

The multi-route model of alexithymia is in principle a clinical model. This means that while it is fundamentally important to understand its basic mechanisms and contributing factors, it is equally crucial to consider *how* these underlying factors relate to the impairments experienced by alexithymic individuals. Decision making, in particular, is a primary clinical

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concern and common reason for referral to mental health services for a transdiagnostic range of psychiatric conditions (see recent perspectives on the transdiagnostic nature of decision making and its associated neural mechanisms by Hiser & Koenigs, 2018 and Moutoussis et al., 2021; see Sonuga-Barke et al., 2016 for a developmental perspective). Relevant research on alexithymia, however, is scarce despite its high co-occurrence with those psychiatric conditions. It has been widely demonstrated that one's emotional state can be a beneficial source of information that guides decision-making strategies, whereas failing to be aware of and/or integrate such emotional information at the time – which is likely a disadvantage for alexithymic individuals – may lead to suboptimal decision outcomes (Scarpazza et al., 2017; Shah et al., 2016a). Indeed, recent studies have found that while non-alexithymic individuals would show a high degree of correspondence between their self-reported liking and choices (such as in the scenario of purchasing items), there is a lack of such correspondence in alexithymic individuals, leading to inconsistent and non-economical behaviours (Hogeveen et al., 2021). By the same token, emotions can sometimes produce unwanted influences on judgement and choice (e.g., impulsive shopping and binge-drinking), and that the ability to be aware of these emotional signals would be especially important in reducing their deleterious effects on decision making and related actions (Lerner et al., 2015). In the case of alexithymia, suboptimal decision making as a result of impaired integration of internal emotional information may explain why some alexithymic individuals are prone to engage in maladaptive behaviours when trying to cope with stressful life events and emotional difficulties, such as in the contexts of substance and alcohol misuse and addictions (Morie et al., 2016; Pinard et al., 1996). After all, decision making is very much embedded in almost all aspects of everyday life, ranging from scenarios involving individual choices to group decisions at an organisational level (Hastie & Dawes, 2009). A better understanding of the

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impact of alexithymia on decision making may ultimately inform interventions that improve the life outcomes of a transdiagnostic range of individuals.

One decision-making process that has gained increased attention in the clinical field is information gathering, which refers to the tendency to sample information with the ultimate goal of maximising the probability of making a correct judgment in an unfamiliar context (Cardinale et al., 2021). Having a heightened tendency to gather as much information as possible yet not evaluating the actual need for such information may reflect a maladaptive aversion to uncertainty, which is often thought to be an indication of intolerance of uncertainty (such as in autism: Bervoets et al., 2021; Stark et al., 2021). However, studies have not clarified how autistic and co-occurring alexithymic traits are related to information gathering, and those that utilise experiments to shed light on the underlying cognitive mechanisms are sparse. Given that the inability to be aware of one's emotional state can have deleterious effects on decision making (Lerner et al., 2015), it is plausible that alexithymic individuals would experience additional uncertainty about their emotional states during information gathering, which may further impact on any autistic-trait related processes.

Overview and Scope

This thesis is comprised of five empirical chapters, each addressing one or more guiding questions for refining the multi-route model of alexithymia as described above. In particular, this thesis focuses on studying the contributors of primary alexithymia, i.e., the trait-like aspects of alexithymia that develop across the lifespan and link to future risk of psychopathology. However, where appropriate, some results and study implications will be discussed in relation to relevant research in neuropsychological groups with secondary alexithymia.

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To first identify research gaps in a systematic manner, **Chapter 2** (*what*) presents a systematic review and meta-analysis on past studies that relate to the language hypothesis of alexithymia. This integrated review includes studies that examined the relationship between alexithymic traits and language function, and a small subset of studies that directly compared alexithymic traits between language impaired groups and those with typical language. This is followed by a second meta-analysis on studies that examined the relationship between alexithymic traits and emotional granularity, with the aim to explore the relevance of the theory of constructed emotion (i.e., the ability to differentiate between emotional states and their related concepts, and the role of language).

While tackling the many research issues identified would require effort beyond the scope of this work, **Chapter 3** (*which, when, who*) contributes to a secondary data analysis of the prospective relationship between childhood language development and alexithymic traits in early adolescence. The data were obtained from the Surrey Communication and Language in Education Study (SCALES), one of the few longitudinal cohort studies in the UK that has administered intensive child language assessments over the course of eight years (from the age of 4 and 5), with an assessment of alexithymic traits when these children reached the age of 12 and 13.

Further, since the discussion of the language hypothesis of alexithymia has primarily focused on the role of language deficits, **Chapter 4** (*who*) employs a strength-oriented perspective, using professional writers as a model of language talents to compare their level of alexithymic traits with general individuals who lack the literary expertise of writing extensively about their emotional experiences. This novel approach is useful to test the often-neglected scenario of whether having outstanding language skills and/or interoceptive abilities fosters emotional self-awareness.

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Chapter 5 examines the relationship between alexithymia and emotion concept acquisition with a focus on learning mechanisms (*how*). A series of three experiments was conducted to test if individuals with higher alexithymic traits would show atypical learning of emotional and non-emotional abstract concepts. Informed by recent models of emotion development, a well-established computational paradigm was used to estimate individuals' tendency to learn indirectly from social information relative to direct learning from task performance when learning concepts. The role of co-occurring mood symptoms, including anxious and depressive symptoms and stress, was also considered, due to their comorbidities with alexithymia and potential downstream effects on learning.

Finally, to facilitate the discussion of clinical outcomes associated with alexithymia, **Chapter 6** investigates how autistic and alexithymic traits relate to decision making processes during information gathering. In a typically-developing sample of youths aged 6 to 25, a within-subjects factorial design was used to test if a participant's tendency to gather information about another person would be differentially associated with autistic and alexithymic traits as a function of information gathering cost (no-cost/costly) and information type (emotional/non-emotional). A computational modelling package, which has been well-validated in developmental populations, was used to provide further mechanistic insights into the underlying decision-making processes (*how*).

This thesis ends with **Chapter 7**, which summarises the key findings of the empirical chapters and reflects on their contribution to the refinement of the multi-route model of alexithymia. This final chapter also discusses the strengths and limitations of the analytic methods used from a model building perspective, namely data synthesis, structural equation modelling, and computational modelling, with the aim of providing a guiding framework for future study designs and analytic strategies. Clinical implications and future directions are discussed at the end of the chapter.

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Chapter 2**Furthering the Language Hypothesis of Alexithymia:****An Integrated Review and Meta-Analysis**

CHAPTER 2 REVIEW AND META-ANALYSIS

Abstract

Alexithymia, the inability to identify and express one's own feelings, is a subclinical dimensional trait responsible for some of the socioemotional symptoms seen across a range of psychopathological and neurodevelopmental conditions. The language hypothesis of alexithymia posits a language-mediated disruption in the development of discrete and categorical emotion concepts from ambiguous and noisy affective states, exacerbating the risk of developing alexithymia in language impaired individuals. To provide a critical evaluation of the hypothesis, a systematic review and meta-analysis of 29 empirical studies of language function in alexithymia was performed. A modest negative association was found between alexithymia and multi-domain language deficits ($r = -.14$), including structural language, pragmatics, and propensity to use emotional language. Crucially, a more theoretically-relevant subsample analysis comparing alexithymia levels in language impaired and typical individuals revealed larger effects, but a limited number of studies adopted this approach. A synthesis of 11 emotional granularity studies also found an association between alexithymia and reduced granularity of emotion concepts ($r = -.10$). Language impairments and language disorders, therefore, seem to increase the risk of alexithymia. Initial evidence aside, heterogeneous samples and methodological variation suggest the need for more rigorous studies with improved alexithymia assessments.

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Furthering the Language Hypothesis of Alexithymia:

An Integrated Review and Meta-Analysis

Alexithymia is a subclinical dimensional trait characterised by a low degree of emotional self-awareness (Taylor et al., 1991). Specifically, it is a multifaceted construct comprising (i) difficulties identifying and describing one's own feelings, (ii) difficulty recognising emotional experiences from internal bodily signals, and (iii) a thinking style that focuses more on the external and operational aspects of reality, and less on internal self-experiences, notably emotions (Bagby et al., 2020; Nemiah et al., 1976; Taylor et al., 1991). In adult research, alexithymia is commonly assessed using the 20-item Toronto Alexithymia Scale (TAS; Bagby et al., 1994a, 1994b; Parker et al., 2003), a self-report questionnaire that measures the three core facets of alexithymia, namely *difficulties identifying feelings*, *difficulties describing feelings*, and *externally-oriented thinking*. Importantly, a 25-year review has concluded that the TAS-20 demonstrates good reliability and factor validity in a wide range of sociocultural and language settings (Bagby et al., 2020).

Despite its co-occurrence with a variety of psychiatric conditions (such as anxiety, depression, and post-traumatic stress disorder: Albantakis et al., 2020; Preece et al., 2022; Spitzer et al., 2007), the psychological mechanisms that underlie reduced emotional self-awareness in alexithymia are largely unknown. One line of research posits that alexithymia stems from the inaccurate, or otherwise atypical, perception of internal bodily signals (“interoception”), which are informative as to one's affective state (e.g., Brewer et al., 2016; Ernst et al., 2014; Scarpazza et al., 2015). However, as described in Chapter 1, the association between alexithymia and interoceptive abilities is hard to assess as most studies have used measures of interoception which have limited validity (Murphy et al., 2018; Trevisan et al., 2019). Furthermore, interoceptive signals alone are not thought to be sufficient to explain the

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full range of human emotional experience (Khalsa et al., 2018; Quigley et al., 2021), suggesting that alexithymia may arise as a product of atypicalities in systems beyond interoception.

From the constructionist perspective, emotions are concepts derived from “noisy” and ambiguous affective states. This conceptualisation (or “construction”) process is supported by multiple psychological functions (Russell & Barrett, 1999; Lindquist & Barrett, 2008; also see Hoemann et al., 2019, 2020 for a developmental account). Language, in particular, is a necessary (but not sufficient) psychological function that allows one to make sense of current affective experiences, providing convenient access to emotion labels and linguistic devices (e.g., “*feel*”) to identify and communicate one’s own feelings with others (Hoemann et al., 2019; Lindquist, 2017). Language also helps channel ambiguous affective states (e.g., unpleasant sensations) into discrete and specific emotion labels (e.g., anger) (Lindquist et al., 2015a, 2015b; Lindquist, 2017), allowing one to develop discrete emotion concepts (Brooks et al., 2016; Oosterwijk et al., 2012). It has been demonstrated empirically that the presentation of linguistic emotion labels influences subsequent perceptual judgment of (Gendron et al., 2012; Nook et al., 2015), and memory for emotional stimuli (Doyle & Lindquist, 2018), whilst verbal development mediates the development of multidimensional emotion concepts in 6- to 25-year-olds (Nook et al., 2017), all of which suggest an interplay between language and the psychological representation and conceptualisation of emotions.

Although there are only a few direct empirical tests of the language hypothesis of alexithymia, the theoretical claims are clear. First, if language plays a role in the development of emotion concepts, then language impairment would be expected to result in absent or impoverished emotion concepts. Impaired emotion concepts would be expected to lead to difficulties *identifying* one’s own emotions, and thus alexithymia. Second, even if language does not play a role in the development of emotion concepts, language impairment would

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result in difficulties *describing* one's own emotions, again resulting in alexithymia. It should be noted, however, that the language hypothesis of alexithymia posits that language disorder plays a role in exacerbating and/or contributing to high alexithymia in a *subgroup* of individuals, i.e., for those with language impairments (Hobson et al., 2019). Thus, while one would not expect every alexithymic individual to have language problems, one would expect language difficulties to lead to alexithymia (dependent upon the nature of those language deficits - see below). For example, patients with acquired language impairments following penetrating brain injury showed significantly higher degrees of alexithymia than healthy controls; while the extent of brain damage in the inferior frontal gyrus (IFG), a key part of the language network (Poeppel et al., 2012), was associated with higher alexithymia scores (Hobson et al., 2018; but see Hobson et al., 2020). Although the patients with brain injury show that language impairment can lead to alexithymia (in its secondary, acquired form in this case), individuals with alexithymia would not necessarily be expected to have language difficulties. As noted in Chapter 1, individuals with eating disorders are at increased risk of alexithymia (Westwood et al., 2017), but outperform the general population on the National Adult Reading Test (Lopez et al., 2010). Language impairments seem unlikely to explain alexithymia in these individuals, therefore interoceptive impairment may be more relevant to alexithymia in eating disorders.

These theoretical predictions are important in evaluating evidence for the language hypothesis, and make it difficult to interpret the results of studies that compare language function in groups of individuals with, and without, alexithymia. Small effect sizes could be due to a small contribution of language difficulties to alexithymia in all alexithymic individuals, or a larger contribution in a subsample of individuals. Studies which examine levels of alexithymia in individuals with language disorder in comparison to those without a language disorder are easier to interpret, but rare.

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Possible interpretation issues notwithstanding, behavioural studies have generally reported that higher alexithymia is associated with worse language function. The majority of empirical evidence comes from descriptive studies that demonstrate an association between individual differences in alexithymia and a reduced propensity to use emotional language, quantified by the relative proportion of emotional words used when invited to speak or write freely about an emotional event (e.g., Camia et al., 2020; Jelinek et al., 2010; Tull et al., 2005). The degree to which reduced/atypical labelling of emotions stems from general narrative language difficulties or emotion understanding difficulties is still debatable (Barrett, 2013; Hoemann et al., 2020). From the constructionist perspective, it has been suggested that early language milestones, such as pointing to and labelling the surroundings with groups of sounds (“tata”) and simple/pseudo words (“choc-choc” for chocolate), are some of the foundations that help children represent abstract concepts psychologically (Hoemann et al., 2019, 2020). This domain-general language process may also apply to emotion concepts (e.g., Beck et al., 2012; Streubel et al., 2020; also see a theoretical piece by Hoemann & Barrett, 2019), such that the more extensive and richer these representations are (e.g., via regular use and retrieval of these emotion concepts), the better the child’s emotion understanding is (Cole et al., 2010; Pons et al., 2003). Therefore, these emotional language studies, although they seem partly overlapping with the difficulty expressing emotions domain in alexithymia, highlight the opportunity of testing if emotional language impairments contribute to alexithymia, which may stem from at least two language pathways – (i) impoverished emotion concepts due to disrupted language-mediated concept learning in development, and/or (ii) further difficulty retrieving abstract (emotional) lexicon (Hobson et al., 2018).

Other studies have focused on structural language deficits, such as difficulty reading, literal comprehension, and limited grammatical and lexical access assessed by formal

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linguistic assessments and neuropsychological tests (e.g., Karukivi et al., 2012; Winstanley et al., 2019; Wood & Williams, 2007). These structural language results are less consistent (e.g., Hobson & van den Bedem, 2021), but nonetheless point to a negative trend between alexithymia and structural language abilities, or higher degrees of alexithymia in the language impaired group (e.g., in youths with developmental language disorder [DLD] in Hobson & van den Bedem, 2021 and Winstanley et al., 2019). Structural language difficulties in alexithymia may suggest a more fundamental mechanism concerning difficulties communicating emotions in a grammatically comprehensible and coherent manner (e.g., *I* [subject] + *feel* [expressive verb] + *happy* [adjective/emotion concept]).

A smaller body of studies has examined the link between alexithymia and pragmatics, the ability to understand the implicit social messages in language. In Jakobson and Pearson (2021)'s study, participants were asked to judge non-literal statements as jocular, literal, sarcastic, or white lies, and higher alexithymia was associated with lower statement processing speed. Problematically, it remains an open question whether any pragmatic difficulty in alexithymia is indicative of a social language deficit or a broader social cognitive impairment given the high co-occurrence between alexithymia and autistic traits, which have not been dissociated in most empirical studies on pragmatics (Pisani et al., 2021). Empirical issues aside, pragmatic difficulties in alexithymia may hint at a lack of social language learning opportunities in early years, a developmental period when emotion discourses and language activities (e.g., reading and writing about fictional characters) take place frequently with peers and caregivers (Dunn et al., 1991; Harris et al., 2005).

Although in general studies do demonstrate a link between alexithymia and poorer language ability, it should be noted that empirical evidence for the link between alexithymia and language abilities is mixed. Since alexithymia is associated with a wide range of psychiatric conditions, considerable heterogeneity in the demographic and clinical

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characteristics of participants across individual studies may account for some of the variance observed in the relationships between alexithymia and language abilities (Hobson et al., 2019). Moreover, language is a multifaceted construct. There is limited evidence regarding which specific language domain(s) are related to alexithymia, and it is likely that different language domains serve different functions in emotion processing, as noted above.

Examination of the relationships between alexithymia and specific domains of language function may inform discussion of the role language plays in emotional self-awareness (Hobson & van den Bedem, 2021). Furthermore, there are considerable differences between empirical methods and analytical procedures between studies, rendering the interpretation of results across studies difficult. Therefore, a systematic overview and quantitative synthesis of the available evidence is much needed to evaluate the empirical basis of the language hypothesis of alexithymia.

As our primary focus, we first provide a systematic overview of the literature, summarising the sample characteristics and study methods of empirical studies examining language abilities in alexithymia. We then extracted and synthesised the individual effect sizes that quantify the variances in different domains of language abilities that are associated with individual differences in alexithymia. Where possible, we conducted a synthesis of studies that compared alexithymia in individuals with and without language impairments. We also synthesised the few studies that comprehensively reported the association between structural language difficulties and specific TAS subscales. To further evaluate the applicability of the constructionist idea that language impairments disrupt the representation and development of emotion concepts which leads to alexithymia, we present a follow-up meta-analysis synthesising the association between alexithymia and emotional granularity – individual differences in perceiving similarities and differences between emotion concepts.

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With respect to predictions, if language disorder leads to alexithymia, then there should be a significant negative association between alexithymia and language function. Due to heterogenous samples across clinical conditions, and the fact that most studies investigated language function in alexithymia rather than alexithymia in those with language impairment, this association would be expected to be modest. The strength of the association between alexithymia and specific language domains would be expected to vary, although the lack of specificity at the theoretical level makes predictions relating to the size and nature of the differences difficult. For the few studies that adopted a group-based approach, one would expect language impaired groups to be more alexithymic than typical individuals, with a larger effect than that observed in the dimensional studies. This corresponds to the prediction of the language hypothesis that language difficulties represent unique risks for developing alexithymia in language impaired groups, but not all individuals on the alexithymia continuum struggle with language difficulties. Finally, if alexithymia is related to language impairment, and language is necessary for the development of emotion concepts as suggested by constructivist theories of emotion, then one would expect alexithymia to be associated with less granular representation of emotion concepts.

Systematic Review and Meta-Analysis 1

Method

Search Strategy

Following the 2020 Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), a systematic search was performed in July 2021 to identify empirical studies for this review and meta-analysis. The following search terms and derivatives were used: ((Alexithymia OR “emotional awareness”) AND (language OR word OR label*)) in four databases: PubMed, PsycINFO, Medline, and Web of Science.

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These search terms were selected on the basis of previous systematic reviews and/or meta-analyses focused on alexithymia (e.g., Trevisan et al., 2019; Hickman et al., 2020), and theoretical papers on emotion and language (e.g., Lindquist & Gendron, 2013; Lindquist, 2017). Search filters were applied to exclude studies that did not report empirical data (e.g., scoping reviews and commentaries), and articles not in English. No restrictions on publication date were imposed. The same search strategy was used in Google Scholar and WorldCat to identify relevant grey literature (e.g., unpublished doctoral theses). Search results were then crosschecked with studies included in a recent narrative review on cognitive-emotional processing in alexithymia (Luminet et al., 2021). With duplicates removed, 618 articles were identified via the database search, 12 via WorldCat and Google Scholar, and 4 by crosschecking with Luminet and colleagues' (2021) narrative review. To increase study availability, we supplemented the search with one additional dataset from the authors. Together, this resulted in 635 articles.

Study Selection

Abstract screening was conducted independently by the first author (KSL), with ambiguous articles resolved through discussion with JM and HH. Articles deemed relevant based on abstracts and keywords were then included for full-text assessment. The initial screening removed a total of 566 articles (555 from database search), resulting in 69 articles (63 from database search) eligible for full-text screening.

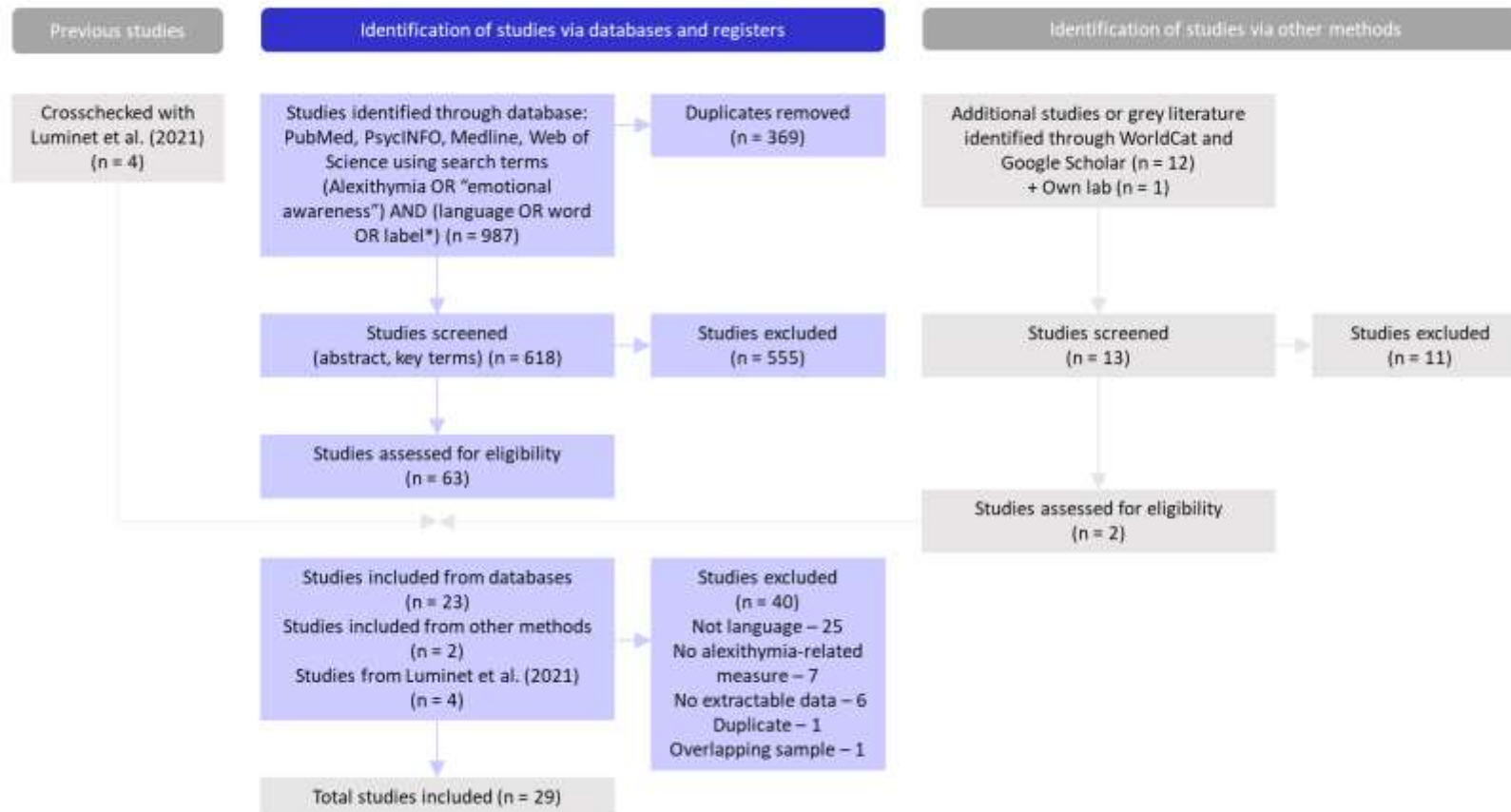
Full texts were assessed by KSL and checked by HH and JM independently. Studies were removed if they did not recruit human participants, reported overlapping samples (the study focusing on the use of emotion-related language was retained), presented non-empirical and/or self-reported questionnaire data for language abilities, were not relevant to alexithymia nor language abilities, measured and analysed language as a control variable/sample

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characteristic and no further analyses in relation to alexithymia or emotional self-awareness were performed, or were not retrievable for full-text assessment. The full-text assessment resulted in a final collection of 29 studies. Twenty-six studies assessed alexithymia/emotional self-awareness using the 20/26-item TAS (Parker et al., 2003); one study used the Children's Alexithymia Measure (CAM) (Way et al., 2010); two studies used the Bermond-Vorst Alexithymia Measure (BVAQ) (Vorst & Bermond, 2001). The CAM has shown strong internal reliability ($\alpha = .92$; Way et al., 2010), whilst the BVAQ correlates highly with TAS ($r_s = .60$ to $.80$; Vorst & Bermond, 2001), supporting the inclusion of these alexithymia measures in the same meta-analysis. Data from nine studies were provided directly from the authors upon request and we are very grateful to those authors. Although as outlined in Chapter 1 that the main focus of this thesis is on primary alexithymia, we have retained the three studies that recruited neuropsychological participants (Hobson et al., 2018, 2020; Wood & Williams, 2017) so as to preserve power for subsequent analyses in this relatively small body of literature, and that these studies have also directly tested alexithymia differences between patient group and general individuals. None of these studies have reported outlying effect sizes as indicated in our sensitivity analyses; their theoretical and methodological implications are presented in the discussion. Further details of the literature search history are presented in the PRISMA flowchart (Figure 2.1).

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Figure 2.1

Literature Search History of Language Studies in Alexithymia

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Data Extraction

Table 2.1 (page 63) provides an overview of the identified studies. The following information was extracted and summarised by the first author: (i) sample characteristics including mean age, sample size, indication (e.g., clinical conditions), percentage female, and descriptive statistics (mean, standard deviation, and range) of alexithymia/emotional self-awareness scores of the study samples; (ii) methods including choice of alexithymia/emotional self-awareness assessment, language task or assessment used. To provide a more nuanced understanding of the association between alexithymia and language abilities, language abilities of interest in the identified studies were classified into three language domains, namely (i) Structural language, (ii) Pragmatics, and (iii) Natural use of emotional language.

Structural language refers to language studies that assessed participants' understanding and use of basic language structures, such as grammar, vocabulary, general reading and comprehension, as well as lexical access abilities. Measures extracted from these structural language studies were primarily accuracy variables, such as behavioural task performance (e.g., Hobson et al., 2018, 2020) and competency scoring on standardised language assessments (e.g., Hobson & van den Bedem, 2021; Karukivi et al., 2012; Nishimura et al., 2009).

Pragmatics refers to language tasks that required participants to make a judgment of the underlying social information of speech or language stimuli, such as to recognise the emotional content (Lane et al., 1996; Maurage et al., 2009; Swart et al., 2009) or sarcasm/humour (Jakobson & Pearson, 2021; Olkonieni et al., 2019) of written sentences. These studies primarily reported accuracy measures in an *n*-alternative-forced-choice context (e.g., Lane et al., 1996; Jakobson & Pearson, 2021), while a few also reported measures of

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efficiency, assessing reaction times when making judgments of the pragmatics stimuli (e.g., Jakobson & Pearson, 2021; Olkonieni et al., 2019; Swart et al., 2009). Two studies used non-experimental assessments of pragmatics competency in youths (e.g., the parent-reported Children's Communication Checklist in Hobson & van den Bedem, 2021; Snow et al., 2016), which are concerned with one's accuracy of understanding and/or use of pragmatics and are conceptually similar to the pragmatic behaviours tested in those laboratory tasks.

Natural use of emotional language refers to narrative tasks that invite participants to speak or write freely about a specific topic or an autobiographical event related to emotions (e.g., Jelinek et al., 2010; Tull et al., 2005), or emotional stimuli presented by the experimenter (e.g., Luminet et al., 2004; Roedema & Simons, 1999). The propensity to use emotional language was then quantified in terms of word frequency using linguistic software, such as the respective proportion of positive and negative emotion words throughout the narrative task (e.g., Vakhrusheva et al., 2020).

It is worth noting that there is no absolute distinction between the three language domains proposed. For instance, the natural use of emotional language would rely on some structural language competence to structure a sentence, whilst the reception of social information via language would require some competence to access lexical devices that often denote a person's emotion. Nonetheless, a systematic classification allows for the comparison of synthesised quantitative findings between language domains, which would be beneficial for hypothesis generation. The classification was initially performed by the first author, and then checked by HH. For the purpose of the meta-analysis, study findings including statistical test(s) used and the relevant statistics for pooling the effect sizes across independent studies were extracted. Further details are discussed below.

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Table 2.1*Overview of Language Studies in Alexithymia (k = 29)*

Study	N	Mean age (years)	% Female	Indication	Measure	Task	Language domain	Alexithymia mean (SD)	Alexithymia range	Alexithymia as DV?
Camia et al. (2020)	8	46	Not reported	Alcohol dependence	TAS-20	Toronto structured interview for alexithymia with recalling of related personal life events	Emotional language use	HA (≥ 61) = 64.25 (2.06) LA (≤ 51) = 43.50 (4.66)	HA = 62-66 LA = 38-49	No
Costa et al. (2007)	53	63.8	27.9	Parkinson's disease, HV	TAS-20	Word list recall, sentence construction, phonological verbal fluency from a standardised neuropsychological test battery	Structural	HA (≥ 61)	Not reported	No
Edwards et al. (2020)	96	21.2	76	HV (undergrads)	TAS-20	Emotional writing exercise requiring participants to engage in six autobiographical recall tasks (negative, neutral or positive experiences) and to reflect upon and write	Emotional language use	Total = 44.35 (12.05)	Not reported	No

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about a past experience that fitted the description. Writings were then analysed with a linguistic software.

Hobson et al. (2018)	17	63.3	Male only	Traumatic brain injury, HV	TAS-20	Token test requiring participants to hear and perform a set of instructions; and Boston Naming Task requiring participants to disregard line drawings and name the item in the picture.	Structural	Boston Naming/ Unimpaired = 50.01 (12.50) Boston Naming/Impaired = 57.55 (12.14) Token Test/ Unimpaired = 50.27 (12.66) Token Test/Impaired = 53.83 (9.45)	Boston Naming/ Unimpaired = 24-81 Boston Naming/Impaired = 44-74 Token Test/ Unimpaired = 24-81 Token Test/Impaired = 24-81	Yes
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Hobson et al. (2020)	118	73.1	46.6	Chronic stroke	TAS-20	Picture naming task asking participants to name the object in the picture; comprehension task instructing participants to point to an item in a picture/to complete a task with no. of repeated instructions needed measured; and sentence reading task requiring participants to read a sentence aloud.	Structural	Total = 49.43 (12.71) Language unimpaired = 48.48 (12.77) Language impaired = 52.03 (12.35)	Total = 27-81 Language unimpaired = 27-76 Language impaired = 27-81	Yes
Hobson & van den Bedem (2021)	289	12.2	54.7	Developmental language disorder, HV	Children's Alexithymia Measure, parent-report	Parent-reported language assessment, Children's Communication Checklist, inquiring about children's structural language and pragmatic language development, and other communicative impairment.	Structural and pragmatics	Total = 1.64 (.56) DLD = 2.01 (.58) Non-DLD = 1.42 (.42) *Standardised scores were reported	Total = 1-4 DLD = 1-3.29 Non-DLD = 1-4	Yes

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Jakobson & Pearson (2021)	70	20.6	51.4	HV	TAS-20	Experimental task requiring participants to indicate which of the five labels (literal positive, literal negative, jocular, sarcastic, white lie) describe the type of statement the speaker (in the video) had made	Pragmatics	Total = 47.2 (10.2)	Not reported	No
Jelinek et al. (2010)	79	40.1	53.2	Trauma survivors with and without developing PTSD symptoms	TAS-20	Standardised clinical interview inquiring about traumatic experiences	Emotional language use	PTSD = 54.04 (9.61) Non-PTSD = 43.76 (9.08)	Not reported	No
Karukivi et al. (2012)	723	19	74	Adolescents with 1 or more eating disorder symptoms, HV	TAS-20	Clinical speech development assessment conducted and examined by nurses	Structural	Not reported	Not reported	Longitudinal assessment: Language -> Alexithymia
Kreitler (2002)	100	22.6	50	HV (undergrads)	TAS-20	Meaning test in which participants were asked to describe stimuli to an imaginary other	Emotional language use	Total = 55.10 (11.53)	Not reported	No

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Lane et al. (1996) – Subtasks 1, 3	380	18-80	51.6	HV	TAS-20	Perception of affect task using sentences that depict a specific emotion that do not include words denoting emotion. Participants then select an item response from a list of seven words denoting emotions.	Pragmatics	Total = 46.1 (11.8)	21-82	No
Luminet et al. (2004)	50	63.6	78.6	HV	BVAQ	Verbal re-evocation session after viewing emotional movies	Emotional language use	Not reported	Not reported	No
Maurage et al. (2009) – Script task	36	47.9	22.2	DSM-IV alcohol dependence, HV	TAS-20	Script emotion recognition task	Pragmatics	Alcoholics = 43.22 (17.69) HV = 42.73 (14.83)	Not reported	No
Meganck et al. (2009)	32	42.7	62.5	Individuals from mental health care centers in Belgium, all met DSM-IV Axis I criteria,	TAS-20	2-hour clinical interview encouraging participants to speak about their problems and interpersonal embedment of these problems, with LIWC analysis	Emotional language use	Total = 59.88 (11.85)	34-81	No

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while some
 also met Axis
 II criteria. All
 patients
 received
 individual
 psychotherapy,
 of which half
 of them were
 taking
 prescribed
 medications

Nishimura et al. (2009)	234	13.7	49.5	HV from junior high schools, adolescent patients with psychosomatic and/or behavioural problems	TAS-20 subscales	Diagnostic literacy test of Japanese reading and vocabulary	Structural	Only the means and SDs of subscales were reported for males and females separately	Not reported	No
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O'Connor & Ashley (2008)	87	20.3	57.5	HV	TAS-20	Pennebaker emotional writing paradigm requiring participants to write about their deepest emotions and thoughts about the most upsetting experiences in their life for 15mins for 3 consecutive days. Writing analysed with a linguistic software.	Emotional language use	Total = 49.79 (9.40) Writing group = 50.88 (11.26) Control = 48.70 (7.53)	Not reported	No
Olkoniemi et al. (2019)	60	24.2	76.7	HV (students)	TAS-20	Read and interpret dialogue statements underlying sarcasm	Pragmatics	Total = 41.18 (8.87)	24-63	No
Paez et al. (1999) – Study 3	70	Not reported	Not reported	HV (undergrads)	TAS-26 (DDF)	Intensive and brief expressive writing exercise	Emotional language use	Not reported	Not reported	No
Renzi et al. (2020)	35	36.2	Female only	Women undergoing assisted reproductive treatment	TAS-20	Writing intervention requiring participants to write about the deepest thoughts and feelings about the experience of the assisted reproduction technology treatment	Emotional language use	Total = 59.63 (9.07) HA = 59.63 (9.07) LA = 35.42 (5.71)	Not reported	No

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Roedema & Simons (1999)	65	Not reported	52.3	HV (undergrads)	TAS-26	Verbally describe one's feelings about the emotional images	Emotional language use	Not reported	Not reported	No
Snow et al. (2016)	100	17.1	15	Young people completing custodial sentences in Australia	TAS-20	Clinical evaluation of language fundamentals, test of language competence, and narrative language task	Structural and pragmatics	Total = 55.0 (10.7)	59% in the likely/possible (≥ 52) ranges	Considered but not performed given that language function was not correlated with TAS scores
Suslow & Junghanns (2002)	31	26	42.9	HV	TAS-20	Lexical decision task of word/nonword stimuli following related/unrelated emotion situation priming	Structural	Total = 40.4 (median = 39) HA = 50.6 (7.4) LA = 29.5 (5.0)	23-64	No
Swart et al. (2009) – Affective semantic task	34	19.7	58.8	HV	BVAQ	Affective prosody task requiring participants to make a response as soon as they identified the emotion expressed in a sentence, either based on	Pragmatics	HA ≥ 26 , 1.5 SD above the overall mean of the verbalizing subscale; LA ≤ 17 . The means and SDs of	Not reported	No

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						content or tone of voice (congruent, incongruent)		BVAQ subscales were reported for HA and LA.		
Tull et al. (2005)	54	27	66.7	HV	TAS-20	Verbalization task asking participants to speak about a past distressing event, analysed with a linguistic software	Emotional language use	Total = 45.52 (10.74)	20-74; only six participants > 61 and nine participants scored between 52-60	No
Vakhrusheva et al. (2020)	72	25.5	51.5	Schizophrenia, HV	TAS-20	Experience sampling with a focus on descriptions of emotional events	Emotional language use	Schizophrenia = 50.54 (14.90) HV = 37.63 (11.31)	Not reported	No
Winstanley et al. (2019)	145	15.8	22.8	Young offenders	TAS-20	Standardised psycholinguistic measures including verbal IQ, formulated sentences and literal understanding spoken paragraphs, test of word reading efficiency,	Structural	DLD = 56.6 (12.6) Non-DLD = 54.6 (10.7)	DLD = 41% HA, 21% MA, 38% LA Non-DLD = 32% HA, 25% MA, 43% LA	Yes

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and reading
comprehension

Wood & Williams (2007)	92	38.7	45.0	Traumatic brain injury, orthopaedic controls	TAS-20	Neuropsychological test battery testing reading and comprehension	Structural	Brain injury = 60.71 (14.66) Orthopaedic = 47.17 (11.17)	Not reported	No
Wotschack et al. (2013)	102	35	42.2	HV	TAS-20	Semi-standardised interviews about emotion knowledge and autobiographic narratives	Emotional language use	HA (> 55) = 67.7 (6.8) LA (< 45) = 38.3 (4.2)	Not reported	No
Yao et al. (2018)	127	22.4	64.6	HV (students)	TAS-20	Lexical decision of word or nonword with emotion (negative, neutral, positive) and concreteness (abstract, concrete) considered	Structural	Total = 46 (11)	22-74	No

Notes. BVAQ = Bermond-Vorst Alexithymia Questionnaire; DDF = Difficulty Describing Feelings subscale; DLD = Developmental language disorder;

HA/MA/LA = High/Medium/Low alexithymia; HV = Healthy volunteers; PTSD = Post-traumatic stress disorder; TAS = Toronto Alexithymia Scale; -- =

Not applicable.

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Statistical Analysis

Given the primary interest of this meta-analysis was to synthesise the effect size of the association between alexithymia and language abilities, correlation coefficients were extracted and pooled as an effect size summary. For studies that reported statistics that are not directly convertible to correlation coefficients (e.g., group-based tests and multi-level modelling), authors were first contacted for the appropriate statistics, while unresolved cases were handled by the effect size conversion functions in the *esc* package (Lüdtke et al., 2019). For prospective studies that conducted multiple measurements over time, the baseline data were extracted.

The meta-analyses were conducted via the R packages *meta* (Balduzzi et al., 2019), *metafor* (Viechtbauer, 2010), and *dmetar* (Harrer et al., 2019). Random-effects models were used for the series of meta-analyses reported here as heterogeneity of effect sizes was expected (Field, 2001; Hunter & Schmidt, 2000), and the conventional restricted maximum likelihood estimator was used (Viechtbauer, 2005). To meet the assumption of the random-effects model that the studies comprised independent groups of participants, a synthesised effect size was computed by averaging the effect sizes in studies that reported multiple measures of a language domain (e.g., Boston Naming and Token Test performance in Hobson et al., 2018; assessment scorings on vocabulary, lexical similarity, and comprehension in Wood & Williams, 2007; and judgement accuracy in Subtasks 1 and 3 in Lane et al., 1996) (Borenstein et al., 2009). Mauraage and colleagues (2009) reported separate effect sizes by emotion categories, and the averaged effect sizes in respect of judgements about happy, angry, and sad pragmatics stimuli were used in the meta-analysis, given that these emotional categories are more commonly used in the literature. Where applicable, signs of the correlation coefficients were reversed prior to the meta-analysis such that a negative correlation denoted poorer language function with increasing alexithymia.

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Briefly, a Fisher r -to- z transformation was performed to standardise the correlation coefficients extracted, thereby allowing the accurate estimation of a pooled effect size across the studies via inverse variance weighting. Heterogeneity of the data was assessed using the Q statistic, which is the sum of the weighted squared differences between the observed effect size of each study and the fixed effect estimate, relative to the null hypothesis of homogeneity. The I^2 statistic was also calculated, which quantifies the percentage of effect size variability not attributable to sampling error (Huedo-Medina et al., 2006). The respective degrees of heterogeneity are low (25%), moderate (50%), and high (75%) (Higgins et al., 2003). Studies that significantly deviated from the 95% confidence interval of the summary effect size were removed. Wherever possible, a publication bias analysis was performed to examine if any null or modest evidence had been excluded from the literature via inspection of asymmetry of the funnel plot and the Egger's test (Egger et al., 1997). For the sake of completeness, publication bias information is reported throughout but should be interpreted with caution given that at least 10 studies are needed for generating reliable estimates. Moreover, influence analysis via the leave-one-out method was used to examine the influence of each individual study on the summary effect size. Baujat plots were generated to depict the contribution of individual studies to overall heterogeneity.

As for the *Main analysis*, an overall analysis inclusive of all individual studies was performed to synthesise the effect sizes indicative of the association between alexithymia and language abilities across domains. To ensure that each independent group of participants contributes to one effect size for the random-effects model, a composite effect size was computed for Hobson and van den Bedem (2021) by averaging the effect sizes for structural language and pragmatics in the same sample. A subgroup analysis was then performed to statistically compare effect size differences between studies classified into structural language, pragmatics, and natural use of emotional language domains. Two studies (Hobson

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& van den Bedem, 2021; Snow et al., 2016) were removed from this subgroup analysis as their effect sizes fell into both structural language and pragmatics categories. To investigate the association between alexithymia and specific language abilities more closely, follow-up analyses were conducted separately within each language domain. Supplementary analyses examining potential differences between clinical and developmental groups, and association with TAS-20 subscales are described throughout, and presented in the **Supplementary**

Materials.

Finally, we analysed a subset of 4 studies (4 effect sizes) that compared the degree of alexithymia (as dependent variable) between participant groups with and without language impairments. This analysis, although limited by the low number of studies, provides a more direct test of the idea that there are unique risks among individuals with language impairments/disorders for developing alexithymia. For these group-based studies, the means and standard deviations of alexithymia scores for the language impaired and non-impaired groups were extracted for computing standardised mean difference among individual studies, which were then converted to Hedges' g as a pooled summary effect size given the small sample sizes (Hedges & Olkin, 1985).

Results

Systematic Review

Sample Characteristics. Of the 29 studies, the average sample size was 115.8 participants, but considerable variation was observed (median = 72, SD = 142.2, range = 8 to 723). A few studies utilised data from large-scale research projects which may have skewed the mean sample size (e.g., Karukivi et al., 2012; Nishimura et al., 2009). The mean age of participants was 33 years (median = 25.8 years, SD = 25.8, range = 13.7 to 80). Two studies did not report the participants' age (Paez et al., 1999; Roedema & Simons, 1999). Of the 27

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studies that reported gender proportion, the average percentage of female participants was 51.8% (median = 51.6%, $SD = 17$), ranging from 15 to 76.7%. Two studies included only male (Hobson et al., 2018) or female participants (Renzi et al., 2020).

In terms of participants, 21 studies recruited healthy volunteers as the major study sample (14 studies) or comparison group (7 studies). Six of those 21 studies were from university student populations. All studies sampled Caucasian populations, except for one study that recruited junior high school students in Japan (Nishimura et al., 2009). Among studies that recruited clinical samples, four clinical groups were examined. These include patients with brain injury or related neuropsychological insults (3 studies), neuropsychiatric conditions including schizophrenia and Parkinson's disease (2 studies), affective disorders and related substance misuse (4 studies), and youths with developmental and early behavioural concerns (5 studies).

Alexithymia Measures. As detailed in **Study Selection**, the TAS-20 was the most commonly used measure of alexithymia (24 out of 29 studies); two studies used the older 26-item version (Paez et al., 1999; Roedema & Simons, 1999). Two other studies (Luminet et al., 2004; Swart et al., 2009) used the BVAQ (Vorst & Bermond, 2001) and one developmental study (Hobson & van den Bedem, 2021) used the CAM (Way et al., 2010). Twenty-four studies reported the means and standard deviations of alexithymia or emotional self-awareness scores, but only 12 of those also reported the range of alexithymia or emotional self-awareness scores. Among studies that administered the TAS-20, the mean

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alexithymia score was 50.01 (median = 49.43, $SD = 7.91$), which corresponds to a low level of alexithymia based on recommended cutoff scores (Parker et al., 2003).

Language Assessments. A summary of the language measures and language domains of interest is detailed above in **Data Extraction**.

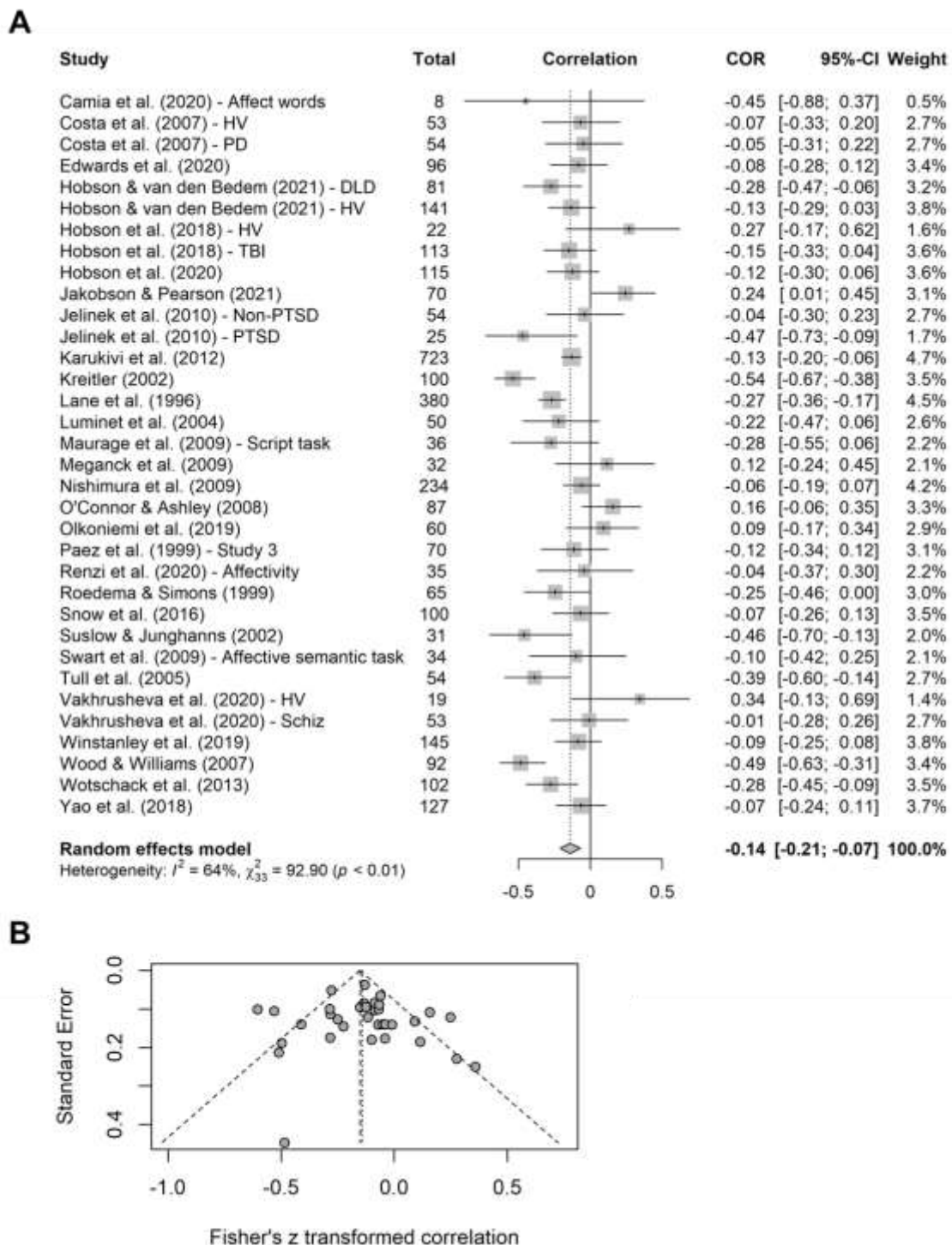
Meta-Analysis

Overall Language Abilities. The overall analysis of language abilities in alexithymia comprised 29 studies (34 effect sizes) and indicated considerable heterogeneity across studies ($Q = 92.90$, $p < .001$; $I^2 = 64.5\%$), supporting the use of a random-effects model for the meta-analysis. The analysis generated a summary effect size of $-.14$ [CI: $-.21$; $-.07$], $p < .001$, across language domains. Influence analyses using the leave-one-out method revealed that the summary effect sizes ranged consistently from $-.13$ to $-.15$, all of which indicated a significant association between alexithymia and language. Results remained largely unchanged with outliers removed (25 studies, 30 effect sizes), with a summary effect size of $-.14$ [CI: $-.19$; $-.09$], $p < .001$, and moderate heterogeneity ($Q = 41.35$, $p = .06$; $I^2 = 29.9\%$). This suggested an R^2 value of 0.02, meaning that 2% of the variance in language abilities across domains was associated with alexithymia. Inspection of the funnel plot and a non-significant Egger's test suggested no evidence for publication bias. Figures 2.2A and 2.2B present the summary effect sizes of the studies, and a funnel plot for detecting publication bias, respectively. A follow-up subgroup analysis (27 studies, 31 effect sizes) was conducted to investigate if the effect sizes significantly differ from each other between the three language domains. However, no significant cross-domain differences were observed regardless of outliers, $Q(2) = .59$, $p = .75$ (see Figure S2.1 in the **Supplementary Materials**).

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Figure 2.2

Overall Language Abilities in Alexithymia



Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each article, and pooled effect size inclusive of outliers across language

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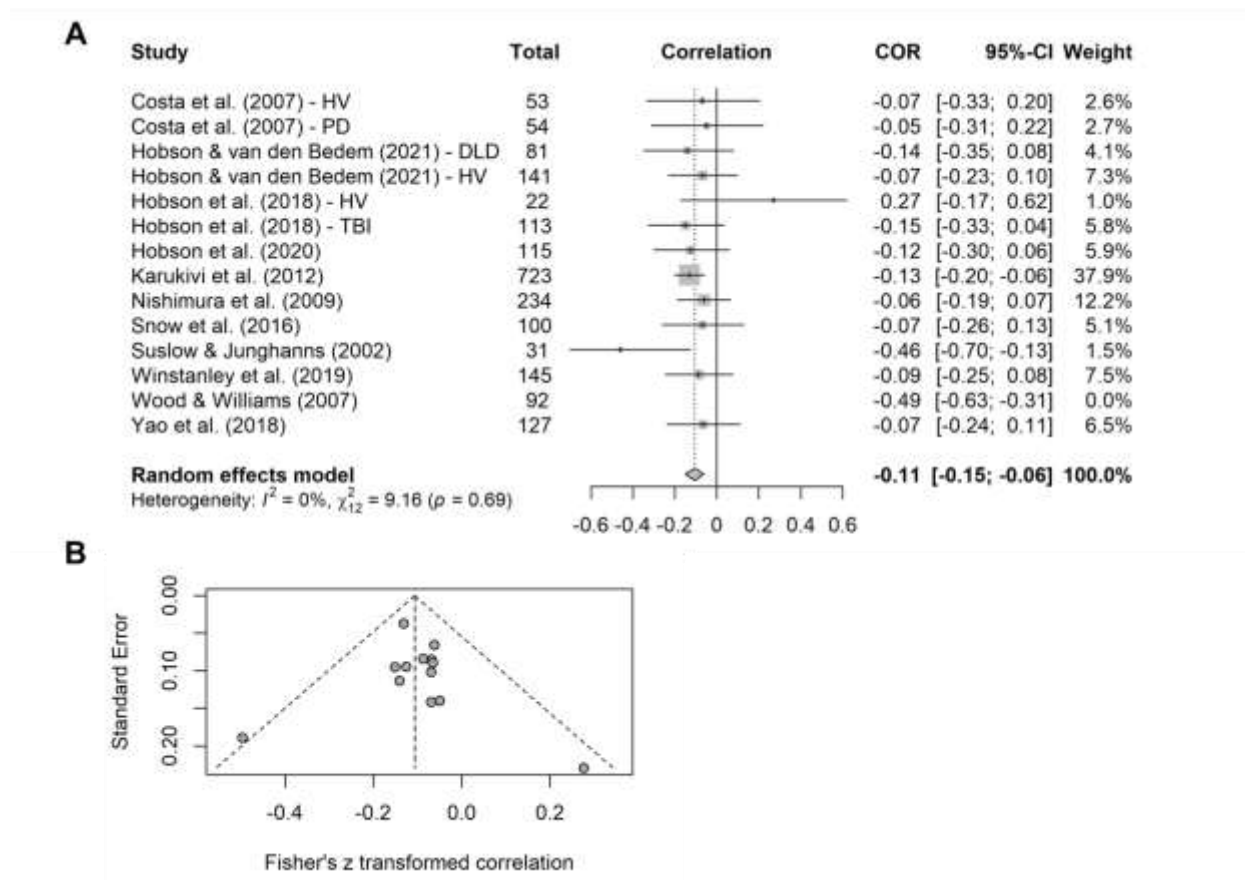
domains. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each language study. DLD = developmental language disorder; HV = healthy volunteers; PD = Parkinson's disease; PTSD = post-traumatic stress disorder; Schiz = patients with schizophrenia; TBI = patients with traumatic brain injury.

We present in the **Supplementary Materials** two other subgroup analyses exploring any group differences in effect sizes between clinical versus non-clinical participants (24 studies, 28 effect sizes), and developmental age groups (26 studies, 30 effect sizes). Both analyses revealed no significant differences.

Structural Language. The analysis of structural language consisted of 11 studies (14 effect sizes) and indicated a statistically significant Q statistic ($Q = 24.5, p = .03$) and an I^2 statistic of 46.9%. The analysis generated a pooled effect size of $-.13$ [CI: $-.19; -.06$], $p < .001$, with an R^2 value of $.02$. That is, 2% of the variance in structural language was associated with alexithymia. Influence analysis indicated that the pooled effect size was not substantially influenced by particular studies, with all effect sizes ranging from $-.11$ to $-.14$. Given the moderate degree of heterogeneity, Wood and Williams (2007), which reported an effect size that significantly exceeded the confidence interval of the pooled effect size, was then removed from the analysis. This analysis revealed a pooled effect size of $-.11$ [CI: $-.15; -.06$], $p < .001$ with an R^2 value of $.01$, meaning that only 1% of the variance in structural language abilities was associated with alexithymia. Low heterogeneity was observed among studies after the removal of outliers ($Q = 9.16, p = .69; I^2 = 0\%$). Inspection of the funnel plot and a non-significant Egger's test suggested no evidence of publication bias in the structural language studies. Figures 2.3A and 2.3B present the effect size summary and funnel plot.

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Figure 2.3

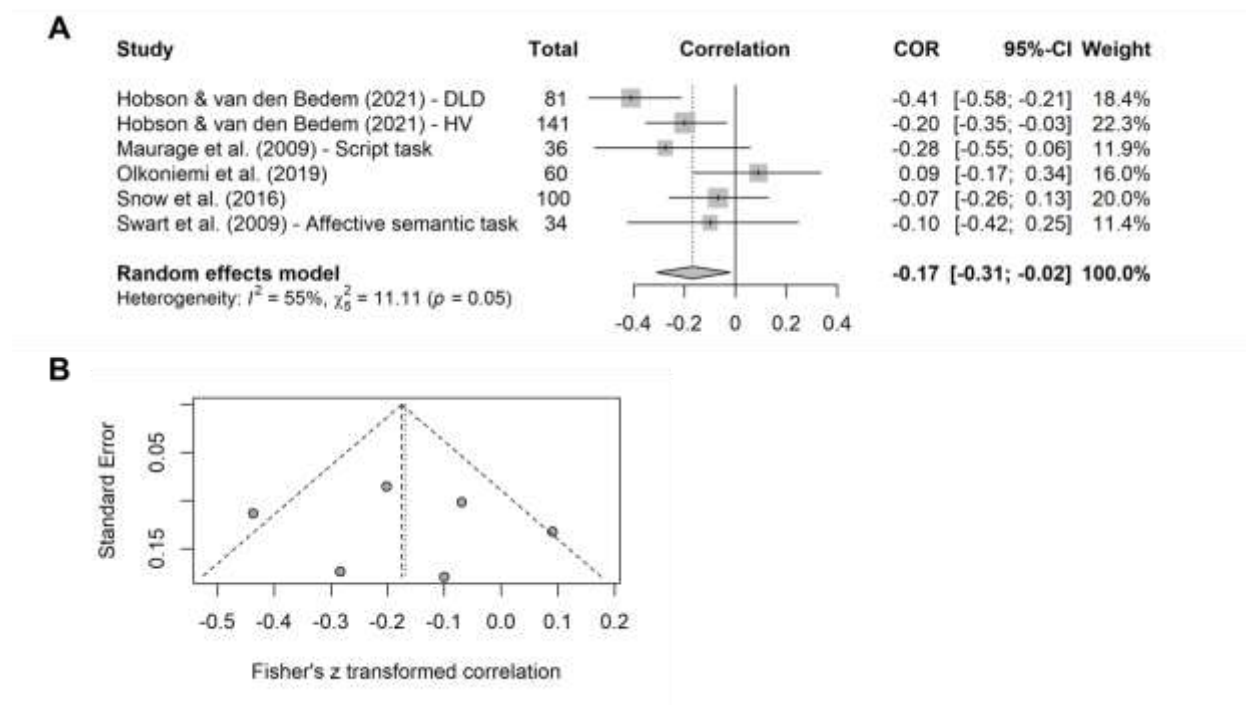
Structural Language Abilities in Alexithymia

Notes. (A) Forest plot showing the individual effect sizes, confidence intervals, and weighting of each structural language study, and effect size summary excluding outlying studies. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each structural language study. DLD = developmental language disorder; HV = healthy volunteers; PD = Parkinson's disease; TBI = patients with traumatic brain injury.

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Pragmatics. The analysis of pragmatics comprised 7 studies (8 effect sizes), with a statistically significant Q statistic ($Q = 26.89, p < .001$) and an I^2 value of 74%. A non-significant pooled effect size of $-.13$ [CI: $-.28; .02$], $p = .09$ was observed. No outlying studies were detected. However, influence analysis indicated that the summary effect sizes varied from $-.09$ to $-.19$, with 6 out of 8 effect sizes crossing the zero boundary slightly. Visual inspection of the Baujat plot also indicated that Jakobson and Pearson's (2021) and Lane and colleagues' (1999) studies had significant influence on the overall heterogeneity (< 2) and pooled results (< 10), respectively. A sensitive analysis was hence conducted by excluding these two studies (5 studies, 6 effect sizes) and revealed a pooled effect size of $-.17$ [CI: $-.31; -.02$], $p = .03, R^2 = .03$ (Figure 2.4A). This suggested that 3% of the variance in pragmatics was associated with alexithymia after removing the influential studies. Low to moderate heterogeneity was observed after the removal of these influential effect sizes ($Q = 11.11, p = .05; I^2 = 55%$). No evidence of publication bias was observed as depicted in the funnel plot (Figure 2.4B); yet low study availability precluded us from validating via the Egger's test.

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Figure 2.4*Pragmatics in Alexithymia*

Notes. (A) Forest plot showing the individual effect sizes, confidence intervals, and weighting of each pragmatics study, and effect size summary excluding influential studies.

(B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each pragmatics study. DLD = developmental language disorder; HV = healthy volunteers.

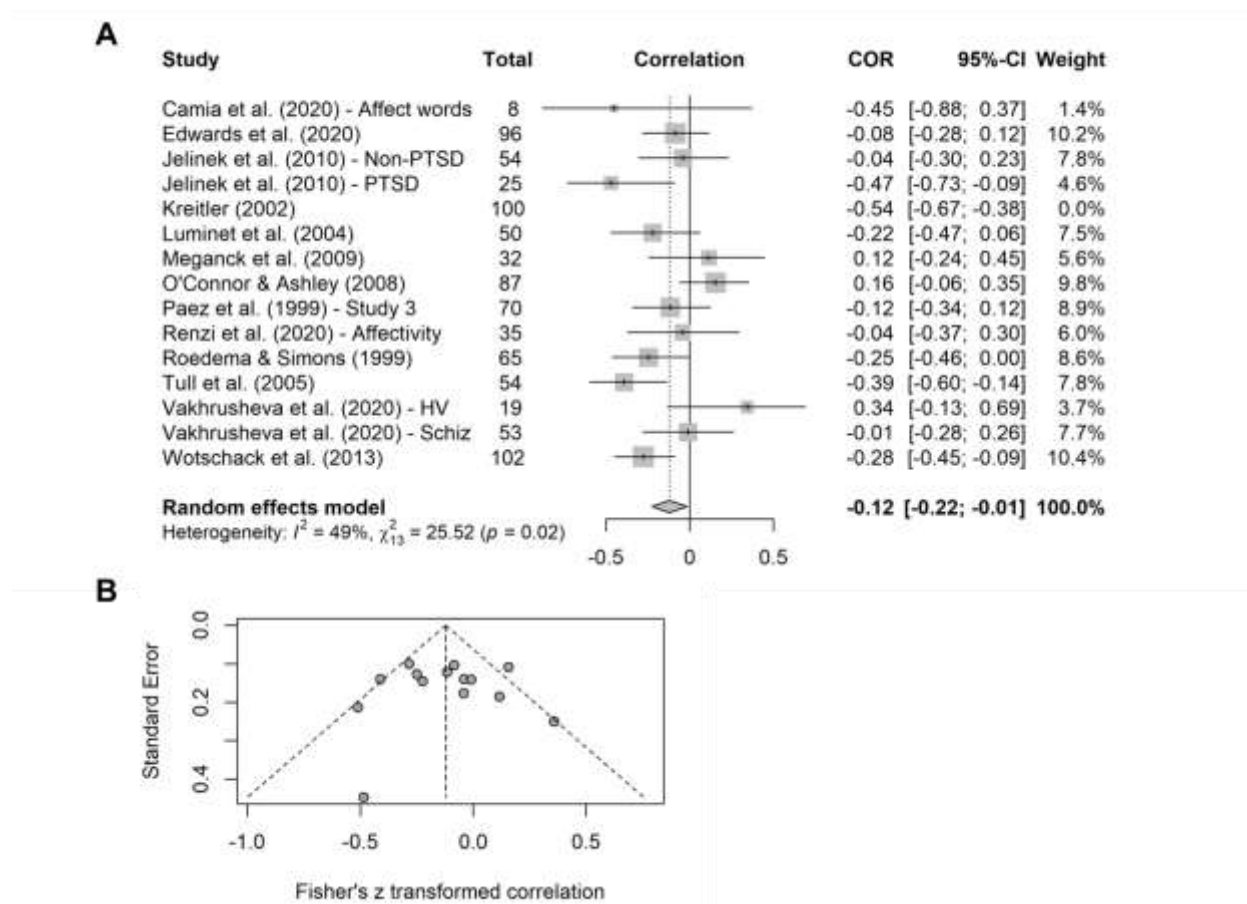
To supplement the main findings above, an exploratory analysis was performed in a subset of three studies ($N = 450$; Lane et al., 1996; Maurage et al., 2009; Swart et al., 2009) that specifically investigated participants' accuracy of understanding emotional states via language. This analysis yielded a pooled effect size of -0.26 [CI: -0.34 ; -0.17], $p < .001$. Low heterogeneity was observed ($Q = .91$, $p = .63$; $I^2 = 0\%$). Further, we analysed another subset of three studies (Jakobson & Pearson, 2021; Olkoniemi et al., 2019; Swart et al., 2009) that

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also reported processing efficiency variables (e.g., reaction times when making judgements of the pragmatics stimuli), and this analysis produced a pooled effect size of $-.20$ [CI: $-.34$; $-.04$], $p = .01$, $R^2 = 0.04$. Low heterogeneity was detected ($Q = .23$, $p = .89$; $I^2 = 0\%$). See Figures S2.2-2.3 for forest plots in the **Supplementary Materials**.

Natural Use of Emotional Language. Finally, the analysis of natural use of emotional language consisted of 13 studies (15 effect sizes). The resulting Q statistic ($Q = 45.38$, $p < .001$) and I^2 statistic (69.1%) indicated moderate to high heterogeneity among studies. The analysis generated a pooled effect size of $-.16$ [CI: $-.28$; $-.03$], $p = .01$. The summary effect sizes were not substantially influenced by individual studies as reflected in the leave-one-out-method analyses, all of which were significant ranging from $-.12$ to $-.19$. Subsequent removal of Kreitler's (2002) outlying study resulted in a pooled effect size of $-.12$ [CI: $-.22$; $-.01$], $p = .03$, with an R^2 value of $.01$, suggesting only 1% of variance was associated with alexithymia (Figure 2.5A). No publication bias was observed upon inspection of the funnel plot (Figure 2.5B) and via the non-significant Egger's test.

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Figure 2.5*Natural Use of Emotional Language in Alexithymia*

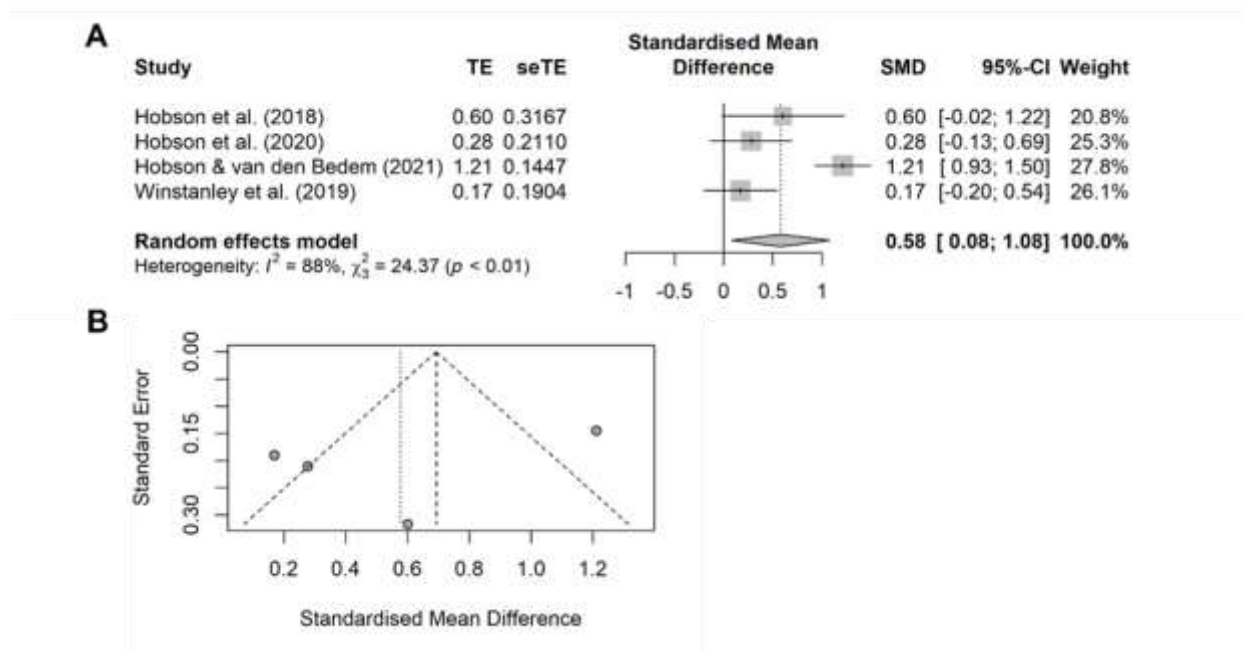
Notes. (A) Forest plot showing the individual effect sizes, confidence intervals, and weighting across individual studies that examined the association between the propensity to use emotional language and alexithymia. Kreitler (2002) was removed from the pooled effect size summary because of outlying data. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each study. HV = healthy volunteers; PTSD = post-traumatic stress disorder; Schiz = patients with schizophrenia.

Clinical studies point to an association between alexithymia and suboptimal emotional well-being (Albantakis et al., 2020; Grabe et al., 2004; Gross & Jazaieri, 2014), which often

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co-occurs with a cognitive bias towards negative emotions as observed in depression and post-traumatic stress disorder (Albantakis et al., 2020; Gross & Jazaieri, 2014; Preece et al., 2022). We therefore speculated that the modest effect observed in the *Natural Use of Emotional Language* analysis might be a product of differential effects of alexithymia on the use of positive and negative emotion language. Two separate follow-up analyses were conducted to synthesise the effect sizes in studies that investigated the propensity to use positive versus negative emotional language. Intriguingly, higher alexithymia was associated with *lower* propensity to use positive emotional language ($r = -.15$) but *higher* propensity to use negative emotional language ($r = .21$) (See Figures S2.4-2.5 in the **Supplementary Materials**).

Differences in Alexithymia between Language Impaired and Non-Impaired Groups. We examined a theoretically more relevant subset of four studies that directly compared the degree of alexithymia (as a dependent variable) between language impaired and non-impaired groups. These studies mostly focused on structural language deficits. Results indicated that participants with language impairments showed significantly higher levels of alexithymia than those without language impairments (standardised mean difference = .58 [CI: .08; 1.08], $p = .02$, Figure 2.6), a moderate effect size that was markedly larger than those found in the studies synthesised above. While no outliers were detected, moderate to high heterogeneity was present among individual studies ($Q = 24.37$, $p < .01$; $I^2 = 87.7\%$).

Figure 2.6*Differences in Alexithymia between Language Impaired and Non-Impaired Groups*

Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each study that analysed group differences in alexithymia between participants with and without language impairments, and pooled effect size summary. (B) Funnel plot visualizing the relationship between standard error and standardised mean difference for each study. HV = healthy volunteer; TBI = patients with traumatic brain injury; TAS = Toronto Alexithymia Scale.

Supplementary TAS Subscales Analyses. Presented in the **Supplementary Materials**, we analysed studies that also reported the association between structural language abilities and TAS subscales. Results suggested that only Externally Oriented Thinking and Difficulty Identifying Feelings were associated with structural language difficulties (Figures S2.6-2.8).

Meta-Analysis 2

Method

Search Strategy

A similar search strategy as described in *Meta-Analysis 1* was used to identify potential empirical studies of the association between alexithymia and emotional granularity. Specifically, based on the 2020 PRISMA guidelines (Page et al., 2021), a systematic search was conducted in PubMed, PsycINFO, Medline, and Web of Science using the search terms and their derivatives: (Alexithymia OR “emotional awareness”) AND “emotional granularity” in August 2021. A systematic literature search was conducted in Google Scholar and WorldCat to identify any additional studies or grey literature. Searches were restricted to empirical studies written in English, with no restrictions on publication date. With duplicates removed, 39 studies were identified via the systematic search of databases, and 8 studies were identified from the other sources. On an exploratory basis, we also compared our search results with alternative search terms and their derivatives in the same databases: (Alexithymia OR “emotional awareness”) AND (“categorisation” OR “categorization” OR “differentiation” OR “generalisation” OR “generalization”), and retrieved the same set of articles as discovered in the initial search, but with more irrelevant literature. The initial search results were then compared with a meta-analysis on emotion differentiation and individual differences in well-being (Erbas et al., 2019), and this provided one additional study (Erbas et al., 2014). Together, this yielded a collection of 28 studies for screening and full-text assessment for eligibility.

Study Selection

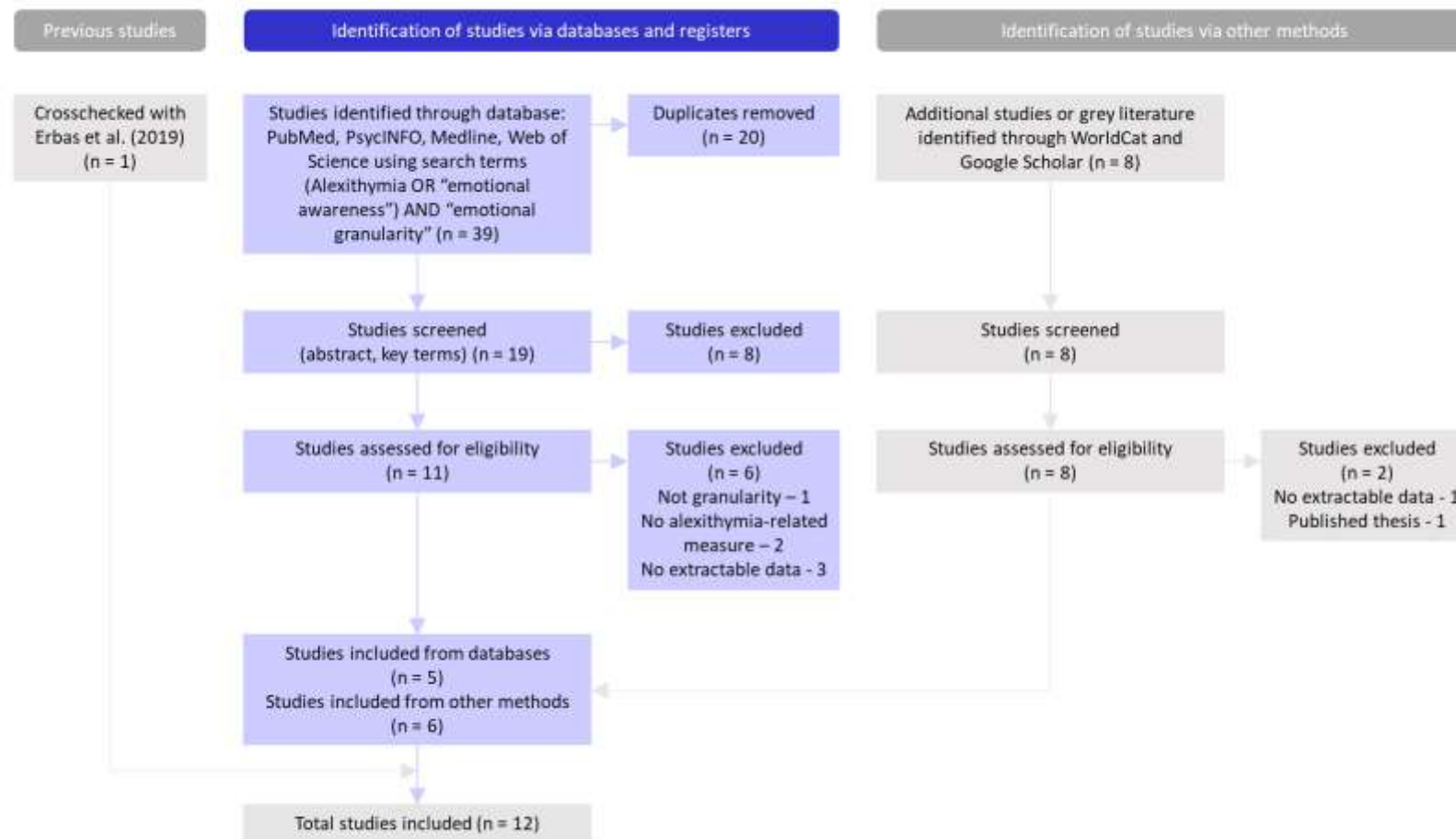
Screening of titles, abstracts, and keywords, and full-text assessment were conducted independently by KSL. Ambiguous studies were discussed with JM. Eight studies from the

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database search were removed following initial screening, leaving 19 studies for full-text assessment. Studies were considered not eligible for data extraction if there were no measures of emotional granularity, no measures of alexithymia/emotional self-awareness, or no extractable data, such as those reporting alexithymia as a sample characteristic without further analysing its association with emotional granularity. This full-text assessment led to a final collection of 12 studies for the meta-analysis. Eleven studies used the TAS-20 and/or its subscales to index individual differences in alexithymia, while one study (Boden et al., 2013) opted for the Trait Meta-Mood Scale (Clarity) to assess emotional self-awareness more broadly. This study was retained as we found no evidence that any of the pooled effect sizes as summarised below were substantially influenced by the measurement choice. The means and standard deviations of alexithymia/emotional self-awareness were reported in 11 studies, four of which also reported the score ranges. Two studies (Experiment 2 in Boden et al., 2013; Ottenstein & Lischetzke, 2020) assessed emotional granularity via conventional experience sampling techniques, in which participants received text prompts to report their daily emotional experiences in terms of valence and arousal. The remaining studies primarily used laboratory-based tasks which required participants to evaluate their feelings in response to a series of emotional stimuli (e.g., pictures, musical excerpts) pre-selected by the experimenters. Figure 2.7 details the literature search history. Data from one study (Edwards & Wupperman, 2017) were provided by the authors.

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Figure 2.7

Literature Search History of Emotional Granularity in Alexithymia

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Data Extraction

Table 2.2 provides a summary of the emotional granularity studies. Sample characteristics, as in *Meta-Analysis 1*, and the emotional granularity measures were extracted. In these studies, emotional granularity was primarily operationalised as the within-person intra-class correlation between different emotions of similar valence across different contexts (e.g., Boden et al., 2013; Erbas et al., 2014; Erbas et al., 2019; Ottenstein & Lischetzke, 2020). By reversing the signs of the correlations for ease of interpretation, lower within-person correlations indicated that the participants did not strongly distinguish between emotion terms when reporting their feelings across contexts, hence lower emotional granularity. Higher within-person correlations, in contrast, were seen as more divergent reporting of emotions, thus higher emotional specificity across situations. A novel emotion consistency task was used in one study (Huggins et al., 2021), in which participants were asked to indicate the image that evokes the stronger emotion within a pair. This produced rank scores for the images, and the differences in rank scores between the chosen and unchosen images were summed to produce emotion consistency scores for each participant. Higher consistency scores indicated higher emotional specificity.

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Table 2.2*Overview of Emotional Granularity Studies in Alexithymia (k = 12)*

Study	N	Mean age (years)	% Female	Indication	Measure	Method	Task	Alexithymia mean (SD)	Alexithymia range
Aaron et al. 2018	108	19.3	67.6	HV (undergrads)	TAS-20	Lab	Emotion induction task requiring participants to identify which of the 16 emotions they experienced the most and rated the intensity of their emotions after watching some emotion inducing clips.	Total = 45.60 (8.53)	30-73
Boden et al. 2013 – Experiment 1	201	19.4	57.9	HV (undergrads)	TMMS (Clarity)	Lab	Scenario rating task requiring participants to read descriptions of emotion-eliciting situations, and rate how they would feel.	Total = 3.31 (.56)	1.55-5
Boden et al. 2013 – Experiment 2	99	19.1	60.6			Sampling	Classic experience sampling exercise in which participants were prompted to record their daily affective experiences (valence, arousal) for 15 days.	Total = 3.34 (.70)	1.18-4.80

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Edwards & Wupperman (2017)	96	20 (median)	76	HV (undergrads)	TAS-20	Lab	Emotion differentiation written exercise requiring participants to engage in autobiographical recall tasks (negative, neutral or positive experiences) and to reflect upon through writing a past experience that fitted the description. Participants then reported how they felt during writing with the Positive and Negative Affect Schedule.	Total = 44.35 (12.05)	Not reported
Erbas et al. (2014) – Experiment 2	131	18.5	84.7	HV (undergrads)	TAS-20 subscales	Lab	Negative emotion differentiation task requiring participants to write down pre-defined descriptions of people and then rate them on emotion terms.	DDF = 2.02 (.94) DIF = 1.32 (.79) EOT = 2.43 (.58)	Not reported
Erbas et al. (2014) – Experiment 3	170	18.4	81.2			Lab	Negative emotion differentiation task requiring participants to rate their emotional responses to a set of standardised emotional stimuli on some emotion terms.	DDF = 2.50 (1.40) DIF = 1.91 (1.24) EOT = 2.18 (.62)	Not reported

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Erbas et al. (2019)*	343	17-19	33.3-81.2	HV (undergrads)	TAS-20 (DIF)	Lab	Negative emotion differentiation tasks asking participants to rate their feelings about some emotional pictures on a list of emotion labels and rating scales (valence, arousal).	Study 1: 1.91 (1.24) Study 2: 1.87 (1.26) Study 6: .94 (.66)	Not reported
Huggins et al. (2021)	96	21	81.3	HV	TAS-20	Lab	Emotional consistency task requiring participants to choose the image that evokes the stronger emotional response within a pair.	Not reported	Not reported
Koven (2014)	96	18.9	59.4	HV (undergrads)	TAS-20	Lab	Affective judgement tasks requiring participants to evaluate the valence and then intensity of the word (appetitive, neutral, or aversive words from the Affective Norms for English Words) and standardised picture stimuli (representative of appetitive, neutral, or aversive images) on a Likert scale.	Total = 47.1 (10.1) HA (≥ 60) = 64.1 (6.2) LA = 33.7 (2.5)	Not reported

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Larwood et al. (2021) – Task 2	162	21.5	43.8	HV	TAS-20	Lab	Affective judgement task requiring participants to rate the emotion of musical excerpts on a valence scale and an arousal scale.	Total = 54.31 (11.91)	26-81
Nandrino et al. (2012) – Task 2	70	21.7 (AN) 19.9 (DEP) 18.8 (HA) 20.5 (HV)	Not reported	AN, DEP, HA, HV	TAS-20	Lab	Subjective evaluation of emotional reactions (valence, arousal) to the pictures.	AN = 59.4 (3.5) DEP = 60.9 (3.5) HA (> 56) = 59.2 (9.7) HV (< 44) = 45.5 (5.4)	Not reported
Ottenstein & Lischetzke (2020) – Study 1	111	35	73	HV	TAS-20 (DDF, DIF)	Sampling	Experience sampling requiring participants to describe their affective states during the reported events with an open-response format, instead of a provided list of emotion terms.	DDF = 2.01 (.56) DIF = 1.88 (.55)	Not reported
Ottenstein & Lischetzke (2020) – Study 2	190	40.4	74			Sampling	Experience sampling requiring participants to describe their affective states during the reported events with an open-	DDF = 1.85 (.52) DIF = 1.72 (.45)	Not reported

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							response format first, and then a closed-ended response format.		
Ready et al. (2019)	83	20.2 (undergrads) 71.3 (older adults)	Not reported	HV (undergrads, older adults)	TAS-20	Lab	Emotion differentiation task requiring participants to rate the difference and similarity (valence, arousal) of some affect terms from the Kessler and Staudinger scales.	Undergrads = 39.48 (8.99) Older adults = 39.04 (9.63)	Not reported
Zhang et al. (2021)	318	22.8	50.6	HV (undergrads)	TAS-20	Lab	Positive emotional granularity task requiring participants to view some standardised movie clips of positive themes and rate how intensely they experienced each emotion.	Total = 50.62 (9.54)	Not reported

Notes. * Erbas et al. (2019) is a meta-analysis of six datasets examining the association between emotion differentiation and well-being, in which Erbas et al. (2014) was included. Effect sizes reported in Erbas et al. (2014) were used in the meta-analyses reported here. AN = Anorexia nervosa; DDF = Difficulty Describing Feelings subscale; DEP = Depression; DIF = Difficulty Identifying Feelings subscale; EOT = Externally Oriented Thinking subscale; HA/LA = High/Low alexithymia; HV = Healthy volunteers; TAS = Toronto Alexithymia Scale; TMMS = Trait Meta-Mood Scale.

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Statistical Analysis

The same statistical procedures were conducted as described previously in *Meta-Analysis 1*. Random-effects models (Field, 2001; Hunter & Schmidt, 2000) and the conventional restricted maximum likelihood estimator were used (Viechtbauer, 2005). Similarly, correlation coefficients of the association between emotional granularity and emotion awareness/alexithymia were extracted, and pooled as a summary effect size of the individual studies. For studies that reported separate effect sizes for positive and negative emotional granularity, the averaged effect size was calculated as a proxy of the effect size of global emotional granularity (Borenstein et al., 2009). A similar approach was used for Larwood and colleagues (2021) who reported separate effect sizes for valence and arousal judgements for musical stimuli, and the averaged effect size was calculated. Two studies (Erbas et al., 2014; Ottenstein & Lischetzke, 2020) reported effect sizes using the TAS-20 subscales, and the averaged effect sizes across subscales were used in the meta-analyses. Erbas and colleagues (2019) was removed from the following analyses as their effect sizes were aggregated across six datasets. Instead, data from one of the datasets was used (Erbas et al., 2014).

An overall analysis of global emotional granularity was first conducted, which summarised the extent to which individual differences in perceiving the similarities/differences between emotion concepts is associated with alexithymia regardless of emotional valence. Studies that only reported effect sizes for either positive or negative emotional granularity were removed from this analysis. Two separate analyses aggregating studies that specifically investigated positive and negative emotional granularity were then performed in order to clarify whether alexithymia is differentially associated with emotional granularity for positive and negative emotions. A subgroup analysis comparing clinical and

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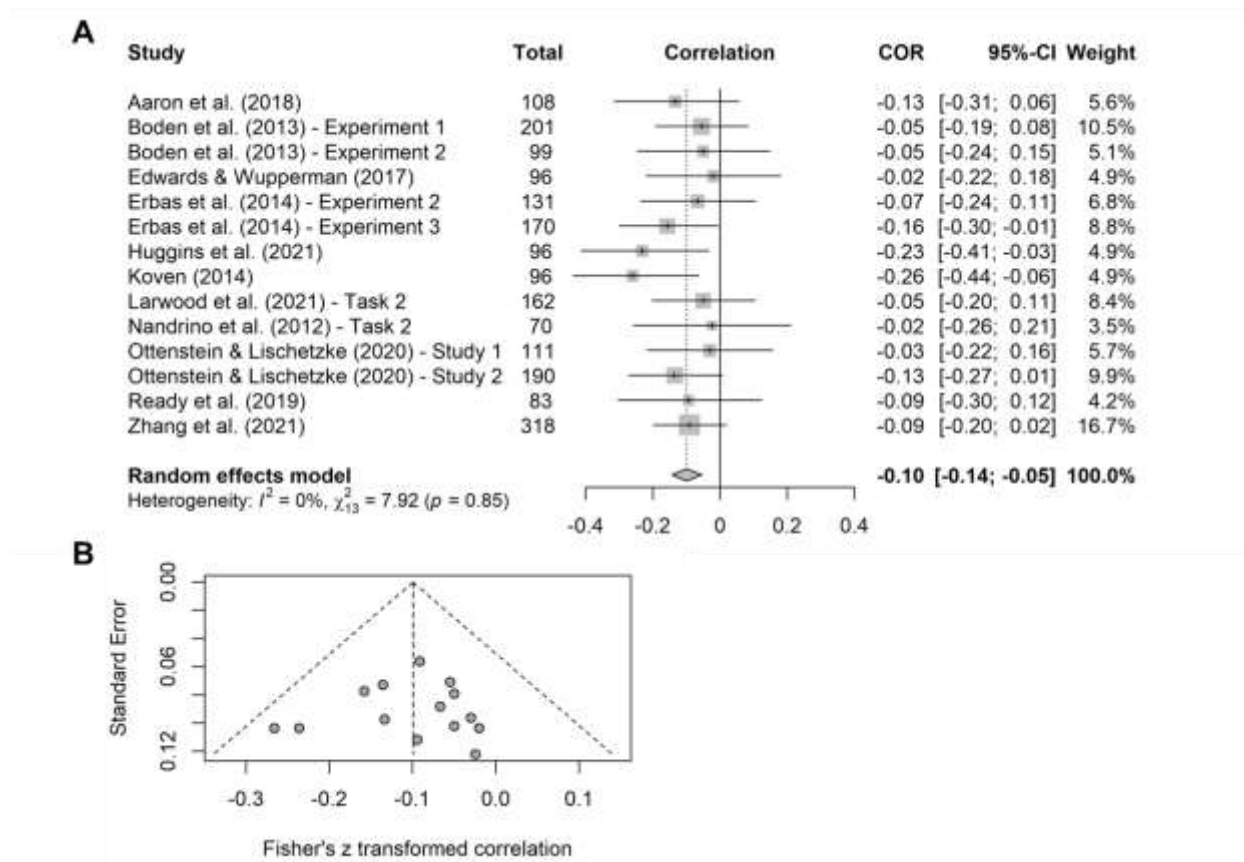
non-clinical participants was not performed, given that 8 out of 11 studies recruited healthy student (undergraduate) samples.

Results

Global Emotional Granularity

The analysis of global emotional granularity comprised 11 studies (14 effect sizes), which indicated a pooled effect size of $-.10$ [CI: $-.14$; $-.05$], $p < .001$, with low heterogeneity observed among individual studies ($Q = 7.92$, $p = .85$; $I^2 = 0\%$). No outliers were detected. The synthesised effect size therefore suggested that only 1% of the variance in emotional granularity was explained by alexithymia. Influence analysis showed that the pooled effect sizes were not substantially driven by any of the individual studies, all of which were statistically significant and ranged from $-.09$ to $-.10$. No publication bias was observed as indicated in the funnel plot and non-significant Egger's test. Figures 2.8A and 2.8B present the individual effect sizes and funnel plot, respectively.

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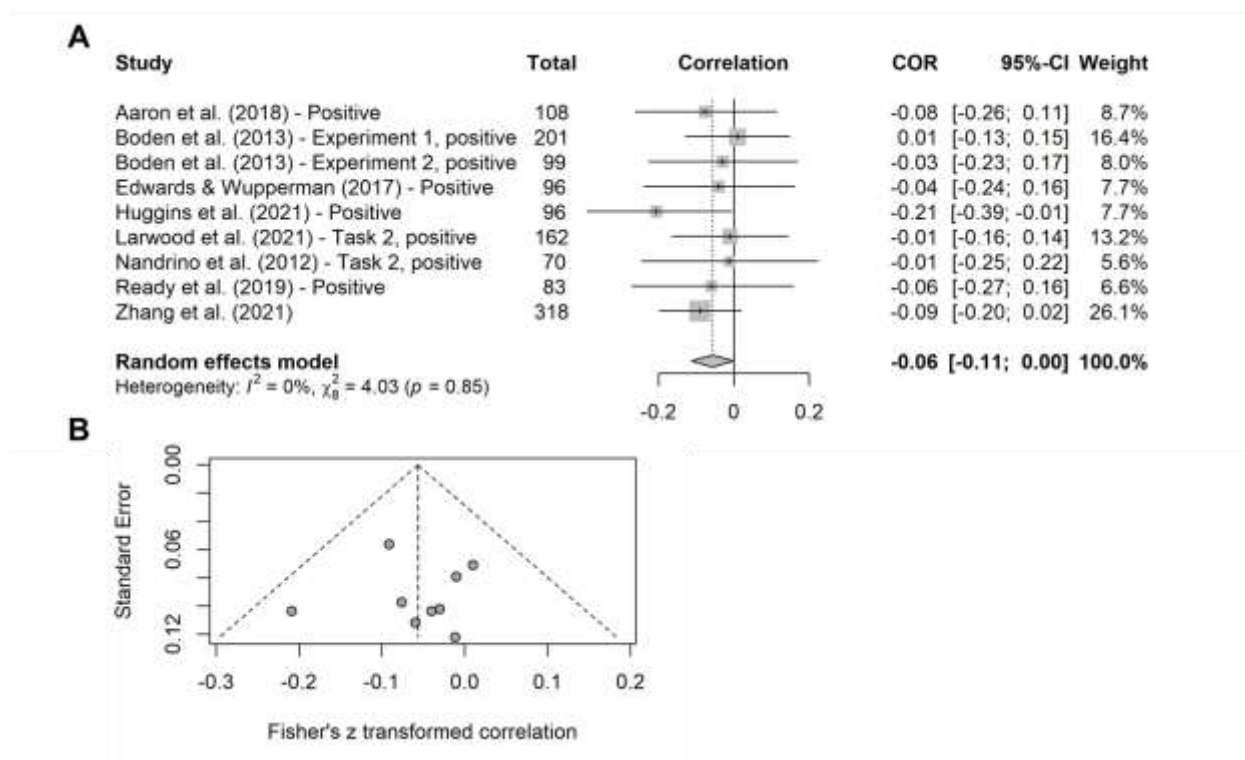
Figure 2.8*Global Emotional Granularity in Alexithymia*

Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each study, and pooled effect size across emotional valence. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each global emotional granularity study.

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Positive Emotional Granularity

The analysis of positive emotional granularity consisted of 8 studies (9 effect sizes), with a borderline significant summary effect size of $-.06$ [CI: $-.11$; $.00$], $p = .05$. The individual studies were relatively homogeneous ($Q = 4.03$, $p = .85$; $I^2 = 0\%$). No outliers were observed. Influence analysis revealed that 8 out of 9 pooled effect sizes crossed the zero boundary, ranging from $-.04$ to $-.07$, which likely suggested a lack of association between positive emotional granularity and alexithymia. Figures 2.9A and 2.9B present the study effect sizes and funnel plot, respectively.

Figure 2.9*Positive Emotional Granularity in Alexithymia*

Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each study, and effect size summary. (B) Funnel plot visualizing the relationship

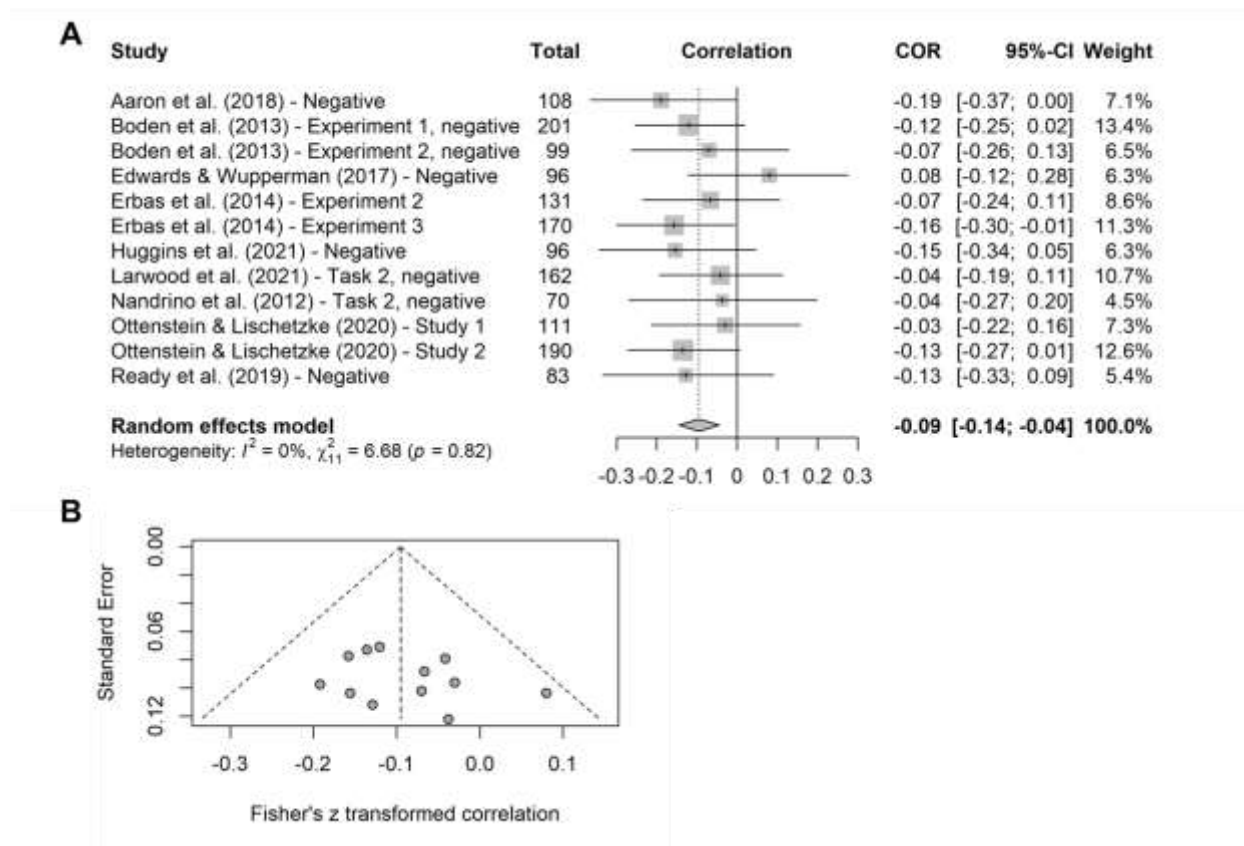
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between standard error and Fisher's z transformed correlation for each positive emotional granularity study.

Negative Emotional Granularity

The analysis of negative emotional granularity comprised 9 studies (12 effect sizes), which produced a pooled effect size of $-.09$ [CI: $-.15$; $-.04$], $p < .001$. Low heterogeneity was observed ($Q = 6.68$, $p = .82$; $I^2 = 0\%$). No outliers were detected. Influence analysis revealed that the pooled summary effect sizes ranged consistently between $-.09$ to $-.11$, all of which were statistically significant. Similar to the case of global emotional granularity, this suggested that approximately 1% of the variance in negative emotional granularity was associated with alexithymia; yet low study availability precluded us from performing the Egger's test for detecting any publication bias. Figures 2.10A and 2.10B present the effect size summary and funnel plot, respectively.

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Figure 2.10*Negative Emotional Granularity in Alexithymia*

Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each study, and effect size summary. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each negative emotional granularity study.

Supplementary Analysis

Three supplementary analyses were performed separately to explore the association between negative emotional granularity and the three TAS subscales. Results showed that only Difficulty Identifying Feelings and Difficulty Describing Feelings were associated with

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lower negative emotional granularity (see Figures S2.9-2.11 in the **Supplementary Materials**).

Discussion

The current work critically evaluated the empirical literature on language abilities in alexithymia. Our systematic review and meta-analysis provide initial support for the language hypothesis of alexithymia (Hobson et al., 2019), that alexithymia is associated with cross-domain language difficulties. These alexithymia-language associations are modest, consistent with the idea that alexithymia may be a product of language difficulties in a subgroup of individuals, rather than a feature of all alexithymic individuals. Further, follow-up analyses suggested that alexithymia is associated with low emotional granularity, which is in line with constructivist theories which would suggest that the alexithymia-language link is a consequence of disrupted conceptualisation of ambiguous affective states (e.g., Lindquist et al., 2015a, 2015b). Nonetheless, considerable heterogeneity in sample characteristics, clinical presentations, and methodological approaches likely contributes to the sometimes mixed, and modest, findings.

We first discuss these findings with respect to the original language hypothesis of alexithymia (Hobson et al., 2019). We then evaluate the applicability of the constructionist theory to the language-alexithymia link, and put forth further theoretical considerations for refining the multi-route model of alexithymia. Finally, we discuss future directions for research on the aetiology of alexithymia.

Refining The Language Hypothesis of Alexithymia

The language hypothesis of alexithymia proposes that, in some individuals, alexithymia may develop as a result of impaired language function. In other individuals, alexithymia may be a product of non-linguistic variables, such as atypical interoception

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(Hobson et al., 2019). Thus, according to the language hypothesis, the majority of individuals with language impairments will likely exhibit higher degrees of alexithymia than those with typical language function, but not all individuals with alexithymia would show significant language impairments. This is reflected in our results: when aggregating all studies that analysed individual differences in alexithymia and language abilities dimensionally, the effect sizes of these associations were modest, whereas in a subset of studies comparing language impaired (e.g., DLD) and non-impaired groups, a larger effect was found where participants with language impairments showed markedly higher degrees of alexithymia than non-impaired participants.

This pattern of results suggests that the link between language function and alexithymia/emotional awareness is likely unidirectional – poor language leads to alexithymia but alexithymia does not lead to poor language. However, this may not apply if levels of alexithymia pass a critical threshold where they severely impact the opportunity for socialisation. If severe alexithymia results in individuals becoming socially isolated, then opportunities for typical language development in childhood, or the development of advanced understanding of pragmatics in adulthood, will be reduced. Indeed, recent studies utilising ecological momentary assessments have found that alexithymia was robustly associated with fewer (Gerber et al., 2019) and poorer quality social interactions (Kafetsios & Hess, 2019). Developmentally, studies have suggested that social interactions provide children with the opportunities to attend to diverse social cues, which support the uptake of linguistic input and language development (Rowe & Weisleder, 2020). Consistent with the existence of a causal link between alexithymia and impaired language, as well as between impaired language and alexithymia, are results from a large longitudinal study of 114,000 mother-child dyads. This study reported bi-directional relationships between language difficulties and child internalising symptoms from 18 months to 8 years, including anxious and depressive

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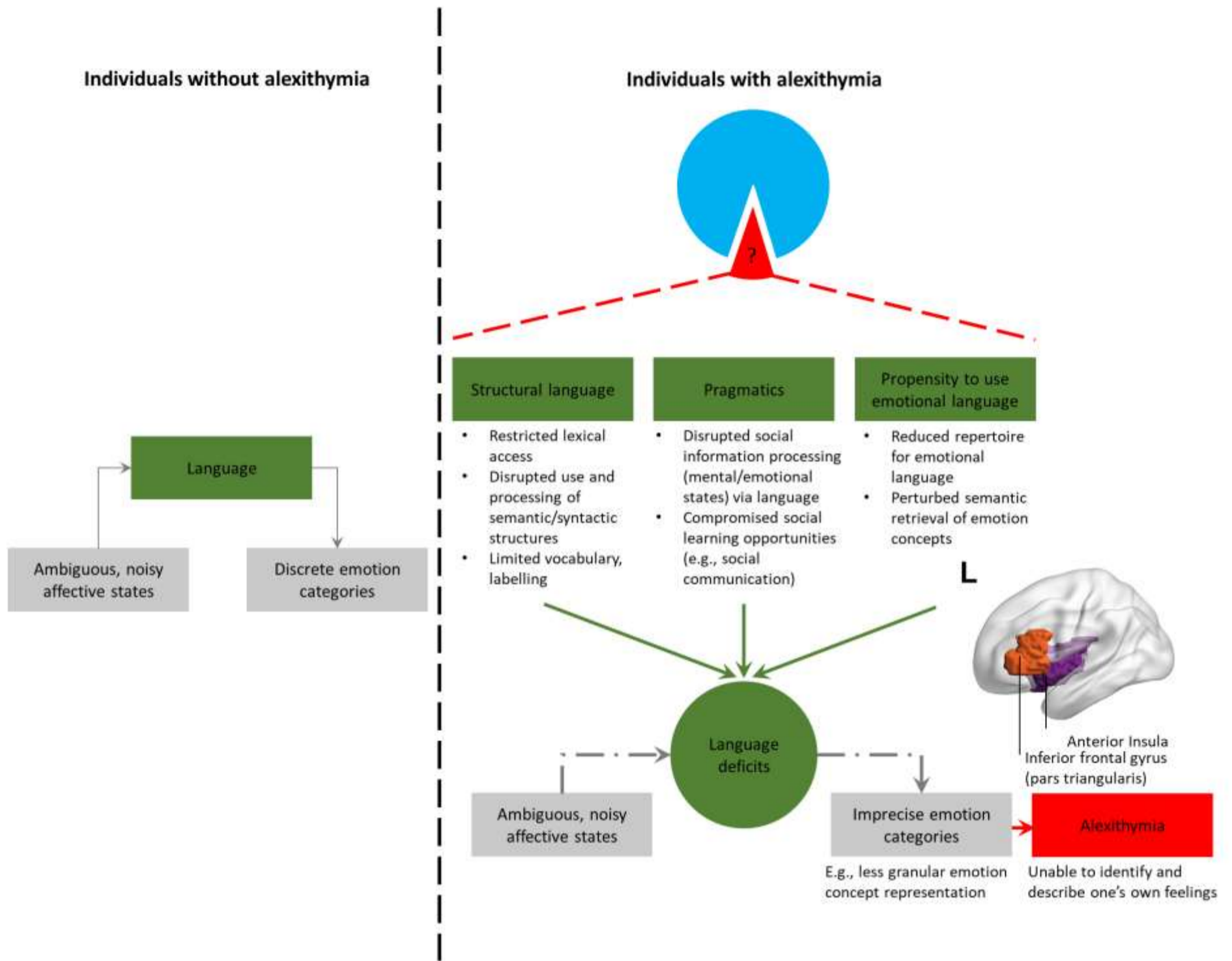
symptoms (Helland et al., 2018), which commonly co-occur with alexithymia. It is clear that longitudinal data measuring alexithymia is urgently needed to clarify the directionality of the language-alexithymia relationship (see Chapter 3).

Alexithymia and Cross-Domain Language Deficits

The empirical literature suggested alexithymia is linked to impairment in several language domains, including structural language, pragmatics, and propensity to use emotional language. The association between alexithymia and multiple language domains may reflect (i) the fact that language domains interact (or that tests of language function are not domain specific), (ii) that alexithymia is associated with a core language component common to a number of different language domains, or (iii) that language domains are independent, but each is necessary for typical levels of emotional self-awareness (i.e., low levels of alexithymia). The potential for different language domains to play differential roles in emotional self-awareness is an exciting avenue for future research; here we briefly outline what these roles may be (Figure 2.11).

Figure 2.11

The Language Hypothesis of Alexithymia



Notes. Left: The theory of constructed emotion suggests that language facilitates the conceptualization of ambiguous and noisy affective states to discrete emotion categories (e.g., unpleasant sensations → fear, anger). Right: Informed by the constructionist theory, the language hypothesis of alexithymia posits that language impairment disrupts the development of discrete emotion concepts from ambiguous affective states, leaving individuals unable to identify and describe their own feelings. A previous study (Hobson et al., 2018) reported that individual differences in alexithymia and language (naming) task performance were most robustly associated with the extent of brain damage in the pars triangularis subregion of inferior frontal gyrus (IFG) and anterior insula (AI), which are regions consistently implicated in emotion word and semantic processing (Brooks et al., 2016; Oosterwijk et al., 2012) and constituent parts of a shared neural network supporting emotional self-awareness, conceptualization, and interoception (Oosterwijk et al., 2012).

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Structural language is key to the development of concepts generally, including emotion concepts. This is demonstrated in a wealth of studies that demonstrate language-mediated acquisition of abstract concepts and vocabulary, including emotion labels, by manipulating semantic and syntactic structures that were more/less useful in signalling the possible meaning and part of speech of novel words (e.g., Marchman et al., 2004; Naigles & Hoff-Ginsberg, 1995; Shablack et al., 2020; see a computational account by Abend et al., 2017). Increased verbal repertoire has also been shown to predict multidimensional representation of emotion concepts from childhood (Nook et al., 2017). While it remains unknown if a domain-general concept acquisition deficit is present in alexithymia (Hobson et al., 2018), individuals with structural language impairments may lack the necessary linguistic tools for acquiring emotion concepts, exacerbating the risk of developing alexithymia. These impairments include difficulties extracting and learning linguistic structures that signal emotion-related words and information, while limited access to these linguistic structures also reduces one's competence to construct coherent language for communicating one's own feelings.

Social communication is a key milieu for developing one's ability to make mental and emotional state inferences via language (Dunn et al., 1991; Harris et al., 2005; Matthews et al., 2018). For instance, quality parent-child discourse on desires and emotions predicts better emotion understanding in children (Tompkins et al., 2018). Results of studies on the link between alexithymia and pragmatic difficulties were mixed, although all pointed to impairments in alexithymia. As noted above, it is difficult given the current evidence base to determine if alexithymia is related to difficulties understanding language pragmatics specifically, or whether problems with pragmatics reflect a larger problem with theory of mind. A recent review of the theory of mind literature in alexithymia revealed that alexithymia was not generally associated with theory of mind difficulties, but the strength of

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association depended on the behavioural dimension of interest (efficiency vs. accuracy vs. propensity) and stimulus type (emotional vs. non-emotional) (Pisani et al., 2021). These data suggest that a wider range of studies, utilising a range of stimuli and requiring a range of response strategies, is necessary in order to provide further clarity on the link between alexithymia, language pragmatics, and theory of mind. One suggestion to dissociate a general effect of alexithymia on theory of mind versus language specifically, is to test other speech or linguistic elements that specifically aid emotional state inference in language, such as prosody and contextual information (e.g., Shablack et al., 2020; also see Ponari et al., 2020 for emotional valence).

Alexithymia is associated with a decreased propensity to use emotional language. This decreased propensity does not necessarily reflect a reduced motivation to use emotional language in individuals with alexithymia, because alexithymia was associated with an *increased* propensity to use negative emotional language. Another possibility is that the bias towards the use of negative emotional language (and away from positive emotional language) may reflect negatively biased semantic retrieval of emotion concepts in alexithymia. This possibility, though only speculation at present, is in line with the previous finding (Hobson et al., 2018) that the extent of penetrating damage in the inferior frontal gyrus – a functional hub implicated in semantic retrieval (Oosterwijk et al., 2012) and emotion word processing (Brooks et al., 2016) – was positively associated with individual differences in alexithymia. Future studies may investigate if this potential semantic retrieval pathway is also implicated in individuals with primary alexithymia. The methodologies used in most of the existing studies on the use of emotional language in alexithymia such as free writing paradigms and interviews often lack the necessary design features to isolate the effects of confounding psychological processes and co-occurring affective symptoms, and so the semantic retrieval hypothesis remains an open question for future research. In addition, inviting participants to

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discuss a past emotional event requires some autobiographical memory capacity and may trigger the bias to recount negative events, especially in those with depressive and PTSD symptoms, making the unique effects of alexithymia difficult to determine (Albantakis et al., 2020; Grabe et al., 2004; Preece et al., 2022).

Despite the empirical issues concerning the study of pragmatics and emotional language in alexithymia detailed above, we consider that it is still premature to conclude that structural language measures are of most use in testing the language hypothesis of alexithymia. This is due to three reasons. First, the three language domains are not functionally independent. For instance, structural language deficits such as restricted lexical access not only disrupt sentence understanding and formation (which impairs narrative emotional language), but also compromise the social competence to engage in and maintain conversations with typically-developing peers, as observed in youths with DLD (Hobson & van den Bedem, 2021). Second, individuals with language disorders and related learning difficulties often show cross-domain language impairments, such that having “pure” deficits in a single language domain may be clinically rare (Moll et al., 2019; Snowling et al., 2019). Third, clinical structural language assessments often have measurement units that are diagnostic (e.g., Token test used in Hobson et al., 2018), whilst lab-based tasks are designed to test specific hypotheses. Task design differences may contribute to different distributions of language variances, thereby affecting the correlation strength with self-ratings of alexithymia, which are subject to other measurement variances from survey artefacts (e.g., question wording and interval scaling) and reporter bias. Nevertheless, ongoing research on cross-domain language deficits and alexithymia has theoretical and clinical implications as it specifies the different aspects of language that contribute to alexithymia. Structural language difficulties may suggest the need for speech and language therapy that improves comprehension and use of lexical devices, whilst pragmatic difficulties may underscore the

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importance of peer support programs that foster social communication skills. The relationship between these language domains and alexithymia will be furthered examined in Chapter 3.

Incorporating A Constructionist Perspective

The constructionist theories of emotion suggest a language-mediated mechanism that enacts the conceptualisation of ambiguous and noisy affective sensations into discrete emotion categories, a mechanism scaffolding emotion concept development (Hoemann et al., 2020; Lindquist et al., 2015a, 2015b; Lindquist, 2017). Under such models, language deficits would be expected to lead to alexithymia, and specifically to the reduced granularity of emotion concepts observed in alexithymia. This collection of granularity studies mostly sampled healthy student participants (see Nook et al., 2018 for potential age differences) and were relatively homogeneous in their methods (see a meta-analysis by Erbas et al., 2019). Therefore, while the current findings were consistent with this constructionist idea that alexithymia is associated with less granular representation of emotion concepts, it is possible that the current estimates would vary in different clinical groups and emotion sampling methods (e.g., ecological momentary assessments vs. stimulus induction techniques), warranting future research.

Limitations and Other Considerations

Several limitations should be noted. First, the present study focused on the association between alexithymia and language abilities; only a small subset of studies analysed differences in alexithymia between language impaired and non-impaired groups, which would provide a more direct test of the idea that clinically significant language impairments exacerbate the risk of developing alexithymia.

Second, low study availability ($k < 10$) precluded the assessment of publication bias for pragmatics and the subscale supplementary analyses, and likely rendered some of the

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subgroup analyses underpowered. Therefore, although our subgroup analysis suggested no significant differences in effect sizes between the language domains, more studies are required to make any further interpretation of the relative significance between these language deficits in alexithymia. We also acknowledge that this meta-analysis was not pre-registered, however we followed the PRISMA guidelines closely to ensure the robustness of our methods.

Third, considerable heterogeneity was observed in the clinical presentation of study participants, including participants with mood-related disorders (e.g., depression and PTSD), neuropsychological conditions (e.g., brain injury and chronic stroke), eating disorders (e.g., anorexia nervosa), and complex psychiatric conditions (e.g., schizophrenia). This likely leads to heterogeneity of results across studies, but testing the language hypothesis in different clinical groups is crucial because it is in line with the transdiagnostic nature of alexithymia, and that alexithymia and language deficits arising after otherwise typical development, such as in response to psychopathology, are likely to involve different etiological pathways than those occur in populations with a developmental history of language problems and/or alexithymia (Hobson et al., 2019). In addition, study participants vary in their developmental stages. Given that core language development happens in early life stages (as early as the first year of life, see Friedmann & Rusou, 2015) and language processing efficiency may decrease because of ageing (e.g., lexical retrieval in Connor et al., 2004), it is likely that the language-alexithymia association would be moderated by these age-related differences if investigated systematically. Future studies may also consider measuring alexithymia among a subset of individuals at the opposite end of the language continuum, such as high-achieving novelists and language experts (see Chapter 4). This would allow it to be determined if emotional self-awareness is associated with language competence across the whole range of competence.

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Fourth, the review revealed that the vast majority of studies did not provide sufficient descriptive information as to the range of alexithymic traits in their samples. To allow for a reliable and generalisable understanding of the association between language abilities and alexithymia, one would need a wide range of alexithymic traits. In addition, ideally recruitment strategies would be such that alexithymia can be dissociated from any co-occurring clinical condition (e.g., a study might include depressed individuals with and without alexithymia, and non-depressed individuals with and without alexithymia).

Fifth, the TAS-20 (Parker et al., 2003) and BVAQ (Vorst & Bermond, 2011) remain the most widely adopted measures of alexithymia, but norming and measurement invariance in different sociocultural and developmental populations, and longitudinal stability are some outstanding measurement issues to be addressed. Notably, informant discrepancy in alexithymia ratings has been observed in small developmental samples (e.g., parent vs. child self-ratings in an ASD sample: Griffin et al., 2016; and in a DLD sample: Hobson & van den Bedem, 2021). Furthermore, it is crucial to test the specificity of the measurement of alexithymia in the presence of other co-occurring socioemotional symptoms (e.g., autistic traits: Cuve et al., 2021; depressive symptoms: Hintikka et al., 2001), and investigate if existing alexithymia assessments capture comparable information between general and clinical populations (for example using item response theory; Williams & Gotham, 2021; Guillén et al., 2014). The latter is especially relevant to estimating the prevalence of alexithymia in language impaired populations, as linguistic difficulties can influence the comprehension of assessment items, hence compromising the reliability and validity of symptom reporting (Nishimura et al., 2009; Snow et al., 2016).

Finally, the current meta-analyses included studies that utilised various methodologies to measure language abilities, leading to moderate to high heterogeneity in the results.

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However, over-reliance on a single language task/assessment can also lead to measurement bias, and most heterogeneity issues were remedied with the removal of outlying studies.

Conclusion

The current review found initial evidence that alexithymia is associated with deficits in multiple language domains, and less granular representation of emotion concepts. Findings support the language hypothesis of alexithymia, and are supportive of the constructionist perspective on language-mediated emotion concept acquisition. Considerable heterogeneity in clinical presentations and study methods calls attention to alexithymia and language function measurement issues, and the need for a theoretical framework outlining the relevant language constructs.

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* Studies included in meta-analysis 1.

** Studies included in meta-analysis 2.

Chapter 2
Supplementary Materials

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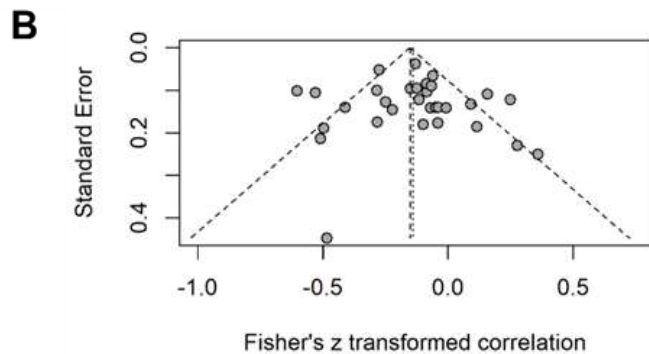
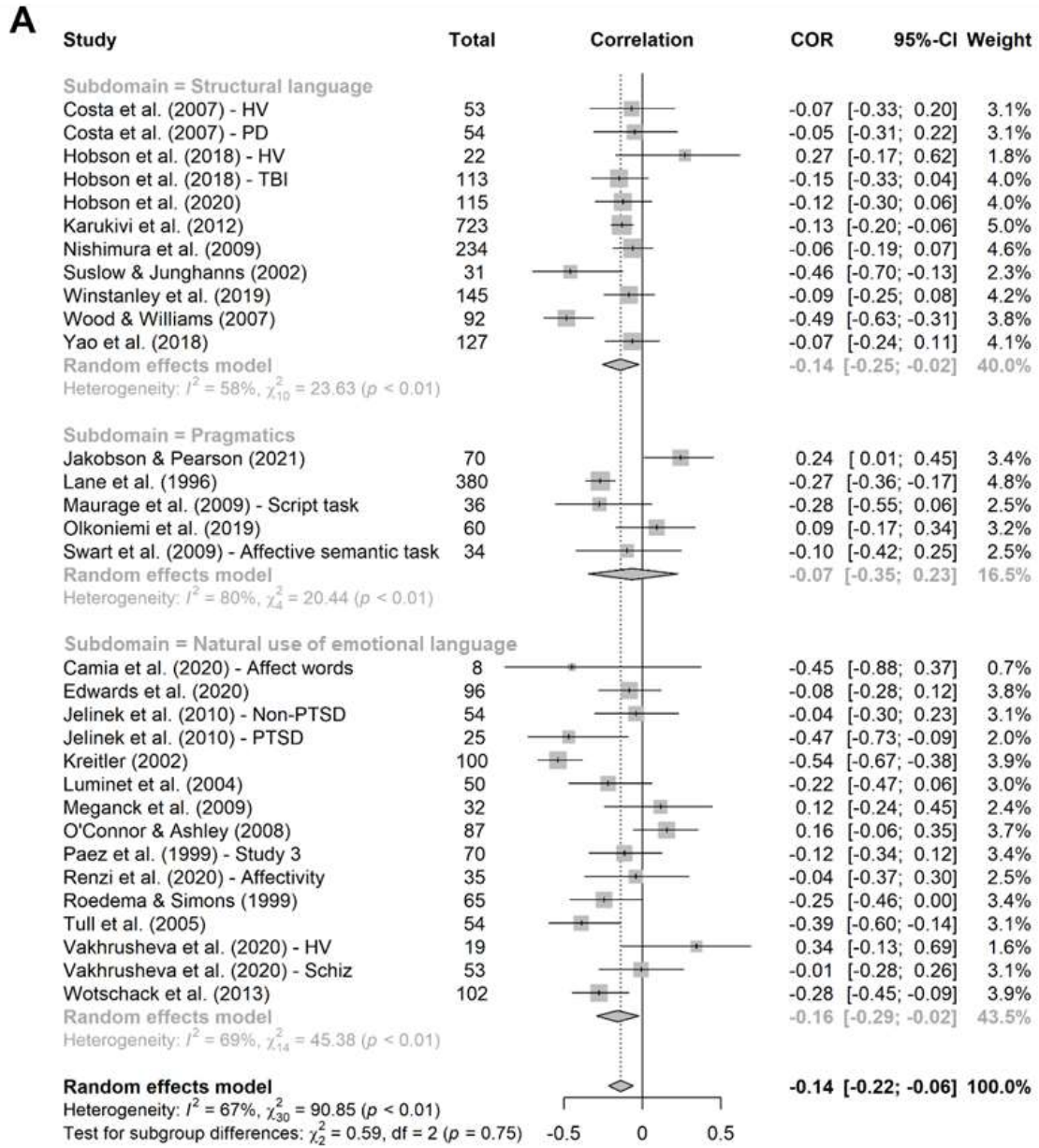
Clinical and Developmental Subgroup Analyses

On an exploratory basis, we conducted two supplementary analyses that tested for any group differences in effect sizes (i) between 25 studies (30 effect sizes) that recruited clinical (11 effect sizes) versus non-clinical (19 effect sizes) participants, and (ii) between 28 studies (33 effect sizes) that recruited different developmental age groups (youths 12-25 years: 15 effect sizes/ adults > 25 years: 12 effect sizes/ older adults > 60 years: 6 effect sizes). Studies reporting pooled effects across clinical and non-clinical groups, and across developmental age groups were excluded. Both analyses reflected that with outlying studies removed, no significant group differences were found regarding the clinical status ($Q[1] = .17, p = .68$) nor developmental age groups of the participants ($Q[2] = .84, p = .66$).

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Figure S2.1

Subgroup Analysis Comparing among Language Domains



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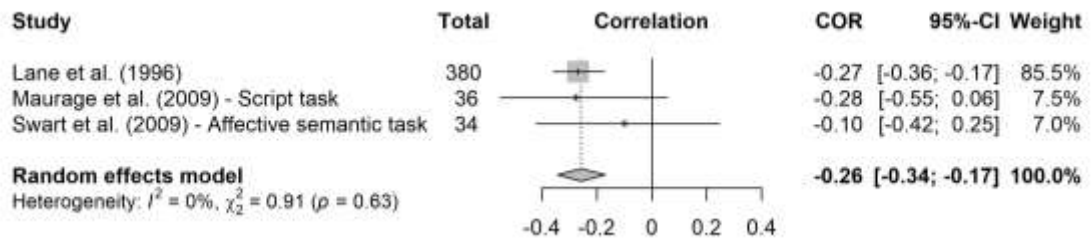
Notes. (A) Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each language study, and effect size summary inclusive of outliers. No significant group differences were found between language domains, regardless of removing outliers or not. (B) Funnel plot for visualizing the relationship between standard error and Fisher's z transformed correlation for each language study. DLD = developmental language disorder; HV = healthy volunteers; PD = Parkinson's disease; PTSD = post-traumatic stress disorder; Schiz = patients with schizophrenia; TBI = patients with traumatic brain injury.

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Supplementary Forest Plots of Pragmatic Studies Involving Emotional States and Processing Efficiency

Figure S2.2

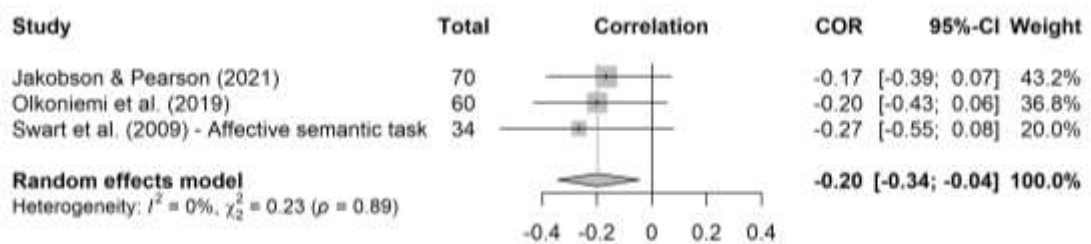
Pragmatics Involving Emotional States in Alexithymia



Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each pragmatics study that specifically tested understanding of emotional states via language, and effect size summary.

Figure S2.3

Processing Efficiency of Pragmatics in Alexithymia



Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each pragmatics study that also analysed processing efficiency variables (e.g., reaction times), and effect size summary.

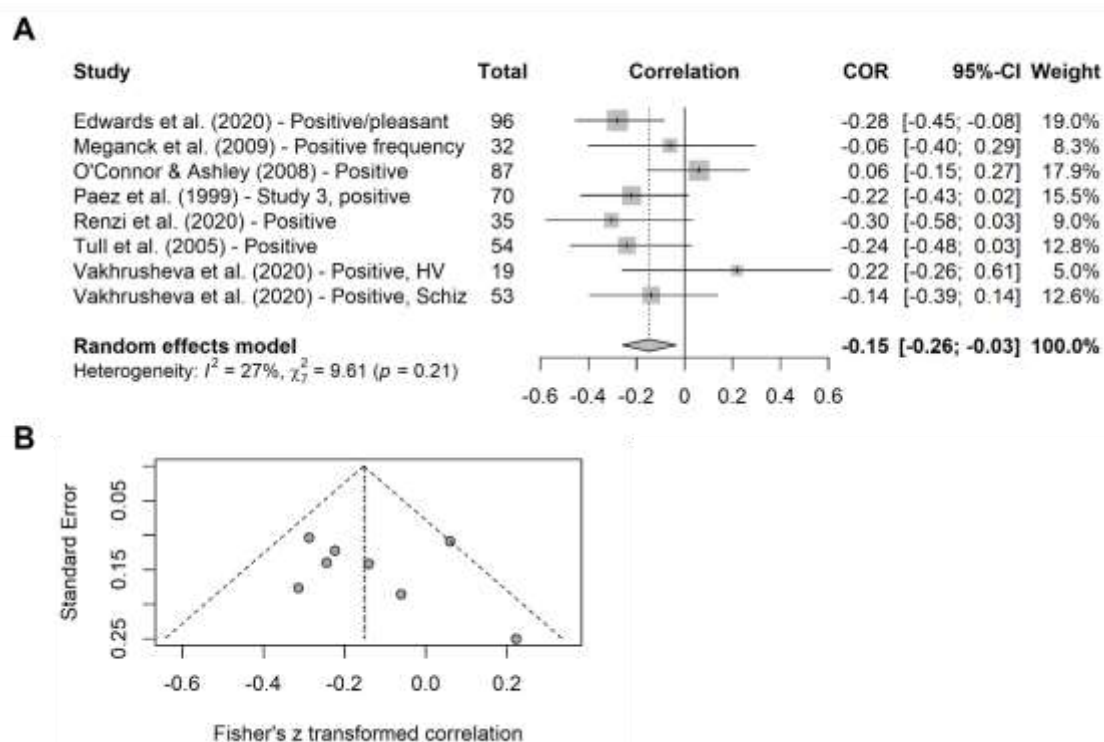
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Propensity to Use Positive and Negative Emotional Language

The analysis of positive emotional language included 7 studies (8 effect sizes), with a pooled effect size of $-.15$ [CI: $-.26$; $-.03$], $p = .01$, and an R^2 value of $.02$ (Figure S2.4). This suggested that 2% of the variance in the propensity to use positive emotional language was explained by alexithymia. Low heterogeneity ($Q = 9.61$, $p = .21$; $I^2 = 27.1\%$) and no outliers were observed. Influence analysis showed that the summary effect sizes ranged from $-.12$ to $-.20$ by leaving one study out at a time, with the confidence intervals of two pooled effect sizes crossing the zero boundary slightly. No publication bias was indicated.

Figure S2.4

Propensity to Use Positive Emotional Language in Alexithymia

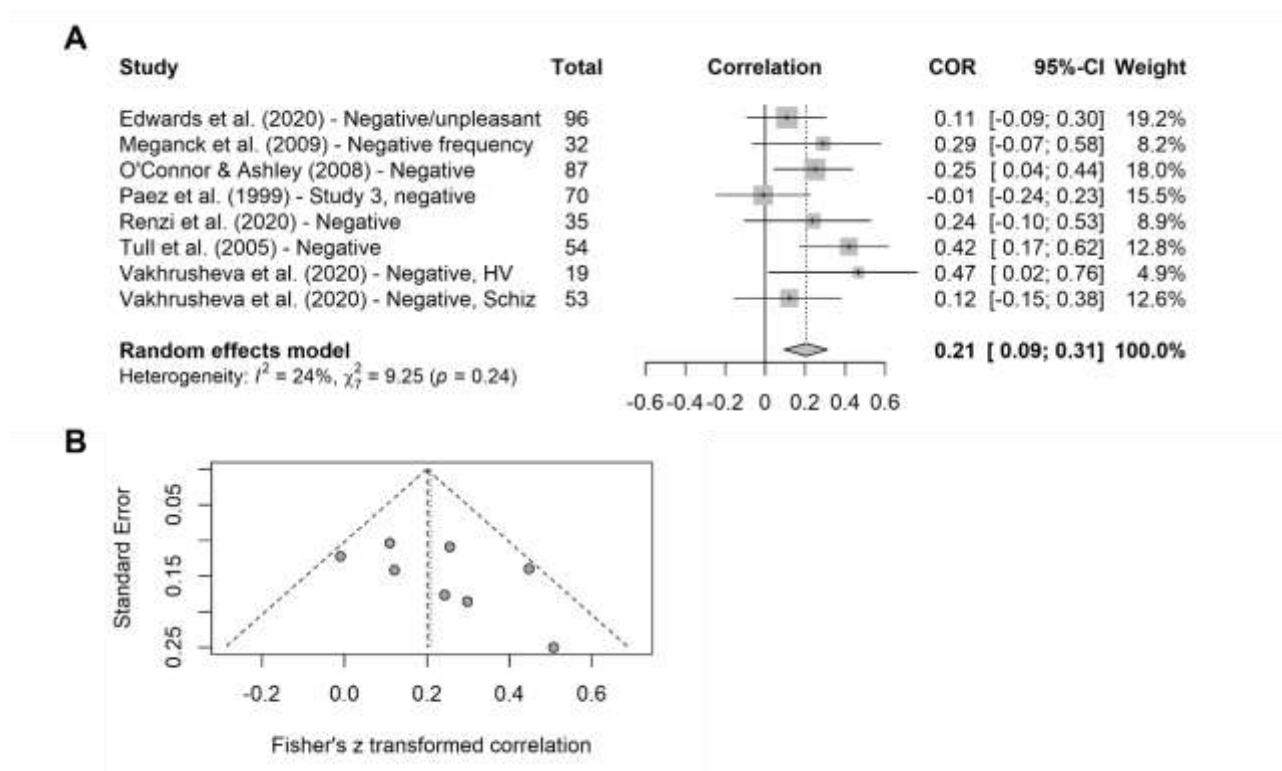


Notes. (A) Forest plot showing the individual effect sizes, confidence intervals, weighting, and pooled effect size across individual studies that specifically examined the propensity to use positive emotional language in alexithymia. (B) Funnel plot visualizing the relationship

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between standard error and Fisher's z transformed correlation for each study. HV = healthy volunteers; Schiz = patients with schizophrenia.

Further, the analysis of negative emotional language use of 7 studies (8 correlation coefficients) revealed differential results in the positive direction, with a pooled effect size of .21 [CI: .09; .31], $p < .001$, and an R^2 value of .04 (Figure S2.5). The pooled effect sizes were all statistically significant and consistently ranged from -.16 to -.24 as indicated by the leave-one-out method. This suggested that 4% of the variance in the propensity to use negative emotional language was explained by alexithymia. Low heterogeneity ($Q = 9.25$, $p = .24$; $I^2 = 24.3\%$) and no outliers were detected. No publication bias was observed.

Figure S2.5*Propensity to Use Negative Emotional Language in Alexithymia*

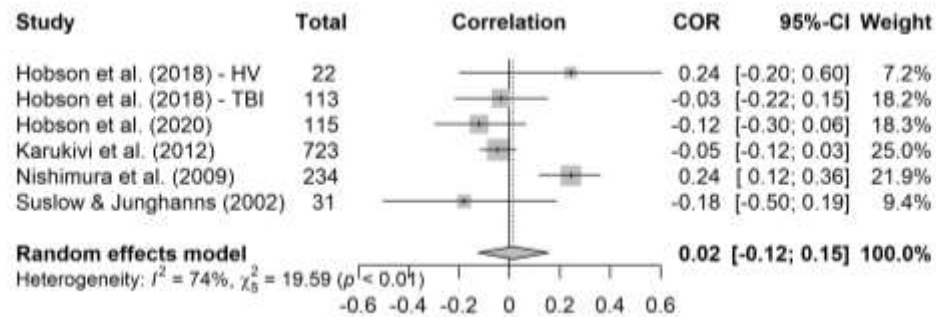
CHAPTER 2 REVIEW AND META-ANALYSIS

Notes. (A) Forest plot showing the individual effect sizes, confidence intervals, weighting, and pooled effect size across individual studies that specifically examined the propensity to use negative emotional language in alexithymia. (B) Funnel plot visualizing the relationship between standard error and Fisher's z transformed correlation for each study. HV = healthy volunteers; Schiz = patients with schizophrenia.

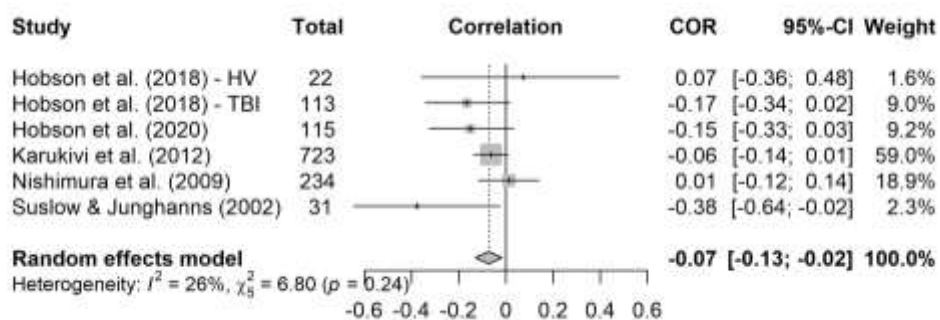
Subscale Analyses of Structural Language Studies

We investigated studies that also analysed the association between language abilities and TAS subscales. Because of low study availability, these subscale analyses were only available for structural language studies. Briefly, the analysis of the TAS Externally Oriented Thinking subscale (5 studies, 6 effect sizes) produced the largest pooled effect size of $-.14$ [$-.23$; $-.05$], $p = .003$. This was then followed by the TAS Difficulty Identifying Feelings subscale (5 studies, 6 effect sizes) with a pooled effect size of $-.07$ [CI: $-.13$; $-.02$], $p = .01$., and finally the TAS Difficulty Describing Feelings subscale (5 studies, 6 effect sizes), which revealed a non-significant pooled effect size of $.02$ [CI: $-.12$; $.15$], $p = .83$. No outliers were detected for all the subscale analyses. Together, these subscale results were consistent with the structural language model as previously described that alexithymia is modestly associated with lower structural language ability. See Figures S2.6-2.8 for forest plots.

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Figure S2.6*Structural Language Abilities in Alexithymia – Difficulty Describing Feelings*

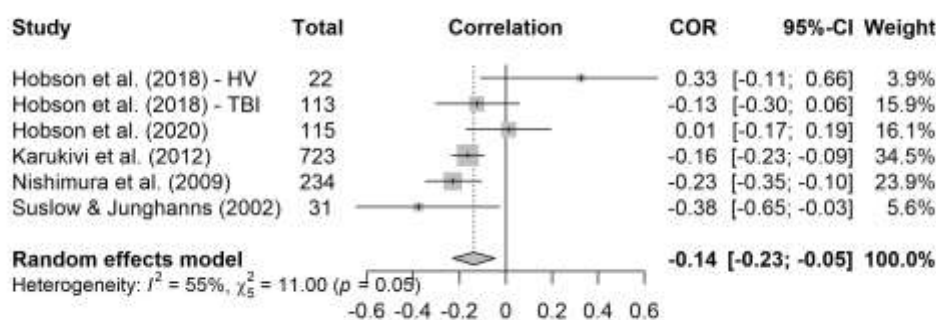
Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each structural language study that analysed the TAS Difficulty Describing Feelings subscale, and effect size HV summary. HV = healthy volunteer; TBI = patients with traumatic brain injury; TAS = Toronto Alexithymia Scale.

Figure S2.7*Structural Language Abilities in Alexithymia – Difficulty Identifying Feelings*

Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each structural language study that analysed the TAS Difficulty Identifying

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Feelings subscale, and effect size summary. HV = healthy volunteer; TBI = patients with traumatic brain injury; TAS = Toronto Alexithymia Scale.

Figure S2.8*Structural Language Abilities in Alexithymia – Externally Oriented Thinking*

Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each structural language study that analysed the TAS Externally Oriented Thinking subscale, and effect size summary. HV = healthy volunteer; TBI = patients with traumatic brain injury; TAS = Toronto Alexithymia Scale.

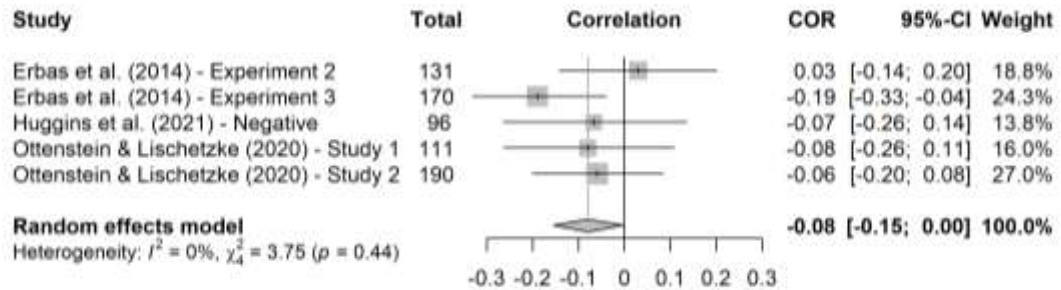
Subscale Analyses of Negative Emotional Granularity Studies

The analysis using the TAS Difficulty Identifying Feelings subscale (3 studies, 5 effect sizes) revealed the largest pooled effect size of $-.20$ [CI: $-.30$; $-.09$], $p < .001$, followed by the TAS Difficulty Describing Feelings subscale (3 studies, 5 effect sizes) with a pooled effect size of $-.08$ [CI: $-.15$; $.00$], $p = .04$, and finally the TAS Externally Oriented Thinking subscale (2 studies, 3 effect sizes) with a non-significant effect size of $.05$ [$-.05$; $.15$], $p = .34$. Low to moderate heterogeneity was observed for these subscale analyses (Qs ranged from 2.22 to 8.46; I^2 ranged from 0% to 52.7%). See Figures S2.9-2.11 for forest plots.

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Figure S2.9

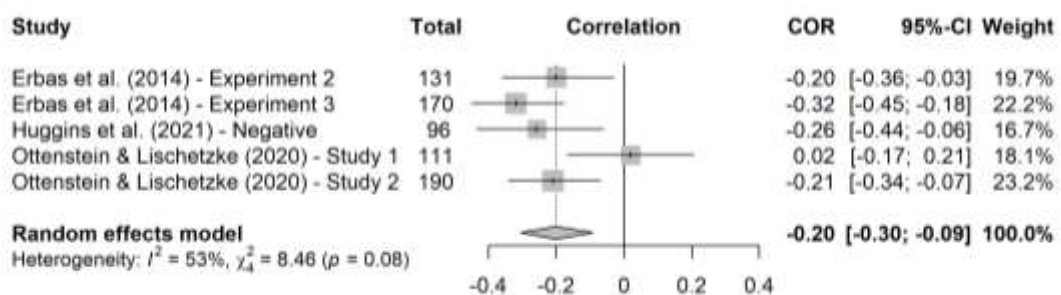
Negative Emotional Granularity in Alexithymia - Difficulty Describing Feelings



Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each negative emotional granularity study that analysed the TAS Difficulty Describing Feelings subscale, and effect size summary. TAS = Toronto Alexithymia Scale.

Figure S2.10

Negative Emotional Granularity in Alexithymia - Difficulty Identifying Feelings

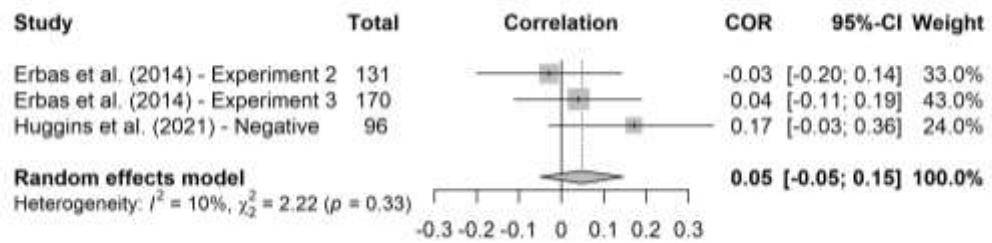


Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each negative emotional granularity study that analysed the TAS Difficulty Identifying Feelings subscale, and effect size summary. TAS = Toronto Alexithymia Scale.

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Figure S2.11

Negative Emotional Granularity in Alexithymia – Externally Oriented Thinking



Notes. Forest plot summarizing the individual effect sizes, confidence intervals, and weighting of each negative emotional granularity study that analysed the TAS externally oriented thinking subscale, and effect size summary. TAS = Toronto Alexithymia Scale.

Chapter 3**Childhood Language Development and Alexithymia in Adolescence:****An Eight-Year Longitudinal Study**

Abstract

Alexithymia predicts increased risks for psychopathology, especially during the transition from childhood to adolescence. However, little is known of the early contributors to alexithymia. The language hypothesis of alexithymia suggests that language deficits play a primary role in predisposing language impaired groups to developing alexithymia; yet longitudinal data tracking prospective relationships between language function and alexithymia are scarce. Leveraging data from the Surrey Communication and Language in Education cohort ($N = 229$, mean age at time point 1 = 5.32 years, $SD = 0.29$, 51.1% female), we investigated the prospective link between childhood language development and alexithymic traits in adolescence. Results indicated that boys with low language function at ages 4-5, and those who later met the diagnostic criteria for language disorders at ages 5-6, reported elevated alexithymic traits when they reached adolescence. Parent-reported child syntax abilities at ages 5-6 revealed a dimensional relationship with alexithymic traits, and this was consistent with behavioural assessments on related structural language abilities. Empirically-derived language groups and latent language trajectories did not predict alexithymic traits in adolescence. While findings support the language hypothesis of alexithymia, greater specificity of the alexithymia construct in developmental populations is needed to guide clinical interventions.

Childhood Language Development and Alexithymia in Adolescence:**An Eight-Year Longitudinal Study**

Alexithymia is a transdiagnostic trait that may explain some of the co-occurring emotional difficulties seen across a range of psychiatric and neurodevelopmental conditions, including those that develop in childhood and adolescence, such as in autism (Kinnaird et al., 2019; Milosavljevic et al., 2016) and feeding and eating disorders (Westwood et al., 2017). While a large body of research on adults has been dedicated to understanding the relationship between alexithymia and interoception (e.g., Trevisan et al., 2019 as described in Chapters 1 and 2), this single approach may not capture the full range of individual differences in the development of alexithymia, some of which stem from early development (Brewer et al., 2021; Murphy et al., 2017; Weissman et al., 2020). It is therefore possible that some adult findings would not be generalisable to specific populations of children and adolescents.

As part of the multi-route model of alexithymia, the language hypothesis of alexithymia posits that individuals with language impairments are at elevated risk of developing alexithymia (Hobson et al., 2019). For instance, children aged 9 to 16 years old with developmental language disorder (DLD) – those who showed wide-spread deficits in their native language(s) that persist from the beginning of formal education and who often experience non-verbal cognitive and socioemotional difficulties (Norbury & Sonuga-Barke, 2017) – showed elevated levels of parent-reported alexithymia compared to children with typical language abilities (Hobson & van den Bedem, 2021). From the constructionist perspective, language impairments may hinder the acquisition and development of discrete emotion categories (Hoemann et al., 2019, 2020). These theories are supported by the meta-analyses in Chapter 2 that alexithymia was associated with language impairments ($r = -.14$) and a less fine-grained perception of emotion experiences ($r = -.10$), and that individuals with

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language impairments/disorder had elevated alexithymic traits as compared to individuals with typical language function.

However, most existing studies on language impairments and alexithymia are cross-sectional, and do not inform as to the direction of cause and effect, i.e. whether language impairments *predispose* some individuals to developing alexithymia. This limitation should be urgently addressed as it would enable the characteristics of early language processes that underpin alexithymia to be identified (Hobson & van den Bedem, 2021). Two studies using longitudinal designs in developmental populations are of particular relevance to this issue. In a study of 723 school children in southwestern Finland (Karukivi et al., 2012), receptive language impairment (the ability to comprehend and follow multipart instructions in particular) assessed by nurses at the age of 5 was prospectively associated with self-reported alexithymia on the 20-item Toronto Alexithymia Scale (TAS-20) (Parker et al., 2003) at the age of 19. This prediction was more prominent in male adolescents but less stable in female adolescents when adjusting for confounds including early socioemotional symptoms and subjective health. Similar findings were reported in a Finnish birth cohort study (Kokkonen et al., 2003, $N = 2,556$), where early speakers (those who were able to utter three or more “words” in the first year of life) were found to have the lowest mean score on the TAS-20 when they reached 30 years old, with a stronger effect found in males than females. However, these sex differences were not interpreted, and it remains unclear if the stronger associations in boys indeed reflect a male-specific risk of developing alexithymia via the language pathway.

As noted in Chapter 2, the scant body of longitudinal studies may be due to the lack of alexithymia measures with desirable validity for use in large-scale cohort studies in developmental populations. Although this may not be an issue in the two studies above, which only measured alexithymia in adulthood using the TAS-20, more intensive language

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assessments are needed to test for any temporal changes in the prospective relationship between early language development and later alexithymia. Critically, while both studies above utilised medical screening tools to assess speech development, it is unclear if children who displayed some of those speech deficits constitute a clinically meaningful subgroup that corresponds to the current diagnostic criteria for childhood language disorders. This group approach is of theoretical importance as it directly tests the prediction that alexithymia should characterise children with language impairments/disorders, but it covaries with language ability in developmental groups where the degree of language difficulties is more heterogenous, such as in autism (Hobson et al., 2019). Relatedly, the use of binary screening items (pass/fail; yes/no) lacks a dimensional perspective that could characterise more clearly the relationship between early language and later alexithymia, given the vast individual differences in early language development (Kidd et al., 2018). Altogether, these methodological considerations may help specify the developmental period during which, and amongst whom, language interventions are most needed for preventing alexithymia and its related negative socioemotional outcomes (Way et al., 2007).

Furthermore, it has been suggested that different domains of language impairments may underpin different pathways to alexithymia. For instance, while children with DLD showed high rates of alexithymia, alexithymia was contemporaneously associated with pragmatic but not structural language difficulties rated by parents (Hobson & van den Bedem, 2021). The authors therefore suggested a disrupted social learning pathway that restricts children with DLD from communicating emotional difficulties effectively in social situations.

Nevertheless, Chapter 2 found a similar magnitude of correlation between alexithymia and each of speech, pragmatic and structural language abilities. Further investigation is warranted to clarify if differential associations exist between specific language domains and alexithymic traits, especially from a prospective point of view.

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To address the above research gaps, the current study tested the prospective relationship between early language function between the ages of 4-5 years old and alexithymic traits at the age of 12-13 years old using data from the Surrey Communication and Language in Education Study (SCALES) (Norbury et al., 2016). The SCALES is one of the few longitudinal studies that collected intensive data on child language development and alexithymic traits from early childhood to early adolescence, which would allow for testing differences in later alexithymia between language groups identified at early time points, as well as evaluating the directional relationship from early language impairments to later alexithymia within a reasonable timespan.

We hypothesised that there would be significant differences in later alexithymic traits between children with language impairments and peers with typical language abilities. We expected that early language function would be prospectively associated with later alexithymic traits. Due to the dearth of longitudinal studies in the field, we did not hold specific hypotheses regarding the directionality of these group differences and associations. We also explored sex differences in these dimensional relationships.

Method

Participants

Participants were drawn from the Surrey Communication and Language in Education Study (SCALES), a longitudinal cohort study of language development and disorder recruiting 7,267 children from the age of four and five years in Surrey, a county in the south of the UK (Norbury et al., 2016). Briefly, following the initial screening phase (T1), 529 children and their parents were selected to form an in-depth cohort for longitudinal language and mental health assessments over the course of eight years (T2 to T5). Note that all

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children who attended special schools were excluded from the in-depth cohort, due to the fact that their pervasive developmental impairments would impose significant challenges on completing the test battery as noted in the user guide. Children who used English as an additional language at the time of data collection were excluded to form another study cohort. For the purpose of this study, we included all children ($N = 229$, 43.3% of the in-depth cohort) (mean age at T1 = 5.32 years, $SD = 0.29$, 51.1% female) who completed the Emotion Awareness Questionnaire (EAQ) (Rieffe et al., 2008), which measures multiple domains of alexithymic traits in children and adolescents (see below), amid the COVID-19 pandemic at T5 (12 to 13 years old). The study design and further recruitment procedures of the SCALES were detailed in the original report (Norbury et al., 2016). The SCALES project was approved by the research ethics committees at Royal Holloway, University of London (T1 to T3), and University College London (T4 to T5) (9733/002). Parents provided written informed consent, whilst children provided verbal and written assent throughout the project.

Measures

Child Language Development at T1 to T3

The Children's Communication Checklist 2 (CCC-2) (Bishop, 2003) is a well-established assessment of child language and communication skills, and is commonly used to screen for communication difficulties in children aged 4 to 16 years. Due to practicalities and participation burden, different versions of the CCC-2 were used in the SCALES. At T1 (4 to 5 years old), teachers completed the short 13-item version of CCC-2 (Norbury et al., 2004). At T2 (5 to 6 years old), parents completed the full 70-item version of CCC-2. At T3 (7 to 8 years old), parents completed the short CCC-2. At T2 and T3, we prioritised the use of parent reports due to the considerations that parents have the most contact with their children at this developmental period, and that parent ratings have a lower rater-to-child ratio than teacher

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reports based in classroom settings (Bishop & Baird, 2001; Norbury et al., 2004). These considerations provide more reliable and specific observations of child communication behaviours, especially for identifying latent language profiles (see Statistical Analyses). The attrition rates for teacher reports in children with complete parent reports of CCC-2 and EAQ data were also relatively high (> 25%), which was not compatible with the intention to model language development over time. In the current sample, T1 teacher reports were moderately correlated with parent reports (T2 = .47, T3 = .54). We did not use T4 CCC-2 data due to high attrition rates for both reporters (> 40%).

For both versions of the CCC-2, teachers and parents reported the frequency with which the child displayed certain language and/or communication behaviours. An example item is “*Mixes up words that sound similar, e.g., might say ‘telephone’ for ‘television’ or ‘magician’ for ‘musician’.*” Responses were rated on a four-point Likert scale (0 = less than once a week; 3 = several times (more than twice a day) or always). As stated in the user guide, items that describe language strengths were reverse-scored such that higher scores reflect more language difficulties. The full CCC-2 comprises eight communication subscales (seven items each), namely speech, syntax, semantics, coherence, inappropriate initiation, stereotyped language, use of context, nonverbal communication; and two additional subscales – social relations and interests – for calculating the social-interaction deviance composite in children with autism (not applicable to this study as only four children were diagnosed with autism in the T2 analytic sample, see Statistical Analyses). The short CCC-2 consists of 13 items that best discriminated children with language difficulties from peers with typically-developing language skills (Norbury et al., 2004). The CCC-2 subscales and the short CCC-2 showed high internal consistency (Cronbach’s alphas = .65 and .87, respectively), whilst the short CCC-2 is strongly correlated with CCC-2 total scores, $r(515) = .88$. We analysed the short CCC-2 z-scores at T1. In the SCALES dataset, these had been previously z-transformed

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by season of birth and sex. Since season of birth information was not available due to data protection requirements, we z-transformed the CCC-2 total and subscale raw scores at T2 and the short CCC-2 total raw scores at T3 by sex to approximate the initial standardisation at T1.

Child Alexithymic Traits at T5

Children completed the Emotion Awareness Questionnaire (EAQ) (Rieffe et al., 2008), which was added to the SCALES protocol for data collection at T5. Items were rated on a three-point Likert scale (Not true, Sometimes true, Often true), where higher scores indicate higher levels of emotion awareness. The six EAQ subscales (Cronbach's alphas reported in brackets) were differentiating emotions (.84), verbal sharing of emotions (.75), not hiding emotions (.80), bodily awareness of emotions (.78), attention to others' emotions (.60), and analyses of emotions (.72). The EAQ showed acceptable to good internal consistency for the six subscales, consistent with previous validation and large developmental samples (e.g., Hobson & van den Bedem, 2021, Rieffe et al., 2008, Rieffe & De Rooij, 2012). The raw scores of the subscales were analysed.

Co-Occurring Socioemotional Symptoms at T1

Teachers completed the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997) as part of the initial screening at T1. The SDQ (25 items) assesses five domains of socioemotional and behavioural symptoms in children aged 3 to 16 years, including emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and prosocial behaviour. Items were rated on a three-point Likert scale (Not true, Somewhat true, Certainly true). Higher scores indicate higher levels of symptoms (Goodman & Goodman, 2009). Considering that socioemotional difficulties are common in children with language impairments (e.g., Goh et al., 2021), we entered the SDQ total difficulties

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scores at T1 as covariates of no interest in our subsequent analyses to clarify the unique prospective relationship between early language function and later alexithymia.

Non-Verbal Reasoning at T2

Children completed the Block Design subset of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III) (Wechsler, 2003) as a measure of non-verbal reasoning at T2. Children were required to recreate patterns as shown on the test demonstration and pictures using coloured cubes. The assessment was terminated when scoring no marks for three consecutive items. As developmental studies have shown varying non-verbal reasoning abilities in children with language disorders/impairments (Botting, 2005; Henry et al., 2012; Norbury et al., 2016), the total accuracy scores were treated as covariates of no interest in subsequent analyses, so as to ascertain that any associations identified would be specific to language rather than broader cognitive abilities. Higher scores reflect higher accuracy.

Statistical Analyses

We first characterised the developmental profiles of our full sample by summarising their sociodemographic information. This included the child's ethnicity (white/other), parental education level, deprivation quintile (determined by the Income Deprivation Affecting Children Index using household postcodes), whether the child had an autism diagnosis, number of immediate family members (parents and siblings) diagnosed with autism/attention deficit hyperactivity disorder (ADHD)/conduct disorder (CD)/dyspraxia (DCD), and the level of speech therapy and special education support the child received at school. These variables were ascertained from the background survey completed by parents and teachers at T1 and T2.

To examine the relationship between the presence of language impairments and later alexithymia, children with and without language impairments were compared on later

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alexithymia scores. The categorisation of language impaired vs. non-impaired groups took different forms at the different time points (see **Supplementary Materials** for a summary). For T1, we first conducted non-parametric Wilcoxon tests to compare differences in T5 alexithymic traits between high and low language functioning groups at T1 separately for girls and boys. Group membership was pre-determined by children's short CCC-2 scores at T1 screening, where children scoring below the 14th percentile by season of birth and sex were classified as having low language function and at risk of developmental language disorder (DLD) (Norbury et al., 2017). Next, we performed Spearman correlations to test the dimensional relationships between T1 language function and T5 alexithymic traits in the full sample. Significant tests were further evaluated by robust linear regressions adjusted for non-verbal reasoning and co-occurring socioemotional symptoms with age entered as a control variable.

A similar group approach was applied to the T2 data. We first conducted Wilcoxon tests to compare differences in alexithymic traits between (i) children diagnosed with language disorder (scoring -1.5 standard deviations on at least two out of five language composite scores, computed based on a language assessment battery in the SCALES, see **Supplementary Materials**) and peers with typically-developing language, and (ii) children diagnosed with and without DLD (meeting criteria for language disorder, *and* neither having a biomedical condition, such as Down syndrome and epilepsy, nor a non-verbal ability composite score of -2 standard deviations suggesting an intellectual disability). These group membership variables were pre-determined and available in the dataset.

Next, taking advantage of the in-depth information acquired by the full CCC-2 at T2, we performed a latent profile analysis (LPA) to empirically categorise children into distinct language profiles based on their eight subscale scores that assess specific language domain skills. This consisted of a subset of 139 children (mean age = 5.34 years, 58.3% female) with

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sufficient data on the CCC-2 at T2 and EAQ at T5 for the modelling. These children were from similar sociodemographic background as the excluded children, but showed better language function on the short CCC-2 at T1 (Cohen's $d = 0.59$) and lower levels of co-occurring socioemotional symptoms on the SDQ (Cohen's $d = 0.52$) than the excluded peers (see Limitations). The sample characteristics of this selected sample are presented in Table S3.1. Specifically, a manual Bolck-Croon-Hagenaars (BCH) approach was used to estimate the most probable language profile a child belonged to while adjusting for the effects of sociodemographic variables and covariates as listed above (Asparouhov & Muthén, 2014). A one-profile solution was first fitted to the data, followed by solutions with one additional profile than the previous one until the best solution was identified, which was indexed by: (i) the greatest relative reduction in the Akaike Information Criterion (AIC), Bayesian Information Criteria (BIC), and sample-size adjusted BIC (ABIC), (ii) entropy $> .90$, (iii) statistically significant Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR LRT), Lo-Mendell-Rubin adjusted likelihood ratio test (LMR adjusted LRT), and parametric bootstrapped likelihood ratio test (PB LRT) with $ps < .05$, and (iv) reasonable subgroup sizes ($\sim 10\%$) for subsequent comparisons (Nylund-Gibson and Choi, 2018). Differences in alexithymic traits were compared between the latent profiles using the Kruskal-Wallis test. We then conducted the same correlation and regression tests to evaluate the prospective relationship between T2 multi-domain language function and T5 alexithymic traits in this selected sample. For these correlation tests, we used a Bonferroni correction of $.05/6$ EAQ outcomes at T5 = $.008$ to correct for multiple tests.

Finally, adding T3 data to the analyses ($n = 139$), we performed a latent growth curve analysis (LGCA) to categorise children into distinct trajectories of global language development based on their CCC-2 total scores from T1 to T3. The same modelling procedures and model fit indices were applied as described above for the LPA using T2 data

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alone (Jung & Wickrama, 2008). In the case of LCGA, we specifically relaxed the assumption of linearity by estimating the trajectories between each time point separately as this approach has higher ecological validity than assuming a constant growth rate in language development across T1 to T3 (Deserno et al., 2023). Similarly, we conducted the same group comparisons for alexithymic traits between the latent trajectories, and tested the prospective relationships between T3 language function and T5 alexithymic traits in this selected sample.

All statistical analyses were conducted in R (R Core Team, 2021), except for the LPA and LCGA, which were conducted in Mplus version 8.3 (Muthén & Muthén, 1998-2017). Statistical tests were significant at $\alpha = .05$, two-tailed, unless otherwise specified.

Missing data

We used missForest to impute missing items on the CCC-2 at T2 (0.7 to 1.4%) and short CCC-2 total scores at T3 (21.6%), which is a random-forest based machine learning algorithm that iteratively samples and predicts missing items without conventional statistical assumptions (Stekhoven, 2022; Stekhoven & Bühlmann, 2012). The algorithm returned a normalised root mean square error (NRMSE) of 0.03, suggesting the imputation was robust and that the original and imputed datasets were highly comparable.

Results

Table 3.1 summarises the sample characteristics of the full sample. Briefly, the majority of children were white (93.9%), from the least deprived quintile (37.1%), and with parents attaining A-levels or similar vocational qualifications (mothers: 32.4%; fathers: 38.9%). The mean raw score on non-verbal reasoning test was 26.08 ($SD = 4.15$), whilst the mean total difficulties score on the SDQ was 8.24 ($SD = 6.71$). In terms of school support, 28.4% and 13.2% children received continuous speech therapy and special education support,

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respectively, over T2 and T3. The mean total score on the short CCC-2 at T1 was 15.83 ($SD = 11.73$, range = 0 to 39).

Table 3.1

Sample Characteristics (N = 229)

	Mean/n	SD/%	Min	Max
T1 Child age (years)	5.32	0.29	4.75	5.83
T1 Female participants	117	51.1		
T1 Child ethnicity				
White	215	93.9		
Other	14	6.1		
T1 Deprivation quintile				
1st	5	2.2		
2nd	30	13.1		
3rd	46	20.1		
4th	63	27.5		
5th	85	37.1		
T1 Language function				
Low	122	53.3		
High	107	46.7		
T1 Child ASD diagnosis				
Yes	5	2.2		
No	224	97.8		
T2 Mother's education level				
<=GCSEs	42	24.3		
A-levels/Vocational qualification	56	32.4		
Degree	53	30.6		
Higher degree	22	12.7		
T2 Father's education level				
<=GCSEs	47	28.1		
A-levels/Vocational qualification	65	38.9		
Degree	36	21.6		

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Higher degree	19	11.4		
T2 Family medical history				
>1 ASD/ADHD/CD/DCD	26	14.9		
None	148	85.1		
T1 Strength and difficulties				
Total difficulties	8.24	6.71	0	32
T2 Non-verbal reasoning				
Block design	26.08	4.15	15	40
T2-T3 School support				
Speech therapy				
0	156	68.1		
1	8	3.5		
2	65	28.4		
Special education needs				
0	128	62.7		
1	49	24.0		
2	27	13.2		

Notes. ASD = Autism Spectrum Disorder; ADHD = Attention Deficit Hyperactivity Disorder; CD = Conduct Disorder; DCD = Dyspraxia.

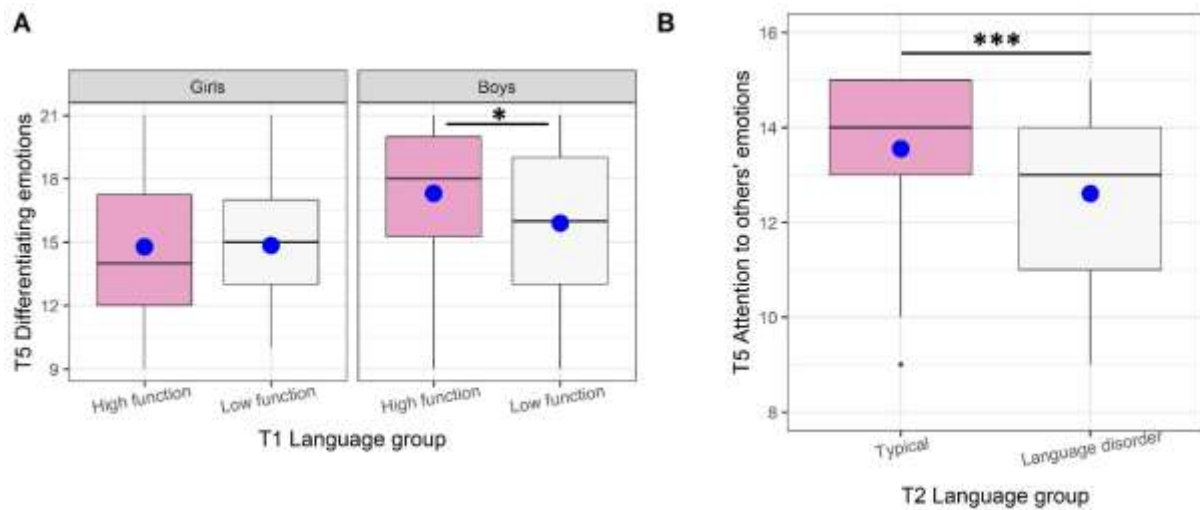
T1 Group Comparisons and Prospective Relationships with T5 Alexithymia

Table 3.2 summarises the comparisons of T5 alexithymic traits between girls and boys with high and low language function at T1 (4 to 5 years old). Specifically, boys with low language function reported more difficulties differentiating emotions at T5 (mean = 15.90, $SD = 3.55$) than boys with high language function (mean = 17.32, $SD = 2.93$), although this effect was small to medium ($W = 1908.5$, $p = .04$, effect size $r = 0.20$) (Figure 3.1A). No other significant group differences in T5 alexithymic traits were found for boys ($W_s = 1510.5$ to 1647.5 , $p_s = .56$ to $.89$) and girls ($W_s = 1503.5$ to 1971.5 , $p_s = .14$ to $.69$).

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Figure 3.1

Comparison of T5 Alexithymic Traits between Language Groups Identified at T1 and T2 (N = 229)



Notes. (A) Comparison between boys and girls with high and low language function at T1 screening. (B) Comparison between children who met the diagnostic criteria for language disorder and peers with typically-developing language skills at T2. Blue dots denote the mean values of groups. * $p < .05$ *** $p < .001$ (two-tailed).

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Table 3.2*Comparison of T5 Alexithymic Trait Domains between Language Groups Identified at T1 (N = 229)*

	Female (F)							Male (M)						
	Low (n = 60)		High (n = 57)		Comparison			Low (n = 62)		High (n = 50)		Comparison		
	Mean	SD	Mean	SD	W	p	r	Mean	SD	Mean	SD	W	p	r
T1 CCC total score	23.28	8.00	4.40	4.78	9	<0.001	0.86	26.18	7.07	7.10	6.44	16	<0.001	0.85
T5 Alexithymia - EAQ														
Differentiating emotions	14.73	2.93	14.67	3.70	1637	0.691	0.04	15.90	3.55	17.32	2.93	1908.5	0.035	0.20
Verbal sharing of emotions	5.67	1.80	5.35	1.80	1530	0.319	0.09	6.24	1.53	6.42	1.84	1647.5	0.563	0.06
Not hiding emotions	9.67	2.58	9.32	2.82	1531	0.326	0.09	10.10	2.27	9.92	2.34	1510.5	0.818	0.02
Bodily awareness of emotions	10.12	2.62	9.61	3.03	1503.5	0.258	0.10	10.56	2.58	10.42	2.57	1526.5	0.892	0.01
Attention to others' emotions	13.28	1.79	13.93	1.10	1971.5	0.139	0.14	13.05	1.55	13.16	1.68	1641	0.589	0.05
Analyses of own emotions	10.63	2.57	11.23	2.16	1928.5	0.231	0.11	11.13	2.08	10.80	2.60	1523.5	0.878	0.01

Notes. CCC-2 = Children's Communication Checklist 2; EAQ = Emotion Awareness Questionnaire; High/Low = High/Low language functioning.

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From a dimensional perspective, more language difficulties at T1 were significantly correlated with paying less attention to others' emotions at T5 in the full sample, $r(227) = -.16, p = .02$. This correlation, however, did not survive the robust linear regression when adjusting for non-verbal reasoning and co-occurring socioemotional symptoms (Estimate = $-0.09 [-0.31; 0.13], SE = 0.11, t = -0.80, p = .43$). No correlations were observed for other EAQ domains, $r_s = -.03$ to $.10$.

T2 Group Differences in T5 Alexithymia

Table 3.3 summarises the comparisons of T5 alexithymic traits between children who fulfilled the diagnostic criteria for language disorder ($n = 48$) and peers with typically-developing language function at T2 (5 to 6 years old). Amongst the EAQ domains, the language disorder group reported paying significantly less attention to others' emotions at T5 (mean = 13.55, $SD = 1.52$) than their peers (mean = 12.60, $SD = 1.59$), $W = 5878, p < .001$, effect size $r = 0.26$ (Figure 3.1B, page 160). No other group differences were observed, $W_s = 4292$ to $4902, p_s = .17$ to $.90$.

We then compared differences in T5 alexithymic traits between children who further fulfilled the diagnostic criteria for DLD ($n = 35$) and peers who did not meet diagnostic criteria (Table 3.3). Children in the DLD group reported paying slightly less attention to others' emotions at T5 (mean = 13.52, $SD = 1.53$) than their peers (mean = 12.46, $SD = 1.54$), $W = 4737.50, p < .001$, effect size $r = 0.25$. No other group differences were found, $W_s = 3264.50$ to $3851.50, p_s = .20$ to $.86$.

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Table 3.3

Comparison of T5 Alexithymic Trait Domains between T2 Language Disorder Groups and Typically-Developing Group (N = 229)

T5 Alexithymia - EAQ	<u>TD (n = 181)</u>		<u>Language disorder (n = 48)</u>		<u>Group comparison</u>		
	Mean	SD	Mean	SD	W	p	r
Differentiating emotions	15.76	3.47	14.98	3.33	4902.00	0.170	0.09
Verbal sharing of emotions	5.92	1.81	5.88	1.67	4398.50	0.893	0.09
Not hiding emotions	9.77	2.50	9.67	2.56	4605.00	0.520	0.04
Bodily awareness of emotions	10.17	2.75	10.21	2.61	4293.50	0.902	0.01
Attention to others' emotions	13.55	1.52	12.60	1.59	5878.00	<0.001	0.26
Analyses of own emotions	10.94	2.41	10.98	2.16	4292.00	0.899	0.09
T5 Alexithymia - EAQ	<u>Non-DLD (n = 194)</u>		<u>DLD (n = 35)</u>		<u>Group comparison</u>		
	Mean	SD	Mean	SD	W	p	r
Differentiating emotions	15.73	3.42	14.89	3.55	3851.50	0.204	0.08
Verbal sharing of emotions	5.92	1.79	5.86	1.73	3460.00	0.856	0.01
Not hiding emotions	9.80	2.50	9.49	2.61	3728.00	0.353	0.06
Bodily awareness of emotions	10.16	2.75	10.29	2.55	3284.00	0.758	0.02
Attention to others' emotions	13.52	1.53	12.46	1.54	4737.50	<0.001	0.25
Analyses of own emotions	10.93	2.40	11.06	2.11	3264.50	0.716	0.020

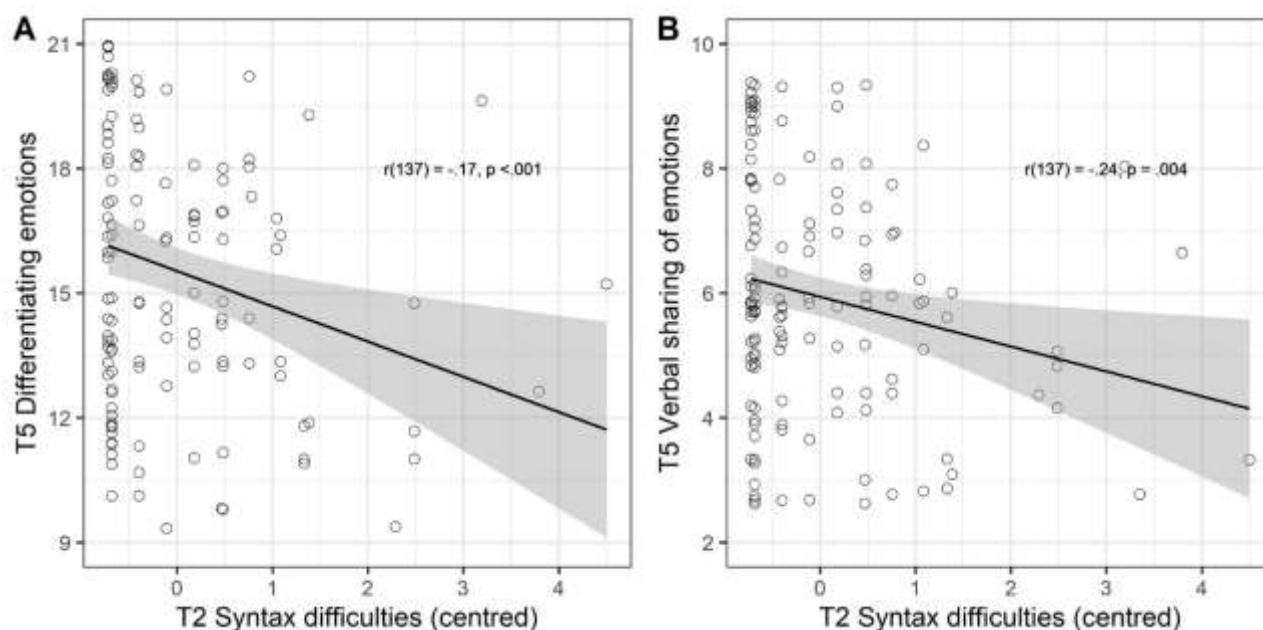
Notes. CCC-2 = Children's Communication Checklist 2; DLD = Developmental Language Disorder; EAQ = Emotion Awareness Questionnaire; TD = typically-developing children.

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T2 Latent Profiles and Prospective Relationships with T5 Alexithymia

Next, utilising the selected sample ($n = 139$), the LPA suggested a three-profile solution based on children's parent-reported CCC-2 scores on the eight language subscales at T2 (Figure S3.1). This consisted of children with typically-developing language function ($n = 90$) (CCC-2 mean = 13.83, $SD = 9.63$), children with moderate language difficulties ($n = 37$) (CCC-2 mean = 48.02, $SD = 12.73$), and children with severe language impairments across all language domains ($n = 12$, 10 of whom were in the low language functioning group at T1) (CCC-2 mean = 83.37, $SD = 16.25$). Model fit indices and a descriptive summary of the subgroup sample characteristics are presented in Tables S3.2-3.3. Sex ratio was relatively balanced within each LPA group, suggesting that sex had a negligible effect on classification. Subsequent group comparisons suggested no significant differences in alexithymic traits between these empirically-derived language groups, $\chi^2 = 0.13$ to 3.43, $ps = .18$ to .94 (Table S3.4).

From a dimensional perspective, Spearman correlations suggested that poorer syntax and speech at T2 were correlated with more difficulties differentiating emotions at T5 (Figure 3.2A). Poorer syntax was also correlated with less verbal sharing of emotions at T5 (Figure 3.2B). Using robust linear regressions, poorer syntax at T2 significantly predicted more difficulties differentiating emotions (Estimate = -0.84 [-1.48; -0.20] SE = 0.33, $t = -2.56$, $p = .01$, partial $r = -.22$) and less verbal sharing of emotions at T5 (Estimate = -0.42 [-0.76; -0.07], SE = 0.18, $t = -2.36$, $p = .02$, partial $r = -.20$) when adjusting for non-verbal reasoning and co-occurring socioemotional symptoms and controlling for age differences. The association between T2 speech and T5 differentiating emotions was no longer significant after the adjustments (Estimate = -.042 [-1.10; 0.27], SE = 0.35, $t = -1.19$, $p = .24$).

Figure 3.2*Dimensional Relationships between Early Language Function and T5 Alexithymic Traits*

Notes. The dimensional relationship between (A) T2 syntax difficulties and T5 differentiating emotions, (B) T2 syntax difficulties and T5 verbal sharing of emotions.

Similar regression analyses were performed with the behavioural language assessment items used for identifying children with language disorder at T2. Prospective relationships were mainly found between receptive and expressive language domains that demand syntax skills and difficulties differentiating emotions at T5 (see **Supplementary Materials**).

T1 to T3 Latent Trajectories and Prospective Relationships with T5 Alexithymia

The LCGA suggested a four-trajectory solution using children's CCC-2 total scores from T1 to T3 (4/5 years old to 7/8 years old), which captured distinct trajectories of global language development from the age of 4 to 8 years old (Figure S3.2). These included children with minimal language concerns throughout ($n = 46$), children who showed persistent

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language impairments ($n = 15$, 13 of whom were in the low language functioning group at T1), children with steady improvement who attained typical language over the years ($n = 60$), and children who showed less improvement with moderate language concerns ($n = 18$). Sex ratio was generally balanced within each trajectory group. Model fit indices and the sample characteristics of these trajectory groups are presented in Tables S3.5-3.6. Similar to the LPA results at T2, no significant differences in alexithymic traits were found between these language development trajectories, $\chi^2 = 0.26$ to 5.26 , $ps = .15$ to $.97$ (Table S3.7).

In the dimensional analyses, lower global language function at T3 was correlated with more difficulties differentiating emotions, $r(137) = -.19$, $p = .03$, but this relationship did not survive Bonferroni correction. No other significant correlations were found, $rs = -.11$ to $.02$.

Supplementary Analyses

To explore potential sex differences in the dimensional relationship between early language function and alexithymia, we repeated the same correlational tests in boys and girls separately. In line with the two longitudinal studies (Karukivi et al., 2012; Kokkonen et al., 2003), these associations were found to be stronger in boys than girls (see **Supplementary Materials**).

Discussion

The present study provides supporting evidence for the language hypothesis of alexithymia, which predicts that children with language difficulties and disorders are at elevated risks of developing alexithymia (Hobson et al., 2019). Specifically, we found that boys with lower language function at 4 to 5 years old reported having more difficulties differentiating emotions when they reached 12 to 13 years old, whilst children who later met the diagnostic criteria for language disorder at 5 to 6 years old reported paying less attention

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to others' emotions at ages 12 to 13. From a dimensional point of view, childhood language difficulties were prospectively associated with higher alexithymic traits in early adolescence. These associations emerged after one year of formal education (5 to 6 years old).

Our group comparisons serve as a primary test of the language hypothesis of alexithymia. Although difficulties differentiating emotions assessed by the EAQ seem to correspond closely to the key alexithymia construct measured by the TAS-20 in adults (Rieffe et al., 2006, 2007), such a group difference was only found in boys with low language function when comparing to boys with high language function at 4 to 5 years old. Moreover, children who met the diagnostic criteria for language disorder and DLD at 5 to 6 years old reported having a lower *tendency* to attend to others' emotions instead at ages 12 to 13 (e.g., "*it is important to know how my friends are feeling*"), which is a social motivation construct that correlates with but does not define alexithymia (see reviews by Luminet et al., 2021; Pisani et al., 2021). This highlights two important conceptual issues: (i) children up to the age of 13 years old may not have developed the full adult form of alexithymia, and (ii) it may be more appropriate to conceptualise this reduced tendency to attend to others' emotions as a *developmental correlate* suggestive of a high risk of developing alexithymia in later years amongst these children (e.g., mid-adolescence: Hobson & van den Bedem, 2021, although see the discussion on informant disagreement below; adulthood: Karukivi et al., 2012; Kokkonen et al., 2003).

Relevant to the above conceptualisation is the evidence from the same SCALES sample that children with DLD were less accurate in recognising emotions from facial and vocal cues at ages 10 to 12 (Griffiths et al., 2020), another plausible developmental correlate of alexithymia (Trevisan & Birmingham, 2016). Nevertheless, there is as yet the need to demonstrate if low emotion recognition accuracy is a product of reduced motivation to understand others' emotions, atypical perceptual processing of emotional cues (e.g., atypical

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visual attention and reduced eye gaze; Bird et al., 2011; Cuve et al., 2021), or a combination of both that reflects some global atypicalities in emotional state inference in these children (Pisani et al., 2021). From a social perspective, a lower tendency to attend to peers' emotions is likely related to the high rate of social rejection and victimisation in children with language disorders (e.g., Rowley et al., 2012; van den Bedem et al., 2018), as these negative experiences render the communication of emotional experiences with peers less rewarding, which further compromises the quality and quantity of social learning opportunities (Hobson & van den Bedem, 2021). However, it must be noted that the effect sizes of these group differences are small to medium, which suggest that language is likely a contributor to, rather than the sole cause of, the development of alexithymia.

We found no evidence that children with language impairments had poorer bodily awareness of their own negative emotions than peers with typically-developing language. However, a larger sample is needed to conduct further equivalence tests, which is an important next step to confirm if interoception indeed has little direct involvement in the development of alexithymia in these children (Hobson et al., 2019). If language impaired groups are able to perceive internal bodily signals and use them to infer their emotional state, then it is likely that these children struggle to apply discrete and specific linguistic labels to describe and communicate these emotions with others. This has to be tested by allowing participants to apply their own emotion labels to their internal bodily signals as these labels were provided on the EAQ items in the current study (e.g., *“When I am scared or nervous, I feel something in my tummy”*).

The dimensional analyses reveal that syntax difficulties (a structural language domain) are more consistently associated with higher alexithymic traits in early adolescence than domains that concern pragmatics. According to the constructionist theories, syntax abilities, including the use and understanding of grammar and structurally correct sentences,

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support children's extraction of emotional information in written texts and conversations, which facilitates the acquisition and understanding of emotion categories (and their associated emotion concepts) over development (Hoemann et al., 2019; Majid, 2012). Indeed, there is preliminary evidence demonstrating that young children (3 to 5 years old) make use of syntactic features (e.g., word forms that denote parts of speech and the number of sentence arguments) to infer the meaning of unfamiliar adjectives that signal the emotional state of a fictional character alongside contextual cues (Shablack et al., 2020). This supports the idea that not only do syntax abilities facilitate children's understanding and use of language structures *per se*, but these abilities also serve as linguistic pointers to emotional information for children, which are crucial in the early years of expanding their repertoire of emotion concepts and vocabulary (Majid, 2012). With regard to the constructionist view that emotion concepts are an instance of abstract concepts in general (Hoemann et al., 2019, 2020), syntax abilities may potentially support the development and/or acquisition of other domains of abstract concepts, such as internal physiological/bodily states (e.g., hunger and pain).

Speech coherence and semantics did not reveal any significant relationships with alexithymia. This is perhaps surprising as it is intuitive to hypothesise that a child who struggles to communicate in an orderly and coherent manner would experience difficulty communicating their own feelings, a process that requires a reasonable level of speech coherence to articulate complex emotional experiences. One explanation might be that the CCC coherence items primarily focus on the child's general ability to explain and give information about an event, which does not specifically require the use of abstract emotion concepts and related situational information. For semantics, mixed results were found when further analysing behavioural assessments that specifically tested lexical access, suggesting that the null results of parent reports may be due to variance introduced by a wider range of semantic skills on the CCC, and that children may also display different language abilities

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when observed in research settings and with caregivers (Kang et al., 2023; Lindsay et al., 2010). Future studies may wish to focus specifically on the particular aspects of speech coherence and semantic skills that are directly related to emotional self-awareness, and consider the contexts in which these language behaviours are assessed.

The above findings seem to contrast with the cross-sectional study that only found an association between parent reports of pragmatic difficulties and alexithymia in children with DLD (Hobson & van den Bedem, 2021). Here, the only significant pragmatic difficulty was that boys with more inappropriate initiations at 5 to 6 years old were less able to differentiate emotions at 12 to 13 years old than boys with fewer inappropriate initiations. However, a direct comparison between the Hobson and van den Bedem (2021) data and the current data is not possible as the structural language ratings in Hobson and van den Bedem (2021)'s typically-developing participants were not analysed due to low reliability. Importantly, the Hobson and van den Bedem (2021) study sample was from an older age range (9 to 16 years old), which may in fact allude to potential differences in the language-alexithymia relationship in mid-/later adolescence when emotional awareness undergoes rapid development and is closely linked to psychopathology (Weissman et al., 2020). In contrast, the present results are drawn from a longitudinal cohort of children (from 4-5 to 12-13 years old) and backed by convergent relationships between behavioural language assessments that demand similar syntax abilities (such as grammar and reproducing structurally correct sentences) and difficulties differentiating emotions. The current findings are therefore robust to assessment methods.

The language-alexithymia associations observed were more pronounced in boys than girls, a finding that is consistent with the two longitudinal studies (Karukivi et al., 2012; Kokkonen et al., 2003), although are based on a relatively small sample size for validating sex differences. Further inspection of the sex-specific associations (which mostly involve the

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differentiating emotions domain) suggests that despite having reported a comparable range of scores, there were in fact more boys than girls who reported being better able to differentiate emotions at 12 to 13 years old, suggesting the need for more variance in girls to test these small associations. In terms of emotion development more broadly, sex and gender differences in emotion expression are context-dependent and closely related to the sex and gender norms of emotional display rules in a given culture (see a meta-analytic review by Chaplin & Aldao, 2013). Hypothetically, if boys were more discouraged to express fear than girls in a certain culture, it would be reasonable to suggest that boys with language impairments would be disproportionately disadvantaged to develop the skills needed to identify and communicate their emotional distress with others, leading to low emotional self-awareness in later years. Preliminary support for this prediction was demonstrated by one study in both British and Spanish samples that 8 to 10-year-old boys had a lower tendency than girls to choose adaptive communicative strategies to help regulate fear expressed by a game character (López-Pérez & Pacella, 2021). A longitudinal assessment testing if such a gender difference would then predict high levels of alexithymic traits in boys would help inform the potential contribution of Western sex and gender norms to our UK findings.

Limitations

While the present study is one of the few that investigates the prospective relationship between early language function and alexithymia, it is not without limitations. First, only a subset of children provided sufficient CCC data at T2 and T3, and this subset also happened to have lower levels of language difficulties and socioemotional symptoms as compared to peers with insufficient data. This results in a potential loss of language variance for testing the dimensional relationship with alexithymia. Second, alexithymia was measured with child self-reports only, which precluded us from assessing any discrepancy in results when analysing parent-reports (e.g., Griffin et al., 2016). Indeed, Hobson and van den Bedem

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(2021)'s cross-sectional study reported no significant group differences when analysing child self-reported alexithymic traits, but the reasons contributing to the lack of agreement with their parent-reported results are unclear. From a measurement perspective, parent-reports are primarily based on observable child behaviours, whilst child self-reports may provide a more reliable and nuanced assessment of one's own emotional traits as children get older and develop better emotional abilities (Lumley et al., 2007). Relatedly, there remains the question of whether children struggle to report their own alexithymic traits due to their inherent language deficits and/or co-occurring alexithymia (Gaigg et al., 2018; Hobson et al., 2019). Third, the long CCC was not administered at all time points, and nor was the EAQ which was analysed as a distal outcome at T5. Future cross-panel studies are an important next step to investigate if between- and within-person level changes in language function exert bidirectional influences on alexithymic traits over time. Finally, the current sample comprises language profiles and trajectories that are relatively homogenous. A study design that specifically captures more diverse types of language abilities in larger samples (e.g., high structural language abilities but low social language skills) may allow for disentangling the contribution of specific language domains to alexithymia using latent profile techniques.

Clinical Implications

Given the novelty of our findings, it is still early to conclude that language interventions, such as speech therapy, would significantly reduce the risk of developing alexithymia in children with language impairments and disorders. We provide three recommendations for clinical considerations: (i) Children with language impairments and disorders are at risks of developing alexithymia. These developmental correlates are specific to certain alexithymic trait domains (here, difficulty differentiating emotions and paying less attention to others' emotions) but not a global alexithymia construct as defined in adult research; (ii) Syntax difficulties may play a particularly important role in the development of

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alexithymia. Interventions focusing on improving the understanding and use of syntactic features may help children identify and extract emotional information from language, fostering emotion understanding over development; (iii) Clinicians should be mindful of the potential influences of multi-informant assessments (parent-report vs. child-report) and assessment modality (self-report vs. clinic-based behavioural assessments) on clinical decision-making.

Conclusion

In sum, the present study finds supporting longitudinal evidence for the language hypothesis of alexithymia whereby children with language impairments and language disorders are at increased risk of developing alexithymia. Early language function, lower syntax abilities in particular, is prospectively associated with alexithymic traits in early adolescence. To better identify treatment opportunities, greater specificity regarding which alexithymic trait domains these language group differences are present in, and exploration of the potential sources of informant and assessment method discrepancies is warranted.

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Chapter 3
Supplementary Materials

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Categorisation of Language Impaired Groups at Different Time Points

Time point	Total <i>N</i>	Language impaired group(s) (<i>n</i>)	Measures
T1 (4-5 years old)	229	Boys ($n = 62$) and girls ($n = 60$) with low language function: scoring below 14 th percentile on the CCC-2 short form	Teacher-reported CCC-2 short form, z-transformed by season of birth and sex
T2 (5-6 years old)	229	(i) Children with language disorder ($n = 48$): scoring -1.5 standard deviations on at least two out of five language composite scores on the language assessment battery (ii) Children with DLD ($n = 35$): meeting the above criteria for language disorder, <i>and</i> neither having a biomedical condition (such as Down syndrome and epilepsy) nor a non-verbal ability composite score of -2 standard deviations suggestive of an intellectual disability	Language assessment battery testing expressive language, receptive language, vocabulary, grammar, and narrative skills (details see supplementary section Diagnostic Criteria for Language Disorder at T2 below)
T2 (5-6 years old)	139	Children with severe language impairments ($n = 12$) and children with moderate language difficulties ($n = 37$) across all language domains on the CCC-2 subscales; identified by the latent profile analysis	Subscales of parent-reported CCC-2 full form, z-transformed by sex to approximate T1 standardisation
T1-T3 (4-8 years old)	139	Children with persistent language impairments over time ($n = 15$), and children with moderate language concerns and showed less improvement over time ($n = 18$); identified by the latent growth curve analysis	Total scores of T1 teacher-reported CCC-2 short form, T2 parent-reported CCC-2 full form, and T3 parent-reported CCC-2 short form; all z-transformed as described above

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Diagnostic Criteria for Language Disorder at T2

To determine whether children met the criteria for language disorder, children were evaluated by the SCALES team based on their five composite scores on a language assessment battery at T2. These included expressive language (EOWPVT, SASIT, and ACE-Recall), receptive language (ROWPVT, TROG, and ACE-Comp), vocabulary (EOWPVT and ROWPVT), grammar (TROG and SASIT), and narrative skills (ACE-recall and ACE-comp). Higher scores reflect better performance. Children were considered meeting the criteria for language disorder if they scored -1.5 standard deviations on at least two of the five composite scores. Further details of these assessments can be found in the user guide of the SCALES dataset and the original reports referenced below.

Assessment	Domain	Description
Receptive One Word Picture Vocabulary Test (ROWPVT) (Martin & Brownell, 2010)	Receptive language / Vocabulary	Children were asked to hear a word and then pick the corresponding picture from a choice of four.
Expressive One Word Picture Vocabulary Test (EOWPVT) (Martin & Brownell, 2011)	Expressive language / Vocabulary	Contrary to the Receptive Test, children were required to name the actions/concepts/objects as shown on the test pictures.
Test of Reception of Grammar (TROG) (Bishop, 2003)	Receptive language / Grammar	Children were asked to listen to a sentence and then pick the corresponding picture from a choice of four.
School-aged Sentence Imitation Test (SASIT) (Marinis et al., 2011)	Expressive language	Children were asked to repeat 32 sentences. Their accuracy, number of function words, content words, and inflected verbs were scored.
Assessment of Comprehension and Expression – Narrative Recall (ACE-Recall) (Adams et al., 2001)	Expressive language /	Children were asked to listen to a story (monkey in a forest) and then retell the

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	Narrative skills	story to the examiner in the presence of story images.
Assessment of Comprehension and Expression – Narrative Comprehension (ACE-Comp) (SCALES team)	Receptive language / Narrative skills	Following the Recall Test above, children had to answer 12 comprehension questions about the story they had just retold.

Additional References for Behavioural Assessments

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Table S3.1*Sample Characteristics of the Selected Sample (n = 139)*

	Mean/n	SD/%	Min	Max
T1 Child age (years)	5.34	0.29	4.75	5.83
T1 Female participants	81	58.3		
T1 Child ethnicity				
White	131	94.2		
Other	8	5.8		
T1 Deprivation quintile				
1 st	4	2.9		
2 nd	14	10.1		
3 rd	20	14.4		
4 th	41	29.5		
5 th	60	43.2		
T1 Language function				
Low	60	43.2		
High	79	56.8		
T1 Child ASD diagnosis				
Yes	4	2.9		
No	135	97.1		
T2 Mother's education level				
<=GCSEs	32	23.2		
A-levels/Vocational	40	29.0		
qualification				
Degree	45	32.6		
Higher degree	21	15.2		
T2 Father's education level				
<=GCSEs	34	25.4		
A-levels/Vocational	52	38.8		
qualification				
Degree	33	24.6		
Higher degree	15	11.2		

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T2 Family medical history

>1 ASD/ADHD/CD/DCD	18	12.9		
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None	121	87.1		
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T1 Strength and difficulties

Total difficulties	7.02	6.03	0	25
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T2 Non-verbal IQ

Block design	26.38	4.20	15	40
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T2-T3 School support

Speech therapy

0	96	69.1		
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1	2	1.4		
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2	41	29.5		
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Special education needs

0	87	68.5		
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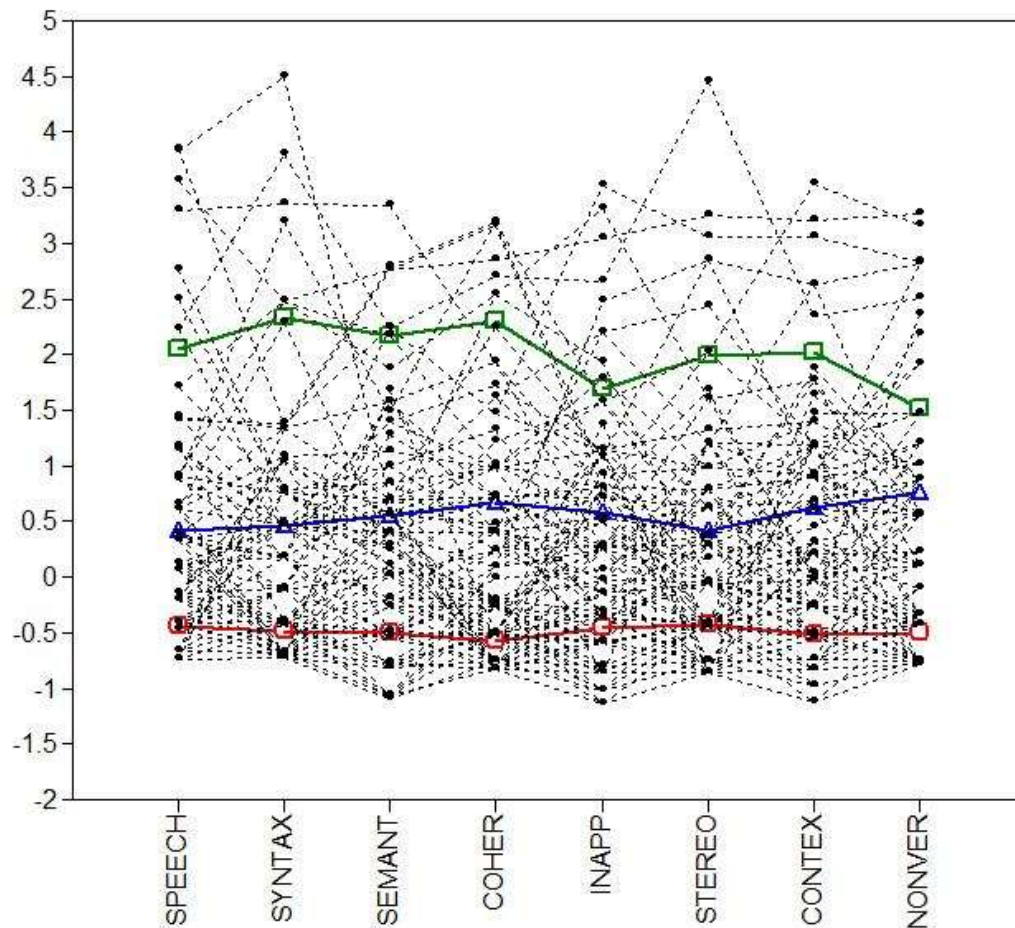
1	29	22.8		
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2	11	8.7		
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Notes. ASD = Autism Spectrum Disorder; ADHD = Attention Deficit

Hyperactivity Disorder; CD = Conduct Disorder; DCD = Dyspraxia.

CHAPTER 3 LANGUAGE DEVELOPMENT AND ALEXITHYMIA

Figure S3.1*Latent Profile Analysis Based on Children's Parent-Reported Full CCC-2 Subscale Scores**Assessing Multi-Domain Language Function at T2 (n = 139)*

Notes. Standardised scores are presented here. Higher scores indicate more language difficulties and impairments. Dotted lines denote individual language profiles across language domains. The latent profile analysis suggests a three-profile solution given the data, namely children with (red: $n = 90$), children with moderate language difficulties (blue: $n = 37$), and children with severe language impairments across all language domains (green: $n = 12$). SEMANT = semantics; COHER = coherence; INAPP = inappropriate initiation; STEREO = stereotyped language; CONTEX = use of context; NONVER = nonverbal communication.

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A descriptive summary of the language Impairments by T2 latent language profiles ($n = 139$) is as follows:

	Profile 1: TD ($n = 90$)				Profile 2: Moderately impaired ($n = 37$)				Profile 3: Severely impaired ($n = 12$)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
T2 CCC-2 (parent, long)	13.83	9.63	0	34	48.02	12.73	28	77	83.37	16.25	64	115
Speech	0.96	1.56	0	7	4.22	3.38	0	13	10.33	4.68	5	17
Syntax	0.68	1.31	0	6	3.95	1.90	0	10	10.33	4.27	3	18
Semantics	1.98	1.95	0	10	5.66	2.02	0	9	11.36	2.47	6	15
Coherence	0.78	1.07	0	4	5.16	2.18	2	11	11.17	3.10	6	16
Inappropriate initiation	2.50	2.39	0	10	6.64	3.44	0	13	11.17	5.01	5	21
Stereotyped language	0.98	1.35	0	6	3.23	2.13	0	9	7.33	3.45	3	15
Use of context	2.01	1.70	0	7	6.32	2.86	1	13	11.67	3.85	8	19
Nonverbal communication	0.69	1.21	0	7	3.84	2.19	0	9	6.00	3.86	0	12

Notes. Raw scores are presented here for descriptive purpose. CCC-2 = Children's Communication Checklist 2; TD = Typically-developing.

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Table S3.2*Model Fit Information of Latent Profile Analysis (n = 139)*

	AIC	Δ AIC	BIC	Δ BIC	ABIC	Entropy	LMR			Best log likelihood						
							VLMR LRT	adjusted LRT	PB LRT	value replicated?	Profile proportions ~10%	Profile 1	Profile 2	Profile 3	Profile 4	
1 Profile	3171.6	--	3218.56	--	3167.93	--	--	--	--	--	--	--	--	--	--	--
		-		-												
2 Profiles	2570.02	601.58	2643.38	575.17	2564.29	0.976	0.0056	0.0062	<.001	Yes	Yes	107	32	--	--	--
		-		-												
3 Profiles	2358.47	211.56	2458.24	185.15	2350.67	0.954	0.2499	0.2571	<.001	Yes	Yes	90	37	12	--	--
		-		-												
4 Profiles	2284.83	73.631	2411.02	47.221	2274.97	0.977	0.3823	0.3865	<.001	Yes	No	94	33	7	5	5

Notes. AIC = Akaike Information Criterion; BIC = Bayesian Information Criteria; ABIC = sample-size adjusted BIC; VLMR LRT = Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR adjusted LRT = Lo-Mendell-Rubin adjusted likelihood ratio test; PB LRT = parametric bootstrapped likelihood ratio test.

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Table S3.3*Sample Characteristics of T2 Latent Language Profiles (n = 139)*

	Profile 1: TD (<i>n</i> = 90)				Profile 2: Moderately impaired (<i>n</i> = 37)				Profile 3: Severely impaired (<i>n</i> = 12)			
	Mean/ <i>n</i>	<i>SD</i>	Min	Max	Mean/ <i>n</i>	<i>SD</i>	Min	Max	Mean/ <i>n</i>	<i>SD</i>	Min	Max
T1 Child age (years)	5.37	0.29	4.83	5.83	5.31	0.27	4.92	5.83	5.19	0.32	4.75	5.75
T1 Female participants	52				22				7			
T1 Child ethnicity												
White	86				34				11			
Other	4				3				1			
T1 Deprivation quintile												
1 st	2				2				0			
2 nd	5				5				4			
3 rd	12				7				1			
4 th	30				8				3			
5 th	41				15				4			
T1 Language function												
Low	27				23				10			
High	63				14				2			
T1 Child ASD diagnosis												
Yes	0				0				4			
No	90				37				8			
T2 Mother's education level												
<=GCSEs	16				15				1			
A-levels/Vocational qualification	22				9				9			
Degree	35				9				1			
Higher degree	17				3				1			
T2 Father's education level												
<=GCSEs	16				13				5			
A-levels/Vocational qualification	34				14				4			

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Degree	25				7					1			
Higher degree	13				1					1			
T2 Family medical history													
>1 ASD/ADHD/CD/DCD	6				6					6			
None	84				31					6			
T1 Strength and difficulties													
Total difficulties	5.39	5.09	0	18	9.49	5.87	1	25	11.67	8.23	1	24	
T2 Non-verbal IQ													
Block design	27.30	4.25	15	40	24.65	3.20	18	32	24.64	4.65	18	32	
T2-T3 School support													
Speech therapy													
0	73				21					2			
1	2				0					0			
2	15				16					10			
Special education needs													
0	73				14					0			
1	10				14					5			
2	3				4					4			

Notes. ASD = Autism Spectrum Disorder; ADHD = Attention Deficit Hyperactivity Disorder; CD = Conduct Disorder; DCD = Dyspraxia.

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Table S3.4*Comparison of T5 Alexithymic Trait Domains between T2 Latent Language Profiles (n = 139)*

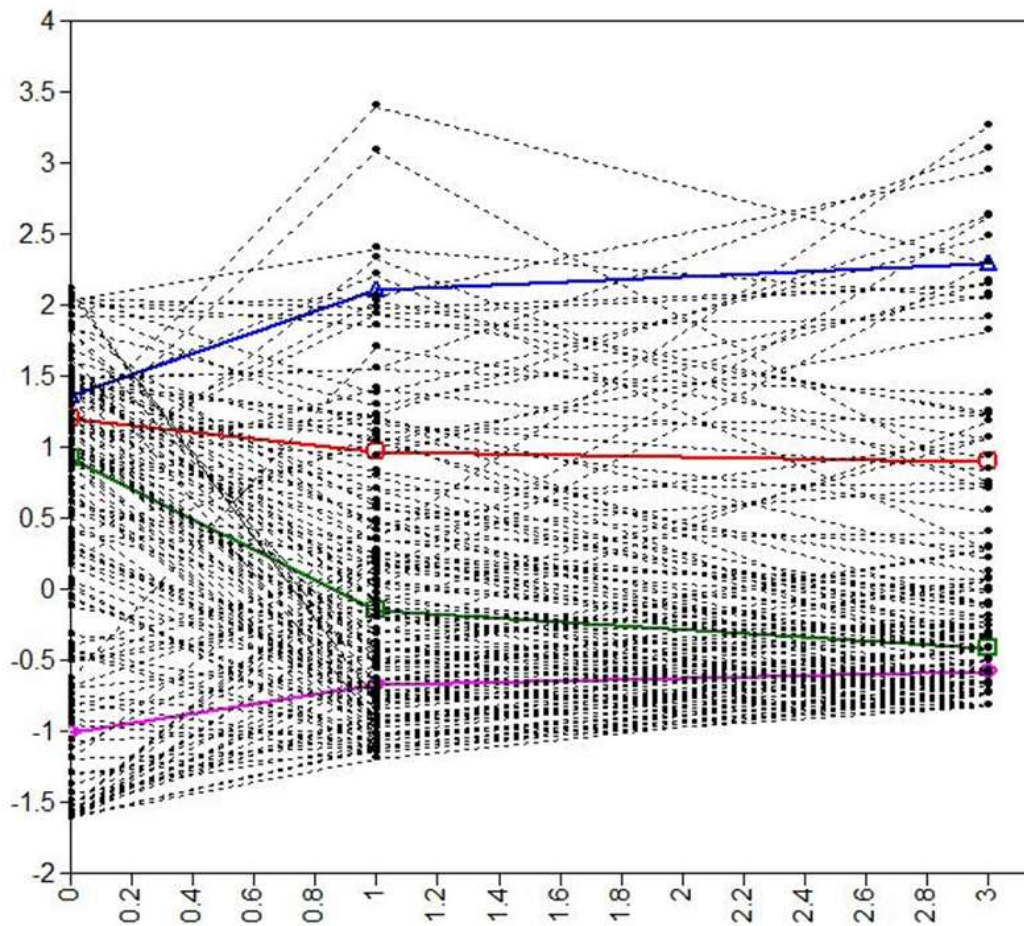
T5 Alexithymia – EAQ	<u>Profile 1: TD (n = 90)</u>		<u>Profile 2: Moderately impaired (n = 37)</u>		<u>Profile 3: Severely impaired (n = 12)</u>		<u>Profile comparison</u>		
	Mean	SD	Mean	SD	Mean	SD	χ^2	<i>p</i>	ϵ^2
Differentiating emotions	15.74	3.62	15.11	3.19	13.92	3.50	3.43	0.180	0.02
Verbal sharing of emotions	6.09	1.86	5.89	1.90	5.00	1.81	3.16	0.206	0.02
Not hiding emotions	9.93	2.64	10.22	2.78	9.33	2.46	0.97	0.616	<.001
Bodily awareness of emotions	10.19	2.74	10.03	2.50	10.42	2.81	0.13	0.937	<.001
Attention to others' emotions	13.66	1.45	13.49	1.52	13.17	2.04	0.53	0.766	<.001
Analyses of own emotions	11.06	2.38	11.08	2.56	11.42	2.15	0.22	0.898	<.001

Notes. EAQ = Emotion Awareness Questionnaire; TD = Typically-developing.

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Figure S3.2

Latent Growth Curve Analysis Based on Children's CCC-2 Total Scores from T1 to T3 (n = 139)



Notes. Standardised scores are presented here. Higher scores indicate more language difficulties and impairments. Dotted lines denote the language development trajectories of individuals from T1 (x-axis = 0) to T3 (x-axis = 3). The latent growth curve analysis suggests a four-trajectory solution given the data, namely children with minimal language concerns throughout (purple: $n = 46$), children who showed persistent language impairments (blue: $n = 15$), children with steady improvement and attained typical language over the years (green: $n = 60$), and children who showed less improvement with moderate language concerns (red: $n = 18$).

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A descriptive summary of the language impairments by T1-T3 language development trajectories ($n = 139$) is as follows:

	Trajectory 1: TD ($n = 46$)				Trajectory 2: Persistently impaired ($n = 15$)				Trajectory 3: Improved ($n = 60$)				Trajectory 4: Less improved ($n = 18$)			
	Mean	<i>SD</i>	Min	Max	Mean	<i>SD</i>	Min	Max	Mean	<i>SD</i>	Min	Max	Mean	<i>SD</i>	Min	Max
T1 CCC-2 (teacher, short)	1.61	2.06	0	8	27.40	11.25	0	39	16.50	8.17	5	39	21.17	8.31	3	38
T2 CCC-2 (parent, long)	13.80	11.98	0	39	64.75	22.49	28	107	22.13	15.00	2	56	60.46	23.36	20	115
T3 CCC-2 (parent, short)	1.13	1.45	0	6	19.95	2.77	16	25	2.40	1.80	0	7	10.40	2.18	6	13

Notes. Raw scores are presented here for descriptive purpose. CCC-2 = Children's Communication Checklist 2; TD = Typically-developing.

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Table S3.5*Model Fit Information of Latent Class Growth Analysis (n = 139)*

	AIC	ΔAIC	BIC	ΔBIC	ABIC	Entropy	VLMR LRT	LMR adjusted LRT	PB LRT	Best log likelihood value replicated?	Trajectory proportions ~10%	Trajectory 1	Trajectory 2	Trajectory 3	Trajectory 4	Trajectory 5
1 Trajectory	1232.82	--	1250.43	--	1231.44	--	--	--	--	--	--	--	--	--	--	--
2 Trajectories	1039.29	-193.53	1065.70	-184.73	1037.22	0.95	<.001	<.001	<.001	Yes	Yes	108	31	--	--	--
3 Trajectories	980.10	-59.18	1015.32	-50.38	977.35	0.98	0.019	0.023	<.001	Yes	Yes	105	19	15	--	--
4 Trajectories	948.60	-31.50	992.62	-22.70	945.16	0.91	0.256	0.271	<.001	Yes	Yes	60	46	18	15	--
5 Trajectories	928.82	-19.79	981.64	-10.98	924.69	0.94	<.001	<.001	<.001	No	No	60	46	18	14	1

Notes. AIC = Akaike Information Criterion; BIC = Bayesian Information Criteria; ABIC = sample-size adjusted BIC; VLMR LRT = Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR adjusted LRT = Lo-Mendell-Rubin adjusted

likelihood ratio test; PB LRT = parametric bootstrapped likelihood ratio test.

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Table S3.6*Sample Characteristics of T1-T3 Language Development Trajectories (n = 139)*

	Trajectory 1: TD (n = 46)				Trajectory 2: Persistently impaired (n = 15)				Trajectory 3: Improved (n = 60)				Trajectory 4: Less improved (n = 18)			
	Mean/n	SD	Min	Max	Mean/n	SD	Min	Max	Mean/n	SD	Min	Max	Mean/n	SD	Min	Max
T1 Child age (years)	5.33	0.28	4.83	5.83	5.28	0.33	4.75	5.83	5.40	0.29	4.92	5.83	5.19	0.27	4.92	5.67
T1 Female participants	30				9				33				9			
Block design																
T1 Child ethnicity																
White	44				15				58				14			
Other	2				0				2				4			
T1 Deprivation quintile																
1 st	1				0				2				1			
2 nd	1				3				7				3			
3 rd	4				3				12				1			
4 th	13				4				17				7			
5 th	27				5				22				6			
T1 Language function																
Low	0				13				33				14			
High	46				2				27				4			
T1 Child ASD diagnosis																
Yes	0				3				0				1			
No	46				12				60				17			
T2 Mother's education level																
<=GCSEs	4				5				17				6			
A-levels/Vocational qualification	11				8				16				5			
Degree	18				1				20				6			
Higher degree	13				1				6				1			
T2 Father's education level																
<=GCSEs	5				4				16				9			
A-levels/Vocational qualification	15				7				26				4			
Degree	16				2				11				4			
Higher degree	9				1				5				0			
T2 Family medical history																
>1 ASD/ADHD/CD/DCD	3				5				5				5			
None	43				10				55				13			
T1 Strength and difficulties																
Total difficulties	3.39	4.10	0	17	10.93	7.13	0	24	7.78	5.30	0	24	10.50	6.88	1	25
T2 Non-verbal IQ	28.54	3.72	15	40	23.36	3.91	18	32	26.27	3.89	20	36	23.56	3.54	18	30
T2-T3 School support																
Speech therapy																
0	44				4				43				5			
1	1				0				1				0			
2	1				11				16				13			
Special education needs																
0	40				1				43				3			
1	2				8				10				9			
2	1				4				3				3			

Notes. ASD = Autism Spectrum Disorder; ADHD = Attention Deficit Hyperactivity Disorder; CD = Conduct Disorder; DCD = Dyspraxia; TD = Typically-developing.

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Table S3.7*Comparison of T5 Alexithymic Trait Domains between T1-T3 Language Development Trajectories (n = 139)*

T5 Alexithymia – EAQ	Trajectory 1: TD (<i>n</i> = 46)		Trajectory 2: Persistently impaired (<i>n</i> = 15)		Trajectory 3: Improved (<i>n</i> = 60)		Trajectory 4: Less improved (<i>n</i> = 18)		Trajectory comparison		
	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>	χ^2	<i>p</i>	ϵ^2
Differentiating emotions	15.96	4.05	14.47	3.29	15.65	3.08	14.06	3.39	5.26	0.154	0.04
Verbal sharing of emotions	6.00	2.16	5.60	1.92	6.12	1.69	5.50	1.72	1.86	0.601	0.01
Not hiding emotions	9.41	2.82	9.60	2.64	10.38	2.59	10.22	2.34	3.72	0.294	0.03
Bodily awareness of emotions	10.00	3.08	10.47	2.59	10.33	2.44	9.78	2.49	0.86	0.836	<.001
Attention to others' emotions	13.87	1.42	13.07	1.98	13.57	1.41	13.22	1.63	3.71	0.294	0.03
Analyses of own emotions	11.15	2.52	10.80	2.76	11.13	2.38	11.06	1.95	0.26	0.965	<.001

Notes. EAQ = Emotion Awareness Questionnaire; TD = Typically-developing.

CHAPTER 3 LANGUAGE DEVELOPMENT AND ALEXITHYMIA

Sex Differences in Language-Alexithymia Relationships

When repeating the dimensional tests within sex at T1 ($N = 229$), there was a significant correlation between T1 language function and difficulties differentiating emotions at T5 in boys, $r(110) = -.19, p = .047$ (girls: $r = .07$), which did not achieve statistical significance when adjusting for non-verbal reasoning and co-occurring socioemotional symptoms (Estimate = $-0.44 [-1.16; 0.29]$, $SE = 0.37, t = -1.18, p = .24$). No other correlations were found for boys ($r_s = -.10$ to $.05$) and girls ($r_s = -.16$ to $.17$), as well as when analysing high and low functioning groups within boys and girls separately ($r_s = -.23$ to $.24$).

For T2 data ($n = 139$), when repeating these analyses in boys only ($n = 58$), poorer language function overall ($r = -.35, p = .006$), and difficulties in speech ($r = -.36, p = .006$), syntax ($r = -.45, p < .001$), semantics ($r = -.36, p = .005$), and inappropriate initiation ($r = -.36, p = .006$) at T2 were significantly correlated with difficulties differentiating emotions at T5 (girls: $r_s = -.03$ to $-.07$). When adjusting for verbal IQ and SDQ scores and controlling for age differences, T2 inappropriate initiation significantly predicted T5 differentiating emotions (Estimate = $-1.09 [-2.09; -0.05]$, $SE = 0.52, t = -2.05, p = .045$, partial $r = -.26$). The association between T2 syntax and T5 differentiating emotions was approaching significance (Estimate = $-1.37 [-2.71; -0.02]$, $SE = 0.69, t = -1.99, p = .052$, partial $r = -.37$). No other associations survived the adjustments (Estimates = -0.41 to -0.65 , $Ses = 0.40$ to $0.46, p_s = .13$ to $.31$). No significant correlations were found for girls, $r_s = -.28$ to $.19$.

Finally, for T3 data ($n = 139$), poorer language function at T3 was correlated with more difficulties differentiating emotions at T5 in boys, $r(56) = -.43, p = .006$ (girls: $r = .05$). This association was confirmed by robust linear regression when adjusting for non-verbal reasoning and SDQ scores and controlling for age differences in boys (Estimate = $-1.34 [-2.59; -.10]$, $SE = .64, t = -2.12, p = .04$, partial $r = -.32$). No other significant associations were found (boys: $r_s = -.21$ to $.01$; girls: $r_s = -.18$ to $.18$).

CHAPTER 3 LANGUAGE DEVELOPMENT AND ALEXITHYMIA

Dimensional Relationships between T2 Behavioural Language Assessment Variables and T5 Alexithymic Traits

On a post-hoc basis, we performed Spearman correlations to explore the relationship between children's performance on the language assessments at T2 and their alexithymic traits at T5 in the selected sample ($n = 137$). Since there were only two children (one boy and one girl) with missing data on these assessments, complete cases were used. To correct for multiple tests, we applied a Bonferroni correction of $.05/6$ EAQ outcome variables at T5 = $.008$ (two-tailed) to these analyses. As expected, children who met the diagnostic criteria for language disorder performed significantly worse on these language assessments than peers with typically-developing language abilities ($t_s = 7.83$ to 9.78 , $p_s < .001$). The same group differences were found between children who further met the diagnostic criteria for developmental language disorder and peers ($t_s = 6.05$ to 9.67 , $p_s < .001$).

Results indicated that better sentence imitation performance on the SASIT at T2 was significantly correlated with children's higher self-perceived ability to differentiate emotions at T5, $r(135) = .26$, $p = .002$. Robust linear regression confirmed that this association remained significant after adjusting for non-verbal reasoning and co-occurring socioemotional symptoms and controlling for age differences, Estimate = 0.13 [0.03 ; 0.22], SE = 0.05 , $t = 2.59$, $p = .01$, partial $r = .26$. No other correlations were found ($r_s = -.12$ to $.18$).

Likewise, when repeating the analyses in boys only ($n = 57$), better sentence imitation on the SASIT was significantly correlated with higher levels of differentiating emotions ($r = .59$, $p < .001$), as well as more verbal sharing of emotions at T5 ($r = .40$, $p = .002$), both of which survived further adjustments in the robust linear regressions (differentiating emotions: Estimate = 0.23 [0.09 ; 0.37], SE = 0.07 , $t = 3.20$, $p = .002$, partial $r = .51$; verbal sharing of

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emotions: Estimate = 0.09 [0.03; 0.16], SE = 0.03, $t = 2.94$, $p = .005$, partial $r = .19$). This suggests that the same association found in the full analytic sample above is likely a product of this moderate to strong association between T2 SASIT performance and T5 differentiating emotions in boys. Boys' higher receptive language abilities on the ROWPVT ($r = .39$, $p < .001$) and TROG ($r = .43$, $p < .001$) at T2 were significantly correlated with higher levels of differentiating emotions at T5. Both associations survived further adjustments (ROWPVT: Estimate = 0.07 [0.02; 0.13], SE = 0.03, $t = 2.49$, $p = .02$, partial $r = .26$; TROG: Estimate = 0.16 [0.03; 0.29], SE = 0.07, $t = 2.35$, $p = .02$, partial $r = .30$). There was a significant correlation between T2 ACE-Recall performance and T5 differentiating emotions in boys ($r = .44$, $p < .001$), but it only achieved marginal significance when adjusting for non-verbal reasoning and SDQ scores (Estimate = 0.26 [-0.002; 0.52], SE = 0.13, $t = 1.95$, $p = .06$).

For the analyses in girls only ($n = 80$), girls who had better expressive language on the EOWPVT at T2 reported paying more attention to others' emotions at T5, $r(78) = .29$, $p = .004$. This association remained significant when adjusting for non-verbal reasoning and co-occurring socioemotional symptoms, and controlling for age differences (Estimate = 0.02 [0.01; 0.04], SE = 0.008, $t = 2.80$, $p = .007$, partial $r = .27$). No other correlations were found ($r_s = -.14$ to $.21$).

Chapter 4**Professional Writers and Alexithymia: Relevance of Interoception and Language**

Abstract

Past research on alexithymia has primarily focused on psychological deficits that give rise to low emotional self-awareness, but studying strengths are equally important as it informs pathways that foster emotional self-awareness. The language hypothesis of alexithymia posits that language impaired groups are at elevated risks of developing alexithymia, yet the role of language talents in emotional self-awareness is unknown. A total of 134 participants comprising 36 professional writers and 98 general individuals took part in this study. Participants completed self-report measures of alexithymic traits, interoceptive accuracy and attention, and completed assessments of general and emotion vocabulary knowledge and an emotion map task that quantified their judgements of the similarity of emotion concepts. Results showed that writers had significantly lower alexithymic traits (mean = 35.89, *SD* = 7.66, median = 35.5, range = 24 to 53) than non-writers (mean = 43.58, *SD* = 11.3, median = 41, range = 22 to 69), and all except one writer were considered non-alexithymic based on established cutoff (≤ 51). This group difference could potentially be explained by the fact that writers reported higher interoceptive accuracy than non-writers, which was in turn associated with low alexithymic traits. This interoceptive pathway was independent of the marginal effect of emotion vocabulary knowledge on alexithymic traits. Writers however did not show robust differences in their conceptual mapping of emotion words as compared to non-writers, and both groups utilised valence-based comparisons as the primary strategy. Findings support the use of a strength-based perspective for widening the discussion of the language hypothesis of alexithymia and theories on the language-emotion link.

Professional Writers and Alexithymia: Relevance of Interoception and Language

*“I always had the deepest affection for people who
carried sublime tears in their silences.”*

Virginia Woolf (1925-1930)

Empirical studies on the link between alexithymia and language have predominantly focused on individuals with low language function and, to a lesser extent, comparing individuals with typical language with language impaired groups, such as those diagnosed with language disorders (see meta-analyses in Chapter 2). This deficit-oriented research approach is not uncommon in clinical psychology and psychiatry more broadly, as it directly characterises the relationship between the clinical trait of interest (alexithymia) and the cognitive-behavioural atypicalities (language impairments) in those with such lived experiences, who would also most likely benefit from the research findings.

In contrast, there is growing advocacy for strength-oriented research that queries whether and how a certain subgroup of individuals would instead demonstrate exceptional capabilities in those psychological domains of interest. This research approach is of clinical relevance, as it addresses psychological difficulties from a positive angle: what the psychological basis of talent is and how expertise (instead of impairments that might cause the seeking of clinical assistance) is acquired in these individuals (Maddux et al., 2004; Seligman & Peterson, 2003). Therefore, studying strengths has the unique feature of allowing researchers and clinicians to identify and understand the “key(s) to success”, promoting the idea of nurturing skills and potential in contrast to treating deficits when working with clinical populations.

There is however a paucity of knowledge regarding the basis of skills and talents in research on alexithymia. It is currently unknown whether individuals who show a

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significantly higher level of awareness of their own feelings as compared to the norm show talent or exceptional skills in psychological domains that subserve emotional self-awareness, such as interoception and language. For instance, studies on Buddhist monks and long-term Buddhist practitioners have inspired clinical work using meditation practices and related mental training to enhance attentional focus (Brefczynski-Lewis et al., 2007; Lutz et al., 2008), improve attention to internal bodily signals and promote empathetic concerns for others (such as the ReSource Project: Kok & Singer, 2017; also see Lutz et al., 2009). Although parallel work that measures alexithymia in Buddhist practitioners does not exist, preliminary studies suggested that mindfulness-based interventions that utilise similar mental training techniques inspired by those Buddhist practices have shown some efficacy in promoting interoceptive functioning and emotional self-awareness in general individuals and subclinical populations (see a systematic review by Norman et al., 2019; a pilot intervention study by Aaron et al., 2020; and a randomised controlled trial by Silveira et al., 2023).

Regarding the role of language in alexithymia, the current study makes use of professional writers as a model for exceptional language skills, comparing their level of alexithymic traits with general individuals who do not intensively engage in such literary activities. Recent theories of emotion development posit that activities such as reading and writing about emotions are some direct learning experiences that foster the acquisition of emotion vocabulary and its related emotion concepts (Hoemann et al., 2019, 2020; Lindquist et al., 2022). From the constructionist perspective, having a large repertoire of emotion vocabulary would provide access to more precise linguistic labels to make sense of vague affective signals as more discrete and specific emotional experiences (Lindquist et al., 2015, 2017), thereby contributing to higher emotional self-awareness (i.e., lower levels of alexithymia). In the case of writers, one would hence expect that the extensive and advanced experience of writing about one's emotional experiences (or those in relation to some

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fictional characters and events) might provide writers with an especially high level of emotional self-awareness (i.e., a very low level of alexithymia), due to their very high level of exposure to, and use of, a rich repertoire of emotion vocabulary and concepts in their literary work.

Other potential pathways associated with increased emotional self-awareness are the ability to represent emotion concepts in a fine-grained fashion and increased interoceptive abilities. In terms of emotion concept representation, it has been found that individuals with higher alexithymic traits have a less granular perception of emotional experiences ($r = -0.10$, see Chapter 2). These alexithymic individuals tend to use a narrow range of emotion labels to describe emotional instances and rate these different instances at similar levels of valence and arousal. This “imprecise” representation of emotional experiences might indicate difficulty differentiating abstract emotion concepts, which may cause one to conflate the boundaries between emotional experiences, contributing to difficulties identifying and describing feelings (Hoemann et al., 2021; Lindquist & Barrett, 2008). There is preliminary evidence suggesting that increased vocabulary knowledge – which may be thought to characterise writers – promotes multi-dimensional representation of emotion concepts as demonstrated by novel analytic methods, such as through mapping one’s perception of the similarity of a series of emotion words with multi-dimensional scaling (Nook et al., 2017). Compared to general individuals, writers might therefore have a more fine-grained representation of emotion concepts, resulting in low levels of alexithymic traits. Furthermore, having exceptional interoceptive abilities, notably the ability to perceive meaningful internal bodily signals with a high degree of accuracy, might also facilitate emotion understanding. For alexithymic individuals, there might be deficits in detecting and accurately monitoring internal bodily signals that are informative of one’s current emotional states (although see a discussion on measurement issues by Trevisan et al., 2019). Despite having been widely discussed in

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clinical populations with co-occurring alexithymia (e.g., reduced emotional granularity in schizophrenia: Vakhrusheva et al., 2020; interoceptive deficits in eating disorders: Jenkinson et al., 2018), these various pathways have not been considered in the realm of talents, among individuals who are instead at the lower end of the alexithymic trait spectrum. Studying professional writers would add nuances to the language hypothesis of alexithymia. The hypothesis predicts that language impairments play a more primary role than interoceptive deficits in the development of alexithymia in language impaired groups (Hobson et al., 2019); yet whether the opposite scenario of having exceptional language skills would guard against the development of alexithymia, regardless of interoceptive ability, is largely unknown.

Based on literature on the positive relationship between language function and emotional abilities, it was hypothesised that professional writers who extensively write about emotional experiences would show significantly lower levels of alexithymia than general individuals who do not intensively engage in those literary activities. Given the novelty of testing the relationship between language talents and alexithymia, and the fact that neither the constructionist theories of emotion nor the language hypothesis of alexithymia has considered the potential mechanisms underlying outstanding emotional abilities, no specific predictions were made regarding the relationship between language talents and other psychological pathways associated with alexithymia.

Method

Participants

A total of 134 participants took part in the study, which comprised 36 professional writers and 98 general individuals who were non-writers (hereafter, non-writers). The professional writers (mean age = 51.31 years, $SD = 10.3$, 83.3% female) were recruited via

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writers' groups and societies from across the UK and from the Royal Literary Fund, a British benevolent fund for professional published authors. The non-writers (mean age = 29.01 years, $SD = 8.44$, 58.2% female) were mainly recruited via online recruitment platforms and sites, including the SONA system at University of Oxford and Testable. All participants declared that they were native English speakers of the target age range (18 to 65 years old), were not diagnosed with any psychiatric disorders and/or experienced any mental health concerns that they would like to seek medical help for, had no history of traumatic brain injury, and were not prescribed with any long-term psychiatric medications. For the purpose of this study, all writers must have been working formally (full-time/part-time) as writers at the time, and mainly composed work that was about one's emotional experiences and/or those in relation to some fictional characters and events. Writers who mainly composed non-fiction work or other compositions that were solely based on factual accounts of real people and events, such as science communication and newspaper articles, were not eligible for the study. This study was approved by the Medical Sciences Interdivisional Research Ethics Committee, University of Oxford (Reference: R84891/RE001).

Measures

Alexithymic Traits

Participants completed the 20-item Toronto Alexithymia Scale (TAS-20) (Parker et al., 2003) which assesses three core domains of alexithymic traits, namely difficulties in identifying feelings, difficulties in describing feelings, and externally-oriented thinking. Responses were rated on a five-point Likert scale ("Strongly disagree" to "Strongly agree"). The internal consistency of the TAS-20 was .84 in non-writers and .72 in writers. Raw scores were analysed.

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Interoceptive Accuracy

The Interoceptive Accuracy Scale (IAS) was used to assess self-perceived ability to accurately perceive internal bodily signals, such as heart rate and the need to urinate (e.g., “I can always accurately perceive when my heart is beating fast / when I need to urinate”) (Murphy et al., 2020). The IAS comprises 21 items rated on a five-point Likert Scale (“Strongly disagree” to “Strongly agree”). Higher scores indicate better self-perceived ability to accurately perceive one’s internal bodily signals. The internal consistency of the IAS was .88 in both non-writers and writers. Raw scores were analysed.

Interoceptive Attention

The Interoceptive Attention Scale (IATS) was used to measure the extent to which one’s attention is focused on internal bodily signals regardless of whether these signals are present or not (Gabriele et al., 2022). The instructions and items of the IATS were almost identical to the IAS, except that the wording of the same interoceptive item was changed to emphasise the degree of attentional focus but not accuracy (e.g., “Most of the time my attention is focused on *whether* my heart is beating fast”). This design feature allows testing for dissociations between the two interoceptive domains and other constructs of interest (Murphy et al., 2019). Participants were also reminded of what would (not) be considered attention to internal bodily signals with specific examples provided in the instructions. Similar to the IAS, the IATS was consisted of 21 items, all of which were rated on a five-point Likert scale (“Strongly disagree” to “Strongly agree”). Higher scores reflect higher self-perceived degree of attentional focus on internal bodily signals. The internal consistency of the IATS was .93 in non-writers and .92 in writers. Raw scores were analysed.

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Self-Perceived Gifts

With reference to the hierarchy of the savant syndrome (Treffert, 1989) and one of the few population-based studies on special skills and autistic traits (Vital et al., 2009), this six-item questionnaire was devised to assess participants' self-perceived gifts in English language skills, describing one's feelings, and describing abstract concepts (such as fairness and justice). The first three items assess self-perceived gifts in the three domains as compared to the participant's general ability level in other skill domains (e.g., "*Do you consider yourself especially better, worse, or about the same, at describing and expressing your own feelings in English, as compared to your general ability level in other areas, such as maths, visual arts, and music?*"). These self-comparing items were rated categorically (Better/Worse/About the same). The remaining three items assess self-perceived gifts in those three domains as compared to others, which are rated out of 100 random people to minimise the requirement to understand statistical terms (e.g., "*Imagine there were 100 random people in a room, how many of them do you think would be better than you at describing and expressing their own feelings in English?*"). For the purpose of this study, participants were also asked about the number of reading and writing hours (per week), and additionally for writers, number of years working formally as a writer, the genre of their literary work, and if they had received any literary awards.

Tasks

Emotion Vocabulary Test

Participants completed an online emotion vocabulary test in which they were asked to define a set of 20 emotion words commonly tested in the emotional granularity literature (e.g., Erbas et al., 2014, also see Chapter 2 for a summary of these studies). These include 10 positive emotion words (affection, amusement, awe, contentment, desire, excitement,

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happiness, interest, peaceful, and surprise) and 10 negative emotion words (anger, anxiety, depression, disgust, embarrassment, fear, guilt, irritation, loneliness, and sadness).

Participants were required to input their responses in a text box with no upper word or time limit, and were prompted to elaborate on their responses if response time was less than 5 seconds on that particular trial. Participants were asked to display the test full screen and asked not to look up dictionary definitions on other devices.

Participants' responses were marked using a marking scheme that was designed with reference to the Oxford and Cambridge dictionaries (Keating et al., 2023), and a study that assessed emotion representation and verbal knowledge in youths aged 6 to 25 (Nook et al., 2017). Responses were scored as in the WASI vocabulary knowledge test, where a score of 2 would be awarded if the response (i) closely resembled the definition provided in the Oxbridge dictionaries, (ii) included a synonym of that emotion, and/or (iii) a specific context that would likely evoke that emotion but not other emotions included on the test. A score of 1 would be awarded if an incomplete dictionary definition was given, or a relevant concept was given but without further elaboration on (or a specific example/context to illustrate) its relevance to that test word (e.g., the word "astonished" mainly entails a very surprised state but lacks the expression of admiration or the feeling of being impressed by outstanding achievement and grandeur that is required for the word "awe"). Responses that were of the opposite valence, the use of personal examples (e.g., when I read a book), and other vague responses (e.g., not happy, not sad, and not angry) would all be marked a score of 0. The 20 item scores were added to form a total sum score, where higher scores reflect better emotion vocabulary knowledge.

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Vocabulary Knowledge

The vocabulary subtest of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II) (Wechsler, 2011) was used to assess participants' general vocabulary understanding. The assessment was performed either during an in-person testing session or a phone call, depending on the participant's availability. Participants were asked to define a list of words and their responses were marked according to the WASI manual (0/1/2). The resulting raw scores were then transformed to age-normed T-scores provided in the assessment manual.

Due to copyright and license issues of the WASI-II, participants recruited via Testable instead completed the vocabulary knowledge test retrieved from Open Psychometrics (<https://openpsychometrics.org/>). The test was comprised of 41 items (four items were removed from the original 45-item test as two items tested emotion words used in the emotion vocabulary test and another 2 items caused technological issues). For each item, participants were required to select the two words, out of a set of five, that had the same or the most similar meaning, where a correct answer (getting both words correct) would be awarded one point. Participants were also given the option to declare that they did not know the answer (for which they received a score of 0 for that item), and received a penalty of -0.35 points for selecting the wrong words. For consistency, the item scores were added to form a total sum score, and then transformed to T-scores using the mean and standard deviation calculated from the scores of participants aged 18 to 65 and whose native language was English as provided in the Open Psychometrics dataset ($N = 7,787$). Higher scores reflect better general vocabulary knowledge. For the sake of subsequent analysis, these T-scores for Testable participants were combined with the WASI-II T-scores for the remaining sample, but we acknowledge that there was no age-normed information regarding the T-score distribution

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of the Open Psychometrics vocabulary test, and that the same T-score might not necessarily correspond to the exact same level of WASI-II performance (see **Limitations**).

Similarity Perception of Emotion Concepts

Participants completed an online emotion map task that assessed their perceived similarity between the emotion concepts defined in the emotion vocabulary test. Specifically, participants were shown the same set of 20 emotion words and were asked to organise the spatial arrangement of these words as if they were creating a mind map for how they would personally feel about these emotions. Participants were encouraged to use the entire screen space (in a two-dimensional manner), and were instructed to place words that were perceived as emotionally similar closer to each other than the other words, but further away from each other if they were perceived as emotionally distinct. There was no time limit on the task and participants were allowed to rearrange the words as many times as they wished until they were satisfied with the final overall spatial arrangement of the words. Participants were also reminded that the task was not to test their understanding or knowledge of these emotion words, but how they subjectively perceived these emotions and there were no right or wrong answers. Note that no axis labels were provided on the screen as it was the study's intention to avoid imposing a pre-determined theoretical framework (e.g., the valence-arousal theory; Russell, 1980) on the participants' reporting of emotion similarity, as such a framework might not necessarily be relevant across the range of individual differences in emotion conceptualisation, such as among those with high alexithymic traits.

The degree of self-perceived similarity between emotion concepts was quantified by calculating the Euclidean distance (h) between each unique pair of emotion words (i.e., 210 unique pairs in total) using their x- and y-coordinates on screen (see equation below), which were then used as the key dependent variable for making statistical inference about the degree

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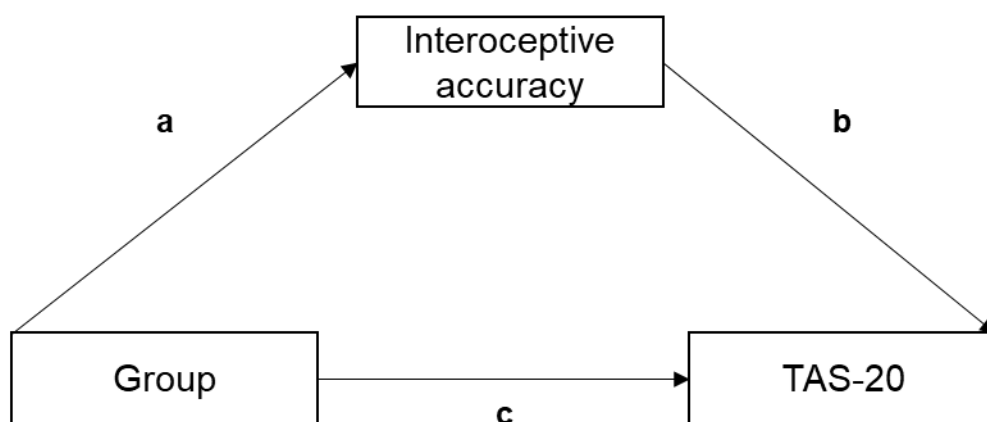
of emotion concept granularity in writers and non-writers. These coordinates were standardised using the participant's actual screen size (due to slight variations in monitor size), and were multiplied by 100 for ease of interpretation:

$$h(x, y) = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2]}$$

Statistical Analyses

The following statistical analyses were performed in R (R Core Team, 2021). All tests were deemed significant at $\alpha = 0.05$ (two-tailed), unless otherwise specified.

The conceptual framework of this study corresponds to a mediation model that tests if the hypothesised group difference in alexithymic traits between writers and non-writers would be mediated by the multiple psychological functions associated with the development of alexithymia. For example, if writers indeed had significantly lower alexithymic traits than non-writers, this could be linked to the fact that writers were significantly more accurate in detecting their internal bodily signals (hence better informing their own emotional states) than non-writers, thereby contributing to high emotional self-awareness (Figure 4.1).

Figure 4.1*Conceptual Model*

- a: Group differences in potential routes of alexithymia
 b: Associations between potential routes and alexithymia
 c: Group difference in alexithymia

Notes. Conceptual model testing interoception and language variables as potential mediators of the hypothesised group difference in alexithymic traits between writers and non-writers (reference). Interoceptive accuracy is used here as an example. TAS-20 = 20-item Toronto Alexithymia Scale.

Accordingly, we first systematically tested the individual paths of this conceptual model, then the overall model comprising all study constructs and their connecting paths. To test our primary hypothesis (path c), a robust linear regression (one-tailed) was used to test if writers were significantly more aware of their own emotions than general individuals. Since the TAS-20 scores were not significantly associated with both age ($r_s = .10$ and $-.11$, $p_s > .27$ in writers and non-writers) and gender (point-biserial $r(96) = .05$, $p = .65$ in non-writers; too few male writers for a robust gender difference test in the writer group), these terms were not added to the model. From a categorical perspective, participants were further grouped into different levels of alexithymia based on the TAS-20 cutoff scores (low alexithymic traits/non-

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alexithymic: 51 or below; moderately alexithymic: 52 to 64, severely alexithymic: 65 or above) (Parker et al., 2003). A chi-squared test (one-tailed) was then used to test if there was a significantly larger proportion of writers being classified into the low alexithymic traits/non-alexithymic category than non-writers. For path a, a series of robust linear regressions was performed to test if writers and non-writers would also differ in the multiple psychological functions associated with the development of alexithymia – namely interoceptive accuracy, interoceptive attention, emotion vocabulary knowledge, and general vocabulary knowledge. Since age was significantly correlated with both interoceptive domains in non-writers and general vocabulary knowledge in both writers and non-writers ($r_s = -.25$ to $.38$, $p_s < .048$), a Group (writers/non-writers) by age interaction term was included in the corresponding regressions to further control for within-group age differences. Point-biserial correlations indicated no gender differences in these psychological functions in non-writers ($r_s = -.13$ to $-.03$, $p_s > .19$). For path b, a separate series of robust linear regressions was used to test the associations between psychological functions (i.e., the potential mediators) and TAS-20. A Bonferroni correction was applied to these regressions, such that only predictors with a p value $< .05/4$ psychological functions = $.013$ would be considered statistically significant.

For conceptual models that achieved statistical significance in all three individual paths, these models were first tested as separate robust mediation models comprising one psychological domain as a single mediator of interest, and then combined as a global mediation model that simultaneously tested those psychological functions as parallel mediators while mutually adjusting for one another's indirect effect. These models were estimated using the lavaan package, with 1,000 bootstrap samples (Rosseel, 2012). While the primary interest of this study was to test the plausibility of considering interoception and language as mediating mechanisms fostering exceptional emotional self-awareness in writers,

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we acknowledged the limitation of using single time-point data to infer the directionality of these constructs (Jose, 2016; Wiedermann & von Eye, 2015; Winer et al., 2016). To provide a comprehensive perspective on the data, alternative mediation models are presented in the **Supplementary Materials** where alexithymia was instead tested as the mediator of the group differences in interoception and language between writers and non-writers.

Next, using all unique Euclidean distances extracted from the emotion map task, two separate principal component analyses (PCA) were conducted to identify principal components of Euclidean distances between emotion words that are representative of the greatest possible amount of statistical information (i.e., variance) in the emotion maps of writers and non-writers. PCA was used to make sense of this high-dimension data (i.e., 210 unique pairs of emotion words x 134 participants = 28,140 Euclidean distances) by (i) comparing the number of principal components that are extractable from the emotion map data for writers and non-writers (if the data can be explained using a smaller number of principal components in one group than the other then this would indicate that the emotion map data are organised in a simpler fashion in the former group, reflecting a less fine-grained representation of emotion concepts), and (ii) qualitatively inspecting the specific pairs of emotion words that contribute to those principal components, with the aim of identifying any potential differences in the strategies used between writers and non-writers when constructing their emotion maps. These PCA extraction techniques are more interpretable than the multi-dimensional scaling used in Nook et al. (2017) for example, as the latter provides little statistical information that describes and/or explains the spatial arrangement of similarity ratings.

Relating the PCA findings to our primary outcome of interest, a principal component regression (PCR) was performed to extract the amount of variance in TAS-20 explained by the principal components identified in the emotion map of writers and non-writers,

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respectively, using the pls package (Wehrens & Mevik, 2007). A 10-fold cross-validation was used to identify the optimal number of principal components when predicting TAS-20 as the outcome variable, which would be indicated by the smallest root mean squared error (of prediction) (RMSEP) ranked across the least to the maximum number of principal components in the emotion map data of each group. Given the unbalanced group size between writers and non-writers, which might bias the identifiable number of principal components and the amount of variance predictive of TAS-20 when comparing the two groups, the non-writers were further split into five internal validation samples (using the writers' group size of 36 as the random sampling size) and the same set of PCA and PCR analyses was re-run in each of these validation samples. The validation results were then compared to the original results in the full sample of non-writers, which allow for assessing the validity of the conclusions drawn from the full-sample comparison. Finally, it was found that 4 writers and 13 non-writers did not utilise all 20 emotion words on the task, which resulted in missing Euclidean distances for the analyses (missing % = 1.2% and 2.6%, respectively). After missing datasets were imputed, re-running the PCAs and PCRs in the imputed datasets resulted in the same conclusions.

Results

Descriptive Statistics and Self-Perceived Gifts

Table 4.1 summarises the demographic information and descriptive statistics of study variables. The current sample of writers reported having worked formally as an author for an average of 17.93 years ($SD = 12.52$). The majority of writers composed novels (31 out of 36), followed by poetry and short stories (8 out of 36 for both genres). Other literary genres included plays (4 out of 36) and children's fiction (3 out of 36). Twenty-three writers declared that they had received multiple literary awards for their work, most of which were considered prestigious in the publishing industry and commonly won by best-selling authors in the UK (note that award names are not specified here so as to preserve anonymity). Writers reported spending significantly more time on reading (mean = 18.06 hours/week, $SD = 15.26$) and writing (mean = 15.67 hours/week, $SD = 8.26$) than non-writers (reading: mean = 8.93 hours/week, $SD = 14.58$, $W = 737$, $p < .001$, effect size $r = 0.45$ (moderate); writing: mean = 5.61 hours/week, $SD = 11.66$, $W = 419.5$, $p < .001$, effect size $r = 0.59$ (large)). Reading and writing hours were not related to alexithymic traits (TAS-20) ($r_s = -.02$ and $-.14$, $p > .11$).

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Table 4.1*Sample Characteristics (N = 134)*

	<u>Writers (n = 36)</u>				<u>Non-writers (n = 98)</u>			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Age (years)	51.31	10.30	26	65	29.01	8.44	18	58
Female, n (%)	30 (83.3)				57 (58.2)			
TAS-20	35.89	7.66	24	53	43.58	11.30	22	69
Low (<=51), n (%)	35 (97.2)				74 (75.5)			
Moderate (52-60), n (%)	1 (2.8)				12 (12.2)			
Severe (>=61), n (%)	0 (0)				12 (12.2)			
DDF	8.89	3.10	5	16	11.99	4.82	5	22
DIF	14.39	5.06	8	27	13.79	6.03	7	32
EOT	12.61	3.83	8	25	17.81	4.24	9	29
IAS	89.00	9.77	71	104	80.52	11.75	52	105
IATS	40.53	13.48	25	78	48.06	16.45	21	92
Emotion vocabulary	25.50	6.51	10	36	22.83	5.85	8	35
General vocabulary	76.33	5.86	58	80	49.13	16.04	19.14	80

Notes. TAS-20 = 20-item Toronto Alexithymia Scale; DDF = Difficulty Describing Feelings;

DIF = Difficulty Identifying Feelings; Externally-Oriented Thinking; IAS = Interoceptive

Accuracy Scale; IATS = Interoceptive Attention Scale. T-scores are presented here for general vocabulary.

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In comparison with non-writers, there was a predominantly larger proportion of writers who considered their English language skills ($\chi^2(2) = 28.83, p < .001, V = 0.46$ (large)) and their abilities to describe their own feelings ($\chi^2(2) = 23.91, p < .001, V = 0.42$ (large)) significantly better than their general ability levels in other domains, such as maths, visual arts, and music. Intriguingly, there was a significantly larger proportion of non-writers who considered their abilities to describe abstract concepts worse than their other skill domains, as compared to writers ($\chi^2(2) = 7.22, p = .03, V = 0.23$ (moderate)), as none of the writers considered their abilities to describe abstract concepts worse than other skill domains.

When commenting on their self-perceived skill levels in the hypothetical scenario of meeting 100 random people in a room, writers estimated a significantly lower number of people who would outperform their English language skills ($W = 2920.5, p < .001$, effect size $r = 0.50$ (large)), and abilities to describe their own feelings ($W = 3056.5, p < .001$, effect size $r = 0.56$ (large)) and abstract concepts ($W = 2527.5, p < .001$, effect size $r = 0.33$ (moderate)), as compared to non-writers. A series of zero-order correlations was conducted to explore the dimensional relationships between alexithymic traits and these self-perceived gifts variables. It was found that individuals with higher alexithymic traits estimated a higher number of people with better English language skills than themselves (i.e., lower self-perceived English language skills) ($r(132) = .25, p = .003$), as well as a higher number of people who are better at describing their own feelings than themselves ($r(132) = .32, p < .001$). Self-perceived ability to describe abstract concepts was not related to alexithymic traits ($r(132) = .08, p = .35$).

Alexithymic Traits in Writers and Non-Writers

Writers had a mean TAS-20 score of 35.89 ($SD = 7.66$, median = 35.5, range = 24 to 53), whilst non-writers had a mean TAS-20 score of 43.58 ($SD = 11.3$, median = 41, range =

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22 to 69). Robust linear regression indicated that writers had significantly lower alexithymic traits than non-writers (Estimate = -7.27 [-10.85; -3.70], SE = 1.82, $t = -3.99$, $p < .001$, one-tailed), with a Cohen's d of 0.69 (moderate) (Figure 4.2). When further exploring group differences in the TAS-20 subscales (two-tailed), it was found that writers scored significantly lower on the externally-oriented thinking (EOT) subscale than non-writers (Estimate = -5.50 [-6.97; -4.03], SE = 0.75, $t = -7.36$, $p < .001$, $d = 1.28$ (large)), but this finding should be interpreted with caution as the internal consistency for the EOT subscale (.55) was low in non-writers. Writers also scored significantly lower on the difficulty describing feelings subscale (Estimate = -2.96 [-4.42; -1.50], SE = 0.75, $t = -3.97$, $p < .001$, $d = 0.69$ (moderate)) than non-writers. No significant group difference was found on the difficulty identifying feelings subscale (Estimate = 0.78 [-1.33; 2.88], SE = 1.07, $t = 0.72$, $p = .47$). The categorical test yielded the same results: when categorising participants into different levels of alexithymic traits based on established cutoff scores on the TAS-20, there was a significantly higher proportion of writers being classified as having low alexithymic traits/non-alexithymic (35 out of 36, 97.2%) than non-writers (74 out of 98, 75.5%), and there were no writers falling into the severely alexithymic category as compared to 12 out of 98 (12.2%) non-writers ($\chi^2(2) = 8.37$, $p = .008$ (one-tailed), $V = 0.25$ (moderate)).

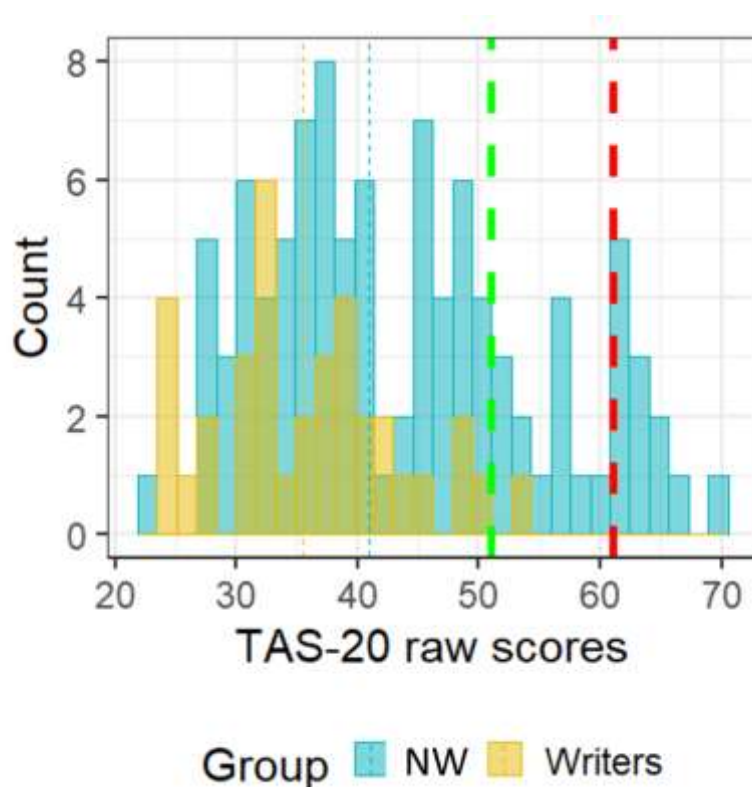
In light of the significant group difference in TAS-20, we further conducted post-hoc comparisons between our writers and the TAS-20 data of two large healthy samples previously recruited from our lab (see Cuve et al., 2022 for recruitment details and sample characteristics). One-sample t-tests indicated that the writers had significantly lower alexithymic traits than past participants in Study 1 ($n = 522$, mean = 47.62, $SD = 11.57$) ($t(35) = -9.19$, $p < .001$, $d = 1.53$ (large)), including the TAS-20 subscales (Study 1 DIF: mean = 16.20, $SD = 5.72$, $t(35) = -1.93$, $p = .03$, $d = 0.32$ (small); EOT: mean = 18.20, $SD = 4.28$, $t(35) = -8.76$, $p < .001$, $d = 1.46$ (large); DDF: mean = 13.22, $SD = 4.53$, $t(35) = -8.39$, p

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<.001, $d = 1.40$ (large)). Similar results were found when comparing writers to past participants in Study 2 ($n = 849$, mean = 46.80, $SD = 12.49$) ($t(35) = -8.55$, $p < .001$, $d = 1.42$ (large)), including the EOT (mean = 18.74, $SD = 4.72$) ($t(35) = -9.61$, $p < .001$, $d = 1.60$ (large)) and DDF subscales (mean = 13.05, $SD = 4.77$) ($t(35) = -8.06$, $p < .001$, $d = 1.34$ (large)), but not the DIF subscale (mean = 15.01, $SD = 6.09$) ($t(35) = -0.74$, $p = .23$, $d = 0.12$ (trivial)).

Figure 4.2

Distribution of TAS-20 Scores in Writers and Non-Writers



Notes. Yellow and blue dashed lines show the median TAS-20 scores in writers and non-writers (NW), respectively. Green dashed line represents the cutoff score for low alexithymic traits/non-alexithymic individuals (51 or below), whilst red dashed line represents the cutoff score for those with severe alexithymia (65 or above). TAS-20 = 20-item Toronto Alexithymia Scale

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As a preliminary test of directionality, a logistic regression predicting group membership (writers/non-writers) from TAS-20 scores while controlling for age was performed. Results indicated that the odds ratio of being in the writer group per unit increase in TAS-20 was 0.90 [0.83; 0.99], $p = .02$, approximating a Cohen's d of 0.06 (trivial). Altogether, the above findings suggested that being a writer increases the odds of low alexithymic traits, whilst having low alexithymic traits would not necessarily increase the odds of being a writer.

Group Differences in Interoception and Language and Their Associations with Alexithymic Traits

Table 4.2 summarises the regression results predicting group differences in interoception and language between writers and non-writers (path a); Table 4.3 (page 228) summarises the associations between psychological functions and alexithymic traits (path b). For interoception, it was found that when controlling for within-group age differences, writers reported significantly higher interoceptive accuracy than non-writers (Estimate = 26.03 [8.37; 43.69], SE = 9.01, $t = 2.89$, $p = .005$, $d = 0.51$ (moderate)). Higher interoceptive accuracy was significantly associated with lower alexithymic traits (Estimate = -0.42 [-0.55; -0.29], SE = 0.07, $t = -6.25$, $p < .001$). Writers also reported paying less attention to interoceptive signals than non-writers, but this group difference was associated with the age confound that older age was significantly associated with lower interoceptive attention in non-writers (Estimate = -0.51 [-0.80; -0.23], SE = 0.15, $t = -3.51$, $p < .001$). Less interoceptive attention was significantly associated with lower alexithymic traits (Estimate = 0.24 [0.09; 0.40], SE = 0.08, $t = 3.09$, $p = .002$).

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Table 4.2

Summary of Robust Linear Regression Predicting Group Differences in Alexithymia-Related Psychological Functions between Writers and Non-Writers

Outcome	Predictor	Estimate	95% LL	95% UL	SE	t	p
IAS	(Intercept)	71.01	63.27	78.74	3.95	18.00	<0.001
	Group: Writers	26.03	8.37	43.69	9.01	2.89	0.005
	Group: NW x age	0.33	0.08	0.58	0.13	2.55	0.012
	Group: Writers x age	-0.15	-0.45	0.15	0.15	-0.99	0.323
IATS	(Intercept)	62.36	52.58	72.15	4.99	12.49	<0.001
	Group: Writers	-7.15	-32.26	17.96	12.81	-0.56	0.578
	Group: NW x age	-0.51	-0.80	-0.23	0.15	-3.51	<0.001
	Group: Writers x age	-0.31	-0.73	0.11	0.22	-1.43	0.156
Emotion vocabulary	(Intercept)	23.08	21.87	24.29	0.62	37.33	<0.001
	Group: Writers	3.35	1.04	5.66	1.18	2.84	0.005
General vocabulary	(Intercept)	56.34	42.65	70.03	6.99	8.07	<0.001
	Group: Writers	6.97	-12.92	26.85	10.15	0.69	0.494
	Group: NW x age	-0.24	-0.63	0.15	0.20	-1.21	0.228
	Group: Writers x age	0.25	0.00	0.51	0.13	1.94	0.055

Notes. Six writers did not attend the WASI-II vocabulary test. NW = non-writers; IAS =

Interceptive Accuracy Scale; IATS = Interceptive Attention Scale.

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Table 4.3

Summary of Robust Linear Regression Predicting Alexithymic Traits with Potential Routes of Alexithymia

Outcome	Predictor	Estimate	95% LL	95% UL	SE	t	p
TAS-20	(Intercept)	75.67	64.05	87.30	5.93	12.76	<0.001
	IAS	-0.42	-0.55	-0.29	0.07	-6.25	<0.001
TAS-20	(Intercept)	30.03	23.49	36.56	3.33	9.01	<0.001
	IATS	0.24	0.09	0.40	0.08	3.09	0.002
TAS-20	(Intercept)	51.98	44.40	59.55	3.87	13.45	<0.001
	Emotion vocabulary	-0.47	-0.75	-0.18	0.14	-3.24	0.002
TAS-20	(Intercept)	52.53	45.09	59.97	3.79	13.84	<0.001
	General vocabulary	-0.20	-0.31	-0.09	0.06	-3.42	<0.001

Notes. Six writers did not attend the WASI-II vocabulary test. IAS = Interoceptive

Accuracy Scale; IATS = Interoceptive Attention Scale; TAS-20 = 20-item Toronto

Alexithymia Scale.

For language, writers had significantly better knowledge of emotion vocabulary than non-writers (Estimate = 3.35 [1.04; 5.66], SE = 1.18, $t = 2.84$, $p = .005$, $d = 0.49$ (moderate)). Better emotion vocabulary knowledge was associated with lower alexithymic traits (Estimate = -0.47 [-0.75; -0.18], SE = 0.14, $t = -3.24$, $p = .002$). Thirty out of thirty-six writers attended the WASI-II assessment. In this subset of the sample ($n = 128$), although better vocabulary knowledge was associated with lower alexithymic traits (Estimate = -0.20 [-0.31; -0.09], SE = 0.06, $t = -3.42$, $p < .001$), writers did not have significantly better vocabulary knowledge than non-writers (Estimate = 6.97 [-12.92; 26.85], SE = 10.15, $t = 0.69$, $p = .49$). Older age

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was marginally associated with better vocabulary knowledge in writers (Estimate = 0.25 [0.00; 0.51], SE = 0.13, $t = 1.94$, $p = .055$).

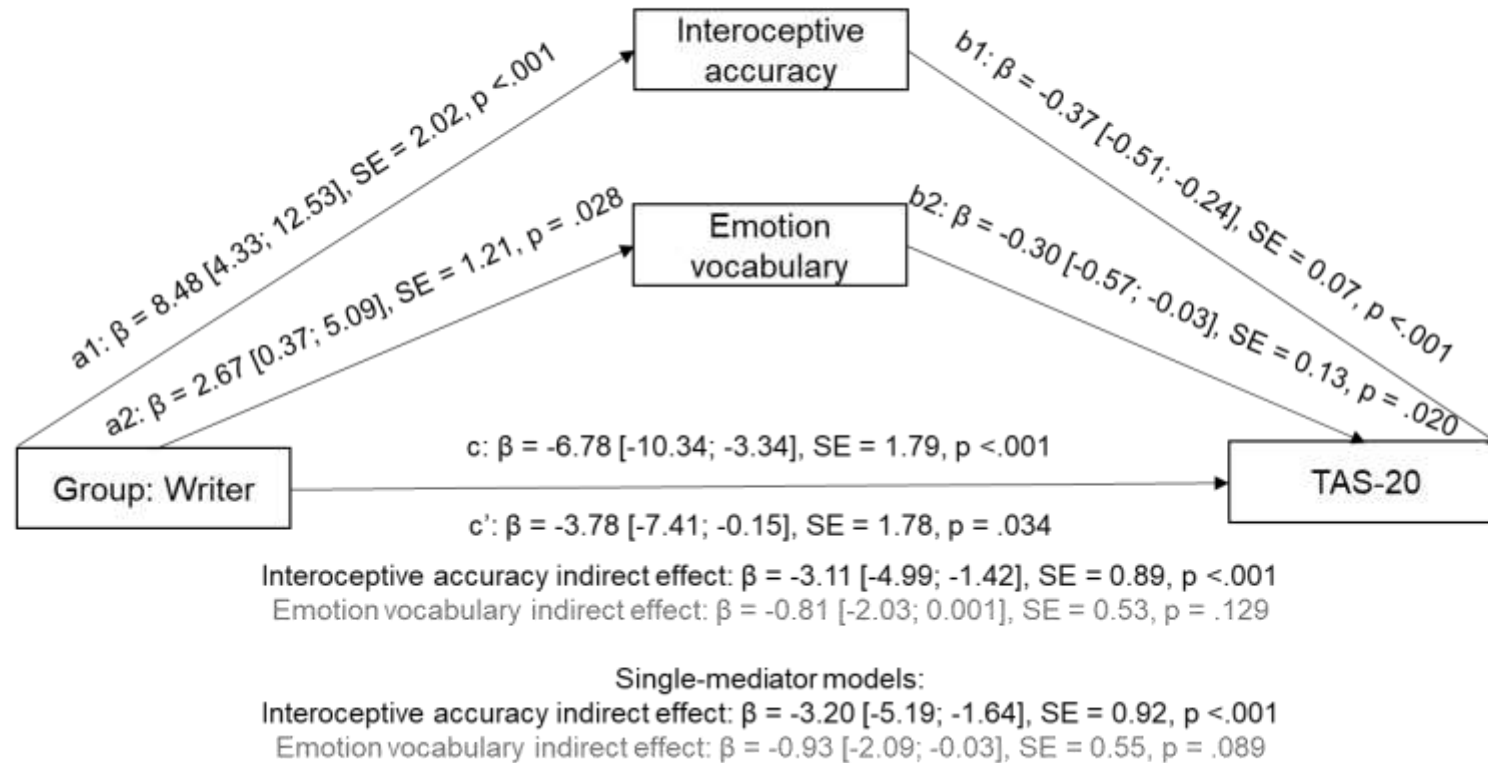
Mediation Models of Interoceptive Accuracy and Emotion Vocabulary Knowledge

Interoceptive accuracy and emotion vocabulary knowledge were the two constructs that showed significant group differences between writers and non-writers (path a) and were significantly associated with alexithymic traits (path b), supporting the use of mediation models. When analysed separately, there was a significant indirect effect of interoceptive accuracy (Estimate = -3.20 [5.19; -1.64], SE = 0.92, $p < .001$), suggesting that low alexithymic traits in writers were associated with the fact that writers were significantly more accurate in perceiving their interoceptive signals than non-writers. The indirect effect of emotion vocabulary knowledge however was only marginally significant (Estimate = -0.93 [-2.09; -0.03], SE = 0.55, $p = .09$). Entering both constructs to the same mediation model as parallel mediators revealed the same results (Figure 4.3): there was a significant indirect effect of interoceptive accuracy (Estimate = -3.11 [-4.99; -1.42], SE = 0.89, $p < .001$), but not for emotion vocabulary knowledge (Estimate = -0.81 [-2.03; 0.001], SE = 0.53, $p = .13$). The direct effect of group on alexithymic traits remained significant after accounting for the indirect effects of interoceptive accuracy and emotion vocabulary (Estimate = -3.78 [-7.41; -0.15], SE = 1.78, $p = .03$), suggesting interoceptive accuracy as a partial mediator.

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Figure 4.3

Parallel Mediation Model of Interoceptive Accuracy and Emotion Vocabulary Knowledge



Notes. Standardised estimates are presented here. TAS-20 = 20-item Toronto Alexithymia Scale.

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Re-running the parallel mediation model with the DDF subscale, which showed a significant group difference previously, revealed similar results: there was a significant indirect effect of interoceptive accuracy (Estimate = -1.27 [-2.08; -0.54], SE = 0.39, $p = .001$), but not emotion vocabulary knowledge (Estimate = -0.19 [-0.62; 0.08], SE = 0.18, $p = .30$). For EOT, however, there were no significant indirect effects for both interoceptive accuracy (Estimate = -0.13 [-0.80; 0.42], SE = 0.30, $p = .68$) and emotion vocabulary knowledge (Estimate = -0.39 [-1.03; 0.01], SE = 0.26, $p = .13$).

Perception of the Similarity of Emotion Concepts

Statistical Structure of Emotion Maps

Table 4.4 (page 233) summarises the PCA results in writers and non-writers. The emotion map data of writers allowed for the extraction of six principal components (58.7% cumulative variance). The first principal component comprised mainly comparisons between positive and negative emotion words (22.75% variance), suggesting a primary mechanism based on valence. The second principal component comprised within-valence comparisons with the use of “anchor words” as key comparators, in that the majority of these Euclidean distances involved comparing “sadness” and “loneliness” with other negative emotion words (11.43%). This was followed by the use of other anchor words as key comparators from the third to sixth principal components. In the full sample of non-writers, PCA revealed only two extractable principal components (30.71% cumulative variance); the first principal component (22.35% variance) comprised valenced-based comparisons between positive and negative emotion words as seen in writers. However, when repeating the PCA in each of the five subsets of non-writers ($n = 36$), results indicated that having 35 components would explain 100% variance, an estimate that approximated that in writers. These internal validations identified four to five principal components in the subsets (average cumulative

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variance = 49.02%): the first and second components revealed a converging pattern with the full-sample analysis that non-writers mainly utilised valence-based comparisons and then within-valence comparisons. However, from the third components onwards, there were some signs of using specific emotion words as key comparators, albeit less consistently in some, but not all, principal components as observed in writers. Specifying the same number of six principal components in non-writers would achieve an average of 55.36% variance, approximating the estimate found in writers.

Altogether, these results suggested that while writers might seem to have a more fine-grained representation of these emotion concepts than the full sample of non-writers, their emotion maps were in fact represented by a similar number of groups of Euclidean distances while controlling for sample size, indicating a comparable degree of complexity between their representations of emotion concepts. Mechanism-wise, both groups shared the primary strategy of differentiating emotions based on valence (positive vs. negative), with some signs of utilising the additional strategy of focusing on specific emotion words as key comparators when making more fine-grained similarity judgments with all other emotion words.

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Table 4.4

Principal Component Analysis of Euclidean Distances between Emotion Word Pairs in Writers and Non-Writers

	<u>Writers</u>		<u>Non-writers (full sample)</u>	
No. of PC (100% variance)	31		84	
No. of PC (≥5% variance)	6	58.70%	2	30.71%
1st	Positive vs. negative	22.75%	Positive vs. negative	22.35%
2nd	Within-valence: sadness and loneliness	11.43%	Within-valence	8.35%
3rd	Desire and excitement	6.97%	--	--
4th	Anger and fear/anxiety	6.26%	--	--
5th	Surprise	6%	--	--
6th	Affection and amusement	5.30%	--	--
<i>Principal component regression predicting alexithymic traits</i>				
	No. of PC	% (RMSEP)	No. of PC	% (RMSEP)
TAS-20	6	26.40 (8.29)	17	33.61 (10.51)

Notes. Specifying six principal components in the non-writers' principal component regression as a direct comparison with the writers' regression results would explain an average of 19.20% variance in their alexithymic traits. PC = principal component; RMSEP = root mean squared error; TAS-20 = 20-item Toronto Alexithymia Scale.

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Predicting Alexithymic Traits

In writers, PCR indicated that despite having explained 26.40% variance in TAS-20, the six principal groups of Euclidean distances (as identified previously in the writers' PCA) had a greater prediction error (RMSEP = 8.29) than the intercept-only model comprising only their mean TAS-20 scores (RMSEP = 7.87; Table 4.4, page 233). Likewise, the PCR in the full sample of non-writers indicated that a model with 17 principal components was considered optimal when predicting TAS-20 (33.61% variance, RMSEP = 10.51), yet this full-sample model was not reproducible in the five validation subsets of non-writers ($n = 36$), where the intercept-only model was found to have the smallest RMSEP in two of the five validation models. These results suggested that neither the writers' nor the non-writers' similarity judgments of emotion concepts were diagnostic of their alexithymic traits. Results remained unchanged in the imputed datasets.

Supplementary Analyses

Three sets of supplementary analyses are presented. First, a sequential mediation model was used to test interoceptive accuracy and emotion vocabulary knowledge as two consecutive mediators. This serves as a preliminary test of the constructionist proposal that linguistic labels facilitate the understanding and making sense of vague affective signals (including internal bodily sensations) as more discrete and specific emotions, thereby promoting better emotional self-awareness. Results however indicated a non-significant association between the two constructs, and that the total indirect effect was not significant (Figure S4.1). Likewise, a follow-up model testing interoceptive accuracy as a shared mediator of alexithymic traits and emotion vocabulary knowledge indicated a non-significant indirect effect to emotion vocabulary, despite providing a better fit to the data than the sequential model (Figure S4.2). Second, addressing the limitation of using single time-point

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data to infer the directionality of these constructs, an alternative mediation model was used to test alexithymic traits as a shared mediator of group differences in interoceptive accuracy and emotion vocabulary knowledge. Results indicated significant indirect effects of alexithymic traits (Figure S4.3). Third, a series of robust linear regressions were performed to test if the associations between alexithymic traits and the interoception and language variables would vary between writers and non-writers using an interaction term between group and each of the psychological constructs. A Bonferroni correction of $p < .013$ was applied to these regressions (Table S4.1 and Figure S4.4). Results showed that lower alexithymic traits were associated with lower interoceptive attention and better general vocabulary knowledge in non-writers. All supplementary results are presented in **Supplementary Materials**.

Discussion

Studying strengths is equally important as studying difficulties and deficits, as it informs the potential mechanisms underlying success in the psychological construct of interest, promoting a skill-oriented perspective that is frequently overlooked in deficit-oriented research and clinical practice. To our knowledge, this is the first empirical study that extends the language hypothesis of alexithymia and the broader link between language and emotion with a focus on language talents. By comparing professional writers who extensively write about emotional experiences with a control group of general individuals who do not have such literary experiences, the primary hypothesis was supported that writers have even lower alexithymic traits than the group of non-writers, who on average reported a low level of alexithymia traits as is typically observed in the literature. The same conclusion can be drawn from a categorical perspective, in that none of the writers surpassed the established cut-off score for severe alexithymia (although one writer scored the lowest possible score in the

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moderate alexithymia category). Importantly, this group difference in alexithymic traits was associated with the fact that writers showed significantly higher interoceptive accuracy and marginally better knowledge of emotion vocabulary than non-writers, which were in turn associated with lower alexithymic traits. While greater interoceptive attention and better general vocabulary knowledge were associated with lower alexithymic traits in general, these pathways were not associated with the group difference in alexithymic traits.

The language hypothesis of alexithymia predicts that language impaired groups have an elevated risk of developing alexithymia. While the current study provides preliminary support for the reverse prediction that writers (a group with high language proficiency) have a reduced risk of developing alexithymia, it should be acknowledged that this may not be directly related to their literary proficiency. In terms of their language expertise, having an extensive repertoire of emotion vocabulary may only play a marginal role in fostering emotional self-awareness in writers; general vocabulary knowledge on the other hand – a domain-general language pathway – does not seem to be a contributing mechanism. Intriguingly though, the low alexithymic traits in writers were instead associated with an interoceptive pathway, whereby being very accurate in perceiving one's internal bodily signals may allow writers to make sense of affective signals that are highly informative of their emotional states. The role of language with respect to alexithymia may therefore be specific to language impaired groups, and having high language proficiency may not necessarily serve as a protective factor that guards against the development of alexithymia (see a similar discussion on the unique risks of developing socio-emotional symptoms in children with a developmental disorder; Goh et al., 2021).

It is important to note that the interoceptive pathway might be specific to interoceptive accuracy, as the lower self-perceived interoceptive attention in writers was possibly a product of their older age than non-writers. This highlights the need to specify the

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interoceptive construct of interest when hypothesising about the possible relevance of interoception to alexithymia (Murphy et al., 2018, 2019; Trevisan et al., 2019). A positive association was found between interoceptive attention and alexithymic traits, which seems to be at odds with the intuition that paying more attention to interoceptive signals would make identifying one's emotional states less difficult. Paying constant attention to interoceptive signals may be a sign of health anxiety and/or medical concern (e.g., someone with bladder issues may be extremely aware of and sensitive to the need to urinate) (Pollatos et al., 2007). A future measure that assesses one's ability to attend to these bodily signals adaptively, such as when there is an actual need to evaluate one's internal states (including emotions), would be useful to clarify its link with alexithymia. It is of course also possible that difficulties determining one's own emotional state (i.e., alexithymia) cause one to pay greater attention to signals from one's body in order to determine one's own emotional state.

Despite being widely discussed in the constructionist literature, both emotion and general vocabulary knowledge do not appear to be key language pathways that foster emotional self-awareness. In particular, regarding the proposal that linguistic labels facilitate the making sense of vague affective states (including internal bodily sensations experienced in an emotional context) as discrete and specific emotions (Lindquist et al., 2015, 2017), our analysis found no evidence for a direct pathway between emotion vocabulary knowledge and interoceptive accuracy that is linked to low alexithymic traits in writers. The accurate perception of interoceptive signals remains a major pathway associated with high emotional self-awareness that is independent of the effect of emotion vocabulary knowledge. Future studies may consider testing other language domains (e.g., structural language abilities in Chapter 3) and their potential interactions with interoception over time, which may indirectly promote emotional self-awareness.

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The strength of the emotion map task is that it does not impose any pre-determined theoretical framework (such as the valence-arousal theory) on the participants' conceptual arrangement of the emotion words, which may not be applicable to individuals with atypical emotional experience and/or clinical populations (Hoemann et al., 2021). Indeed, without such experimenter-imposed constraints (as commonly used in past experience sampling studies which found a modest association between alexithymia and less granular perception of emotions in Chapter 2), our sample of writers created emotion maps that were statistically and structurally comparable to the validation subsets of non-writers. Specifically, although our inspection of the principal components suggest that writers might have a larger number of influential components with the use of "anchor words" (which may indicate some degree of strategic comparisons between smaller groups of emotion concepts), these initial findings were only valid when comparing to the full sample of non-writers as data homogeneity increased with a larger sample of non-writers, thereby exaggerating variations found among the smaller group of writers. One common feature, however, is that both writers and non-writers seemed to have utilised valence (positive/negative) as a primary source of information to differentiate the emotion words but there is no evidence suggesting the use of arousal (high/low) in both groups, which again challenges the validity of imposing the valence-arousal theory on past experience sampling tasks. In terms of predictability, neither the emotion map data of writers nor those of non-writers explained their within-group variance in alexithymic traits well. This indicates that the computation and/or representation of the similarity of emotion concepts may not be a psychological process that underpins alexithymia, and may well instead represent an emotion construct that is distinct from alexithymia (Hoemann et al., 2021).

While the current study found evidence for exceptionally low alexithymic traits in professional writers, the use of single time-point data has the limitation of making it difficult

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– if not impossible – to rule out alternative links between these constructs. For instance, our supplementary analyses pointed out that given the data, it was statistically plausible that high interoceptive accuracy and better emotion vocabulary knowledge could be outcomes of low alexithymic traits in writers. Individuals with poor emotional self-awareness may also encounter more challenges in succeeding as a fiction writer, or somehow be less likely to pursue a literary career. However, our conceptual model is consistent with the mechanistic pathways outlined in the interoceptive and language hypotheses of alexithymia (Brewer et al., 2016; Hobson et al., 2019) and the theory of constructed emotion and language (e.g., Lindquist et al., 2015, 2017), all of which posit interoception and language as cognitive processes that give rise to emotional self-awareness and related abilities. In contrast to interoceptive accuracy, alexithymia is a construct specific to the emotional domain, making it conceptually insufficient to explain the domain-general ability to accurately perceive one’s internal bodily signals.

In terms of measurement, the current set of measures, except WASI-II, was mostly inspired by clinical work and/or designed with the aim to detect potential deficits (such as the IAS and IATS). In other words, our measures may not be sensitive to capture individual differences that are truly representative of exceptional abilities and talents that are far away from the norm. This is in fact a broader issue in the field, as the vast majority of language assessments are clinical tools that lack information on what level of performance would be considered exceptional or gifted, partly because of the prioritisation of clinical utility and the rarity of these “expert” individuals for validity tests. Similar issues have been reported in the study of savant skills in autism (e.g., Howlin et al., 2009), although the nature of talents in some autistic individuals are likely different from those observed in writers. The former may be a product of early neurodevelopmental atypicalities and other autistic symptoms (Happé & Vital, 2009), whereas literary expertise is likely to be a combination of language gifts, literary

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interests, and persistent practice/training. The continuation of talent and expertise research on alexithymia would ultimately require some level of consensus on what constitutes outstanding emotional self-awareness and exceptional skills in its associated psychological pathways (Hoemann et al., 2021).

Strengths and Limitations

This study has various strengths, including the use of a strength-oriented approach to examine the link between language talents and alexithymia, and the measurement of multiple psychological functions (interoception and language) with the aim to test their relative importance to alexithymia. In terms of limitations, due to the novelty of this study, it was not possible to conduct power analysis prior to data collection, and alongside the practical difficulty of recruiting professional writers, the relatively small sample of writers may have limited our power to detect some of the smaller associations and/or confirm their true absence using equivalence tests. Still, the primary finding that writers had especially low alexithymic traits is robust, with at least moderate effect sizes throughout. Recruiting age- and gender-matched non-writers would be ideal to further rule out any potential demographic confounds. Recruiting younger writers would also be useful to test if results generalise to younger age groups, although one might expect that becoming a professional writer would normally require substantial experience. Also note that one might not expect to observe exceptionally low alexithymic traits in non-fiction writers and/or writers who mainly compose factual descriptions of actual events (e.g., journalists and science writers), as these literary experiences do not involve a high level of engagement with one's emotional experiences, although they might help clarify in future research if the group difference in alexithymic traits between fiction writers and general individuals relates to the writing of emotional experiences or extensive writing experience in general. Self-report measures of interoception were used; behavioural assessments (such as the phase adjustment task by Plans et al., 2021) may

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provide a more objective measure of interoceptive abilities. We also could not completely rule out the possibility that some non-writer participants who were recruited via Testable might have provided false information on their English language status, and our non-writers in general might have overestimated their weekly reading and writing time and/or not be representative of population estimates (in comparison with spending a daily average of 3 hours 44 minutes on free time activities in the UK, including reading; Office for National Statistics, 2023). The T-scores for vocabulary knowledge in participants who completed the WASI-II and the vocabulary test from Open Psychometrics permits were combined for the sake of analysis, but there is the possibility that the same T-score may not represent the exact same level of capability in a given age range. Future research on the compatibility of standardised IQ tests and open-source/publicly available psychometric tests would be useful. Finally, direct statistical tests for comparing the results of PCA and PCR between writers and non-writers are not available, and the observed similarities/differences in their emotion map data are primarily based on descriptive statistics.

Conclusion

In sum, the current study reported the first investigation of language talents and their relationship with alexithymic traits. Using professional writers as a model of language talents, it was found that writers had significantly lower alexithymic traits than non-writers, who were within the low to moderate range of alexithymic traits as commonly observed in large-scale studies. The mechanism that underlies the especially low alexithymic traits in writers relates to the widely discussed interoceptive pathway, whereby writers reported being significantly more accurate in perceiving their internal bodily signals than non-writers, which was in turn associated with low alexithymic traits. This interoceptive pathway exists independently alongside emotional vocabulary knowledge, which only showed a marginal effect on low alexithymic traits. We emphasise that the study of language talents is deemed

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crucial to widen the existing discussion surrounding the language hypothesis of alexithymia and theories regarding the link between language and emotional abilities.

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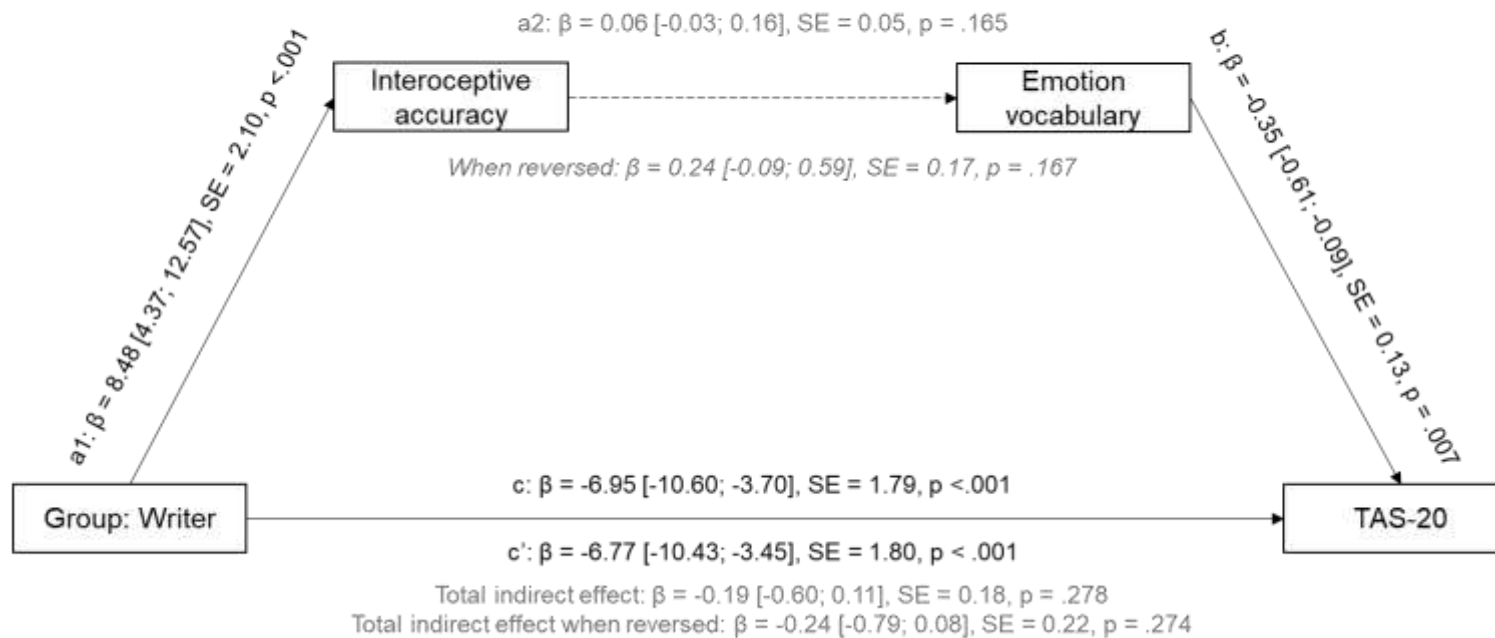
Chapter 4

Supplementary Materials

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Figure S4.1

Sequential Mediation Model Testing Interoceptive Accuracy and Emotion Vocabulary as Consecutive Mediators

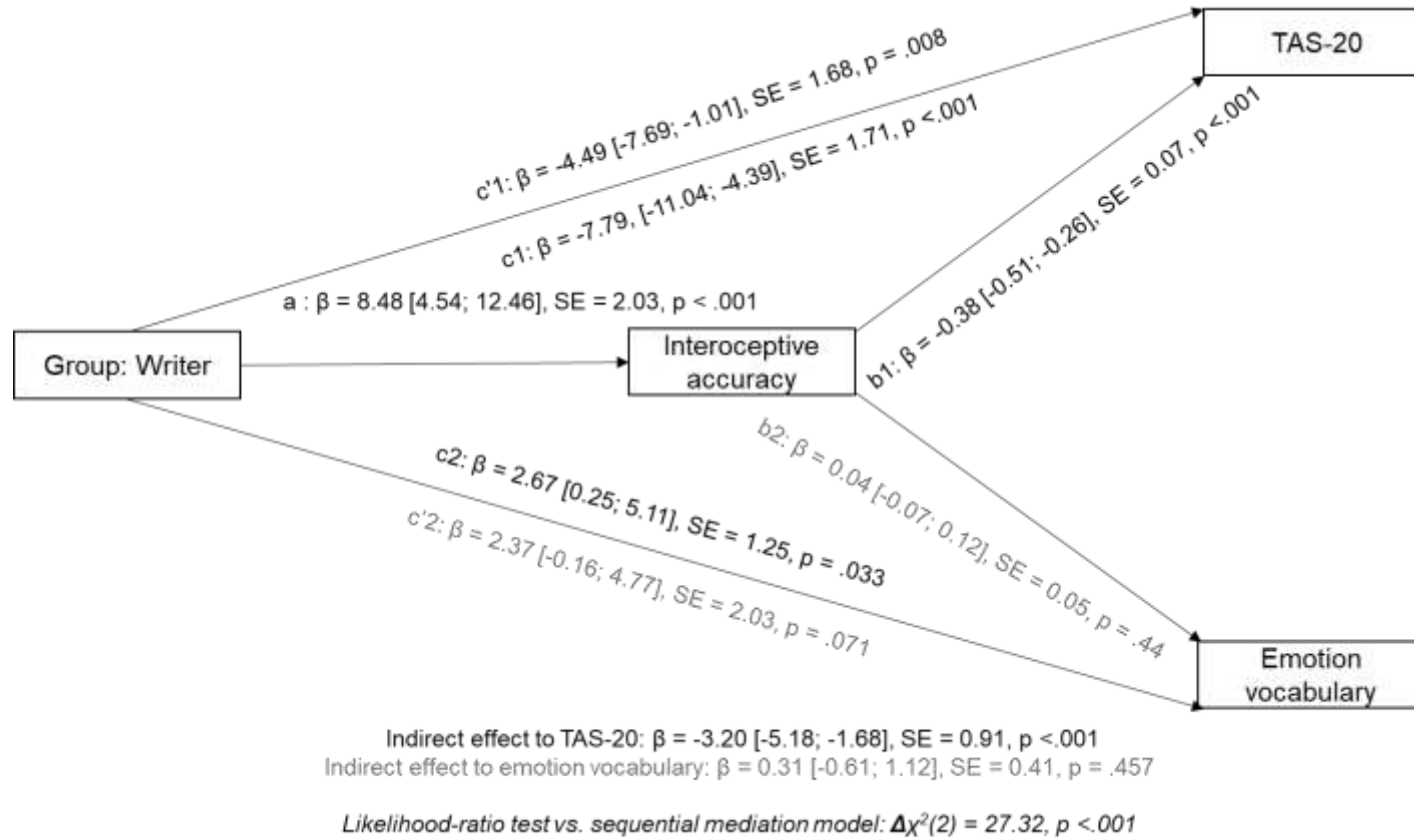


Notes. Standardised estimates are presented here. TAS-20 = TAS-20 = 20-item Toronto Alexithymia Scale.

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Figure S4.2

Follow-Up Model Testing Interoceptive Accuracy as Shared Mediator of Alexithymia and Emotion Vocabulary

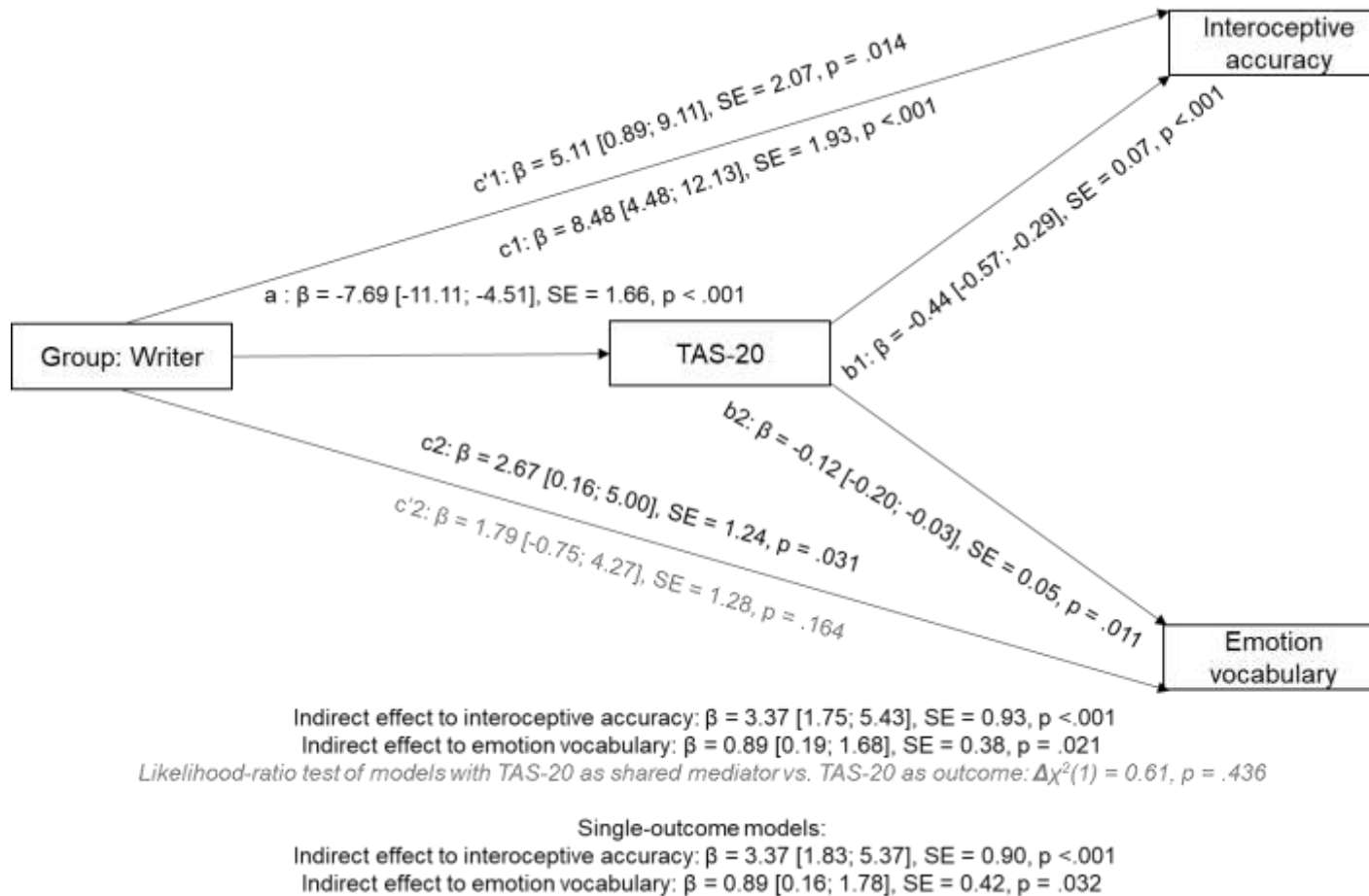


Notes. Standardised estimates are presented here. TAS-20 = TAS-20 = 20-item Toronto Alexithymia Scale.

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Figure S4.3

Exploratory Mediation Model Testing Alexithymia as Shared Mediator of Interoceptive Accuracy and Emotion Vocabulary



Notes. Standardised estimates are presented here. Re-running the model with the difficulty identifying feelings (DDF) subscale showed a significant indirect effect of DDF for interoceptive accuracy (Estimate = 3.05 [1.45; 4.96], SE = 0.90, $p = .001$), but not emotion vocabulary knowledge (Estimate = 0.51 [-0.11;

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1.29], SE = 0.35, $p = .145$). For externally-oriented thinking (EOT) subscale, there was a significant indirect effect of EOT for emotion vocabulary knowledge (Estimate = 1.64 [0.43; 3.04], SE = 0.65, $p = .011$), but not interoceptive accuracy (Estimate = 0.77 [-2.11; 3.39], SE = 1.33, $p = 0.563$). Likelihood ratio tests indicated that both models were considered comparably plausible as their counterpart models treating interoceptive accuracy and emotion vocabulary knowledge as mediators (DDF and EOT: $\Delta\chi^2(1) = 0.61$, $p = .436$), although note that all hypothesised models presented in the main text had lower information criteria than their alternative models. TAS-20 = TAS-20 = 20-item Toronto Alexithymia Scale.

Robust Linear Regressions Predicting Alexithymic Traits with Interaction Terms between Group and Interoception and Language Variables

Table S4.1 summarises the regression results. When predicting alexithymic traits with the interaction term between group and interoceptive accuracy, this interaction term was significant but did not survive Bonferroni correction (Estimate = 0.31 [0.02; 0.60], SE = 0.15, $t = 2.10$, $p = .04$). Specifically, higher interoceptive accuracy was correlated with lower alexithymic traits in non-writers ($r(96) = -.50$, $p < .001$), but not in writers ($r(34) = -.11$, $p = .52$) (Figure S4.4A). There was a significant interaction between group and interoceptive attention (Estimate = -0.33 [-0.59; -0.07], SE = 0.13, $t = -2.49$, $p = .014$), which almost survived Bonferroni correction. Decomposing this interaction effect suggested that lower interoceptive attention was significantly correlated with lower alexithymic traits in non-writers ($r(96) = .35$, $p < .001$), but this relationship was trivial in writers ($r(34) = -.04$, $p = .83$) (Figure S4.4B).

For language variables, the interaction term between group and general vocabulary knowledge almost survived Bonferroni correction (Estimate = 0.55 [0.11; 1.00], SE = 0.23, $t = 2.43$, $p = .016$). Specifically, general vocabulary knowledge showed a positive relationship with alexithymic traits in writers ($r(28) = .26$, $p = .16$), but negatively correlated with alexithymic traits in non-writers at a marginal level ($r(96) = -.20$, $p = .05$) (Figure S4.4C). The interaction term between group and emotion vocabulary knowledge was not significant (Estimate = 0.16 [-0.39; 0.70], SE = 0.28, $t = 0.57$, $p = .57$).

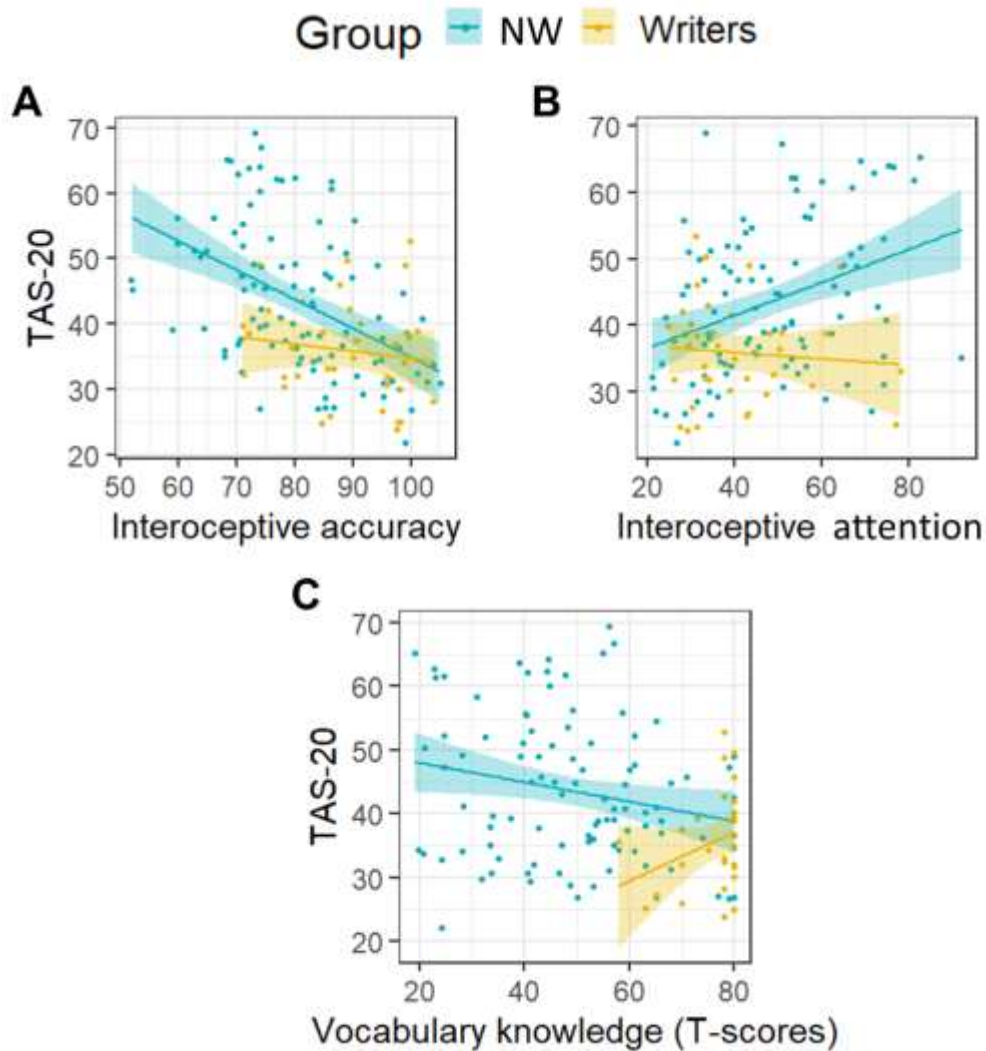
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Table S4.1

Summary of Robust Linear Regression Predicting Alexithymic Traits with Interaction Term between Group and Each of the Interoception and Language Variables

Outcome	Predictor	Estimate	95% LL	95% UL	SE	t	p
TAS-20	(Intercept)	78.45	65.27	91.64	6.73	11.66	<0.001
	Group: Writers	-31.37	-56.50	-6.23	12.82	-2.45	0.016
	IAS	-0.44	-0.59	-0.29	0.08	-5.64	<0.001
	Group x IAS	0.31	0.02	0.60	0.15	2.10	0.037
TAS-20	(Intercept)	30.03	22.25	37.80	3.97	7.57	<0.001
	Group: Writers	7.82	-3.70	19.35	5.88	1.33	0.186
	IATS	0.28	0.11	0.45	0.09	3.17	0.002
	Group x IATS	-0.33	-0.59	-0.07	0.13	-2.49	0.014
TAS-20	(Intercept)	52.77	43.67	61.87	4.64	11.37	<0.001
	Group: Writers	-10.22	-25.16	4.73	7.63	-1.34	0.183
	Emotion vocabulary	-0.42	-0.78	-0.06	0.18	-2.31	0.022
	Group x Emotion vocabulary	0.16	-0.39	0.70	0.28	0.57	0.569
TAS-20	(Intercept)	51.52	42.84	60.20	4.43	11.63	<0.001
	Group: Writers	-45.32	-78.11	-12.54	16.73	-2.71	0.008
	General vocabulary	-0.17	-0.32	-0.02	0.08	-2.17	0.032
	Group x General vocabulary	0.55	0.11	1.00	0.23	2.43	0.016

Notes. Six writers did not attend the WASI-II vocabulary test. IAS = Interoceptive Accuracy Scale; IATS = Interoceptive Attention Scale; TAS-20 = 20-item Toronto Alexithymia Scale.

Figure S4.4*Interaction Scatterplots*

Notes. Scatterplots of the associations between TAS-20 and (A) interoceptive accuracy, (B) interoceptive attention, and (C) vocabulary knowledge (T-scores). No significant interaction was found between group and emotion vocabulary before Bonferroni correction. NW = non-writers; TAS-20 = 20-item Toronto Alexithymia Scale.

Chapter 5**Stochastic Choices Following Learning of Emotion and Non-Emotion Concepts in
Alexithymia Is Due to Co-Occurring Anxiety**

Abstract

Alexithymia is associated with less fine-grained perception of emotional experiences, which constructionist theories suggest could stem from impaired emotion concept acquisition due to suboptimal learning of abstract concepts. A series of three experiments (total $N = 387$) were conducted to test this hypothesis. In Experiments 1 ($N = 75$) and 2 (replication: $N = 138$), participants performed an alien concept learning task in probabilistically stable and volatile environments. They were asked to learn unfamiliar abstract concepts of emotion through direct task feedback or indirect social information from a hypothetical group of individuals who had played the same task previously. In Experiment 3 ($N = 174$), an independent group of participants performed a non-emotional version of the same task in which they were asked to learn abstract concepts of temperature instead. While Experiment 1 found preliminary evidence that alexithymic traits were associated with atypical learning rates, these associations were not replicated in Experiment 2 as informed by conventional and Bayesian statistics. Path analysis instead revealed that alexithymic individuals had elevated co-occurring mood symptoms, and that anxiety symptoms were uniquely associated with the tendency to make more stochastic choices rather than atypical learning. Experiment 3 showed the same anxiety effect when learning non-emotion concepts, suggesting a domain-general characteristic in choice following learning. Findings provide the first evidence for the indirect link between alexithymia and abstract concept use, and underscore the importance of considering the effect of co-occurring mood symptoms in alexithymic individuals.

**Stochastic Choices Following Learning of Emotion and Non-Emotion Concepts in
Alexithymia Is Due to Co-Occurring Anxiety**

Alexithymia commonly co-occurs with a wide range of mood symptoms and disorders, including depression, anxiety, and post-traumatic stress disorder (Grabe et al., 2004; Morie et al., 2019; Preece et al., 2022). These links are perhaps not surprising, as having low emotional self-awareness makes the detection of mood symptoms more challenging, which predisposes these individuals to more instances of emotion dysregulation and difficulties communicating emotional distress with others (Preece et al., 2022; see Weissman et al., 2020 for a developmental perspective).

As described earlier in Chapter 1, studying the psychological processes that underlie alexithymia is challenging, as there exist multiple factors contributing to the risk of developing alexithymia. These are thought to include atypical processing of facial emotion cues (e.g., atypical gaze to the eyes: Cuve et al., 2021) and internal bodily signals that are informative of one's affective states (Murphy et al., 2018; Trevisan et al., 2019). Additionally, the language hypothesis of alexithymia posits that language deficits may limit one's access to emotion labels and linguistic devices that facilitate emotion expression, thereby predisposing those with language disorders to develop alexithymia (Hobson et al., 2019; also see the meta-analysis on related language studies in Chapter 2, and the longitudinal analysis in Chapter 3). From a constructionist perspective, low emotional self-awareness may be related to difficulties acquiring and accessing emotion concepts (Lindquist et al., 2015; Satpute & Lindquist, 2019). This was demonstrated by a study showing that when individuals with alexithymia were primed with useful emotion labels, these individuals showed comparable facial emotion recognition performance to non-alexithymic participants, suggesting that reduced availability of emotion concepts may play a role in alexithymia (Nook et al., 2015).

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Although empirical studies testing emotion concept acquisition in alexithymia are scarce, there has been descriptive evidence suggesting such deficits. Specifically, various forms of affective psychopathology, including alexithymia, are associated with a less fine-grained perception of emotional experiences (Erbas et al., 2019 and Chapter 2). This association is supported by studies requiring participants to provide ecological momentary ratings (valence and arousal) of their daily emotional experiences (e.g., Ottenstein & Lischetzke, 2020) or through the use of stimulus induction procedures (Erbas et al., 2019). These studies found that individuals with high alexithymic traits tended to provide more similar emotional ratings and use a narrower range of emotion labels across instances as compared to those with low alexithymic traits (Chapter 2: $r = -.10$; in autistic individuals: Keating et al., 2023).

While the above experience sampling studies describe how individuals with alexithymia perceive their emotional experiences, those studies are not able to identify atypicalities in the learning mechanisms that are involved in emotion concept acquisition in alexithymia. Constructionist theories propose that emotion categories and their associated concepts can be learned from direct individual experiences, such as through formal learning activities (e.g., reading and writing about emotions) and the perception of internal sensations (e.g., increased heart rate when feeling anxious) (Hoemann et al., 2020; Lindquist, 2013). Alternatively, emotion concepts can be learned socially, by acquiring information about what and how emotion categories are used amongst members of a larger social group or culture (Lindquist et al., 2022). This is considered an indirect pathway as emotion concepts are learned through other individuals who are likely more familiar with and knowledgeable about the sociocultural norms of emotion expression. These indirect social learning processes have been demonstrated by social media studies demonstrating that new users tended to modulate the emotional content of their posts based on the emotion category (positive/negative) that

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was more frequently expressed in the newsfeed (e.g., Brady et al., 2021; Kramer et al., 2014), and that individuals also tended to disproportionately adopt the emotional language used by those of prominent social status, such as politicians and celebrities (Bae & Lee, 2012).

The constructionist framework above is useful for generating and testing hypotheses about emotion concept acquisition in alexithymia. First, facial expressions and internal bodily signals are some conceptual features that are associated with an emotional category or concept (e.g., a frowning face and an accelerated heart rate may represent anger in a given culture) (Hoemann et al., 2020; Lindquist, 2013). Atypical processing of emotional cues and bodily information would suggest that individuals with alexithymia have limited and/or less efficient access to the “learning materials” of an emotion concept (e.g., atypical gaze pattern to facial emotions: Cuve et al., 2021; interoceptive failure: Murphy et al., 2018), thereby reducing the learning rate of emotion concepts. Moreover, studies of first-hand accounts have pointed out that individuals with alexithymia express confusion and uncertainty when processing emotional signals and information on their own (Keefer et al., 2019; Trevisan et al., 2021). Individuals with alexithymia also tend to disregard external emotional information in decision-making and judgement contexts (Brewer et al., 2015; Patil et al., 2016), which may reflect a reduced propensity to rely on social information from others when learning unfamiliar emotion concepts. Furthermore, high rates of social isolation and rejection have been reported in clinical groups with elevated levels of alexithymia (e.g., autism: Sedgewick et al., 2016; Libster et al., 2023, and developmental language disorder: van den Bedem et al., 2018). Reduced social contact predicts that there would be decreased social learning opportunities for alexithymic individuals to acquire emotional information from others. However, the extent to which this effect is confounded by co-occurring mood symptoms (such as depression and anxiety) that are associated with atypical emotion processing and worse bonding with others is unclear (Gerber et al., 2019). Relatedly, computational studies

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have found that anxious individuals show a domain-general deficit in adjusting their learning strategy based on choice outcomes and their associated values, and that their behaviours were more stochastic than non-anxious individuals in environments with variable volatility (Piray & Daw, 2021; Yamamori & Robinson, 2023). An analogous outcome valuation deficit has been observed in alexithymic individuals who made economic choices that were inconsistent with their previous valuations (Hogeveen et al., 2021). Given the high co-occurrence of alexithymia and mood symptoms (Preece et al., 2022, 2023), we expected that alexithymic individuals would make choices stochastically following learning of unfamiliar emotion concepts, and that co-occurring mood symptoms may play a role in this hypothesised effect.

The current study presents a series of three experiments that test the relationship between alexithymia and emotion concept learning. In Experiments 1 and 2 (replication), participants were told to imagine they were travelling in space and were asked to learn unfamiliar emotion concepts that described the joint feeling of sadness and disgust experienced by some alien characters. In Experiment 3, a separate sample of participants performed a structurally identical control task that assessed learning of an abstract temperature concept. The concept learning task was adapted from an original study by Behrens and colleagues (2007), which tested learning rates in probabilistically stable and volatile environments, with task schedules that carefully disentangled direct learning behaviours (i.e., through task performance feedback) from indirect social learning from a hypothetical group of players who had completed the same task earlier (Cook et al., 2014, 2019; Rybicki et al., 2022). We processed participants' behavioural data with a computational modelling package that estimated their direct and indirect learning rates on trials during which the probabilities of a given emotion concept, and of social information being correct, were stable and volatile respectively. This computational model hence provides mechanistic insights into emotion concept learning and its potential relationship with alexithymia.

Experiment 1

Method

Participants

The following exclusion criteria were applied: (i) outside the 18-45 age range (years), (ii) any diagnosed psychiatric conditions significantly affecting mental health, and intellectual and/or language disability, (iii) significant mental health concerns (in particular, significant depressive symptoms or suicidal ideation), (iv) a history of head injury or long-term use of psychiatric medication, and (v) any other forms of inability that make it difficult to read instructions or perform the study tasks at a reasonable level of competence (e.g., not fluent in English, very poor vision, poor internet connection). Due to ethical reasons and the use of aversive images, all potential participants were asked to preview ten example images that approximated the full range of intensity one would experience on the actual study tasks. If any one of the images was rated intolerable by the participant, they were rejected from taking part in the study. This resulted in a final sample of 75 participants (mean age = 25.08 years, $SD = 7.51$, range = 18-45, 58.7% female) recruited from Testable Minds and the university's participant recruitment system (SONA). All participants provided informed consent, and received an honorarium of USD 9-10/hour. This study was approved by the Medical Sciences Interdivisional Research Ethics Committee at the University of Oxford (reference: R79104/RE001).

Trait and Symptom Measures

Toronto Alexithymia Scale (TAS-20). The TAS-20 (Parker et al., 2003) assesses individual differences in three key domains of alexithymia, namely difficulty describing feelings, difficulty identifying feelings, and externally-oriented thinking. Each of the 20 items was rated on a five-point Likert scale (“Strongly disagree” to “Strongly agree”). Higher TAS-20 scores reflect higher levels of alexithymia. The internal consistency was high as measured by Cronbach’s alpha ($\alpha = .84$) in this sample. Total score and the three subscale scores were z-standardised for analysis.

Autism Spectrum Quotient (AQ). The AQ (Baron-Cohen et al., 2001) comprises 50 items that purport to measure five domains of dimensional autistic traits, namely social skill, attention switching, attention to detail, communication, and imagination. Each item was rated on a four-point Likert scale (“Definitely agree” to “Definitely disagree”), and the endorsement of an autistic trait would score one point using the original binary scoring method. Higher AQ scores indicate higher autistic traits. The internal consistency was high ($\alpha = .82$) in this sample. Summed scores were z-standardised for analysis.

Depression Anxiety Stress Scale (DASS-21). The DASS-21 (Lovibond & Lovibond, 1995) contains 21 items that assess self-perceived levels of depressive and anxiety symptoms, and stress over the past week. Participants rated each item on a four-point Likert scale (“Did not apply to me at all” to “Applied to me very much or most of the time”), whereby higher scores indicate higher levels of symptoms. The internal consistency was excellent ($\alpha = .94$) in this sample. Summed subscale scores were calculated according to the standing scoring method and then z-standardised for the analyses.

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Stimuli

A total of 240 sad and disgusted images (120 images each) were presented on the learning and rating tasks. The key reasons for choosing these images were three-fold. First, sadness and disgust have been shown to be substantially easier to display and induce via visual means (especially for images) than other common negative/positive emotions in clinical and general populations (see a meta-analysis of 874 samples by Joseph et al., 2020). Second, from a theoretical perspective, sadness and disgust are considered two qualitatively distinct negative emotions according to prominent theories of emotion (e.g., the valence-arousal model, Russell, 2003; Russell & Barrett, 1999; the six basic emotions, Ekman, 1992). Third, a common linguistic symbol/behaviour that expresses the joint experience of sadness and disgust does not seem to prevail in most urban societies and/or cultural groups (e.g., Ekman & Friesen, 1971; Sauter et al., 2010). Although we did not necessarily endorse the view that these theories speak to the ground truth of how emotions are represented in humans, the empirical evidence and theoretical claims provide a systematic framework that is conceptually relevant to test the learning of unfamiliar emotion concepts (i.e., the joint feeling of sadness and disgust) in this study.

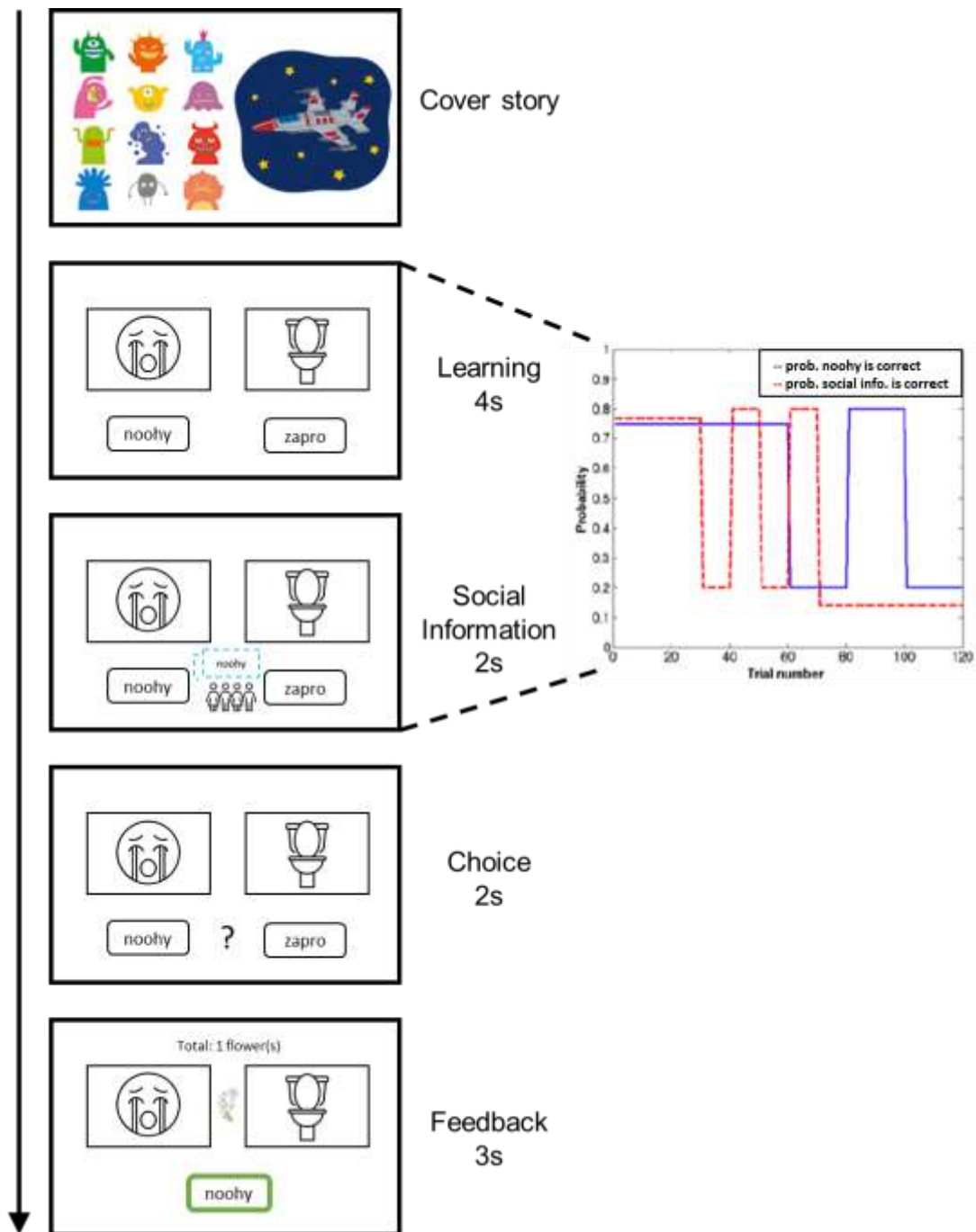
To create 120 unique pairs, these images were carefully selected from three databases: 42 sad and 31 disgusted images from the International Affective Picture System (IAPS) (Lang & Bradley, 2007), 62 sad and 51 disgusted images from the Nencki Affective Picture System by discrete emotional categories (NAPS-BE) (Riegel et al., 2016), and 38 disgust images from the Disgust-Related-Images database (DIRTI) (Haberkamp et al., 2017). For the remaining 16 sad images, we validated some public-domain images on a sample of 22 students. The resolution and size of these images were standardised using GIMP version 2.10.30.

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Emotion Concept Learning Task

This task was modified based on Behrens and colleagues' (2007) reward learning task with indirect social learning information (Cook et al., 2014, 2019) (Figure 5.1). Participants were told the cover story that they were travelling in space where they would interact with aliens that did not speak any human languages and had a very different understanding of emotion from humans. For instance, while most humans would consider “anger” and “fear” two different kinds of emotion, these aliens might consider those were the same emotion and had the same emotion label. To study these aliens, participants were shown a series of sad and disgusted images arranged in pairs, and their task was to choose one of the two alien words (“noohy” or “zapro”) that best described the emotion depicted by the *pair* of images. To implement stable and volatile learning environments as in previous studies (see Behrens et al., 2007 and Cook et al., 2014, 2019, for the probability schedules), participants were told they would travel back and forth in phases (every 10-20 trials), and that they might be on Planet *Htrae* where “noohy” would better describe the images, whereas other times they might be on Planet *Sram* where “zapro” would better describe the images. Before making a choice, participants would see the most popular choice of alien word from a previous group of four human participants indicated by a speech bubble (two males, two females), but their information might be more or less useful in some phases. During each trial, participants were asked to choose a word as quickly as possible, and the correct word would be framed in green. Participants would receive flowers from the aliens for a correct answer, and slugs for a wrong answer. Participants were told that they would earn extra reward if they performed well on the task. A total of 120 trials were completed and pseudo-randomised according to the probability schedules.

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Figure 5.1*Emotion Concept Learning Task*

Notes. This gamified emotion concept learning task was adapted from the reward learning task by Behrens and colleagues (2007) with indirect social learning information implemented as in the studies by Cook and colleagues (2014, 2019). In this study, participants first read a

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cover story that they were travelling in space and met some aliens who did not speak any human languages and had a very different understanding of emotion. Participants saw a series of sad and disgusted image pairs and had to choose the alien word (“noohy” or “zapro”) that better described the emotion depicted by both images. The alien words were consistently presented under the images. Stable and volatile learning environments were implemented based on the original probability schedules in the previous studies, and participants were told that they would travel back and forth between planets in phases (every 10-20 trials), such that “noohy” might better describe the emotion depicted by the images on one planet whilst “zapro” might be the better word on another planet. Participants were randomly assigned to one of the four schedules, which is reproduced here as an example with the permission of the authors. Before making a choice, participants would see the most popular choice made by a hypothetical group of players who had played the same task before, with the understanding that such information might be more or less useful at times. Finally, participants were asked to make a choice as quickly as possible, and the correct word framed in green at the end of each trial. Participants would receive flowers from the aliens for a correct answer, and slugs for a wrong answer. Participants completed 120 trials.

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Stimulus Rating Task

Following the emotion concept learning task, participants completed a stimulus rating task on which they were shown 30 sad and 30 disgusted images that were selected randomly from the test images, and were asked to rate how negative/positive (valence) and calm/energetic (arousal) those images made them feel emotionally on a Likert scale (0 to 100). Participants were also asked to choose one of the six emotion labels (happiness/sadness/fear/disgust/surprise/anger) that they thought best described the emotion depicted by the image. Images were shown one at a time across the 60 trials. To distinguish the rating task from the learning task, participants were reminded that they were no longer travelling in space, and that they should answer as naturally as possible. They were also reminded to disregard the content of the images (e.g., the kind of animals/people/landscapes) when providing their answers, and it was not a requirement to use all the six emotion labels throughout the task, just those they thought were the most appropriate labels.

Procedure

Prior to the actual study tasks, participants were asked to review the study information sheets and confirmed that they understood the use of potentially disturbing images. For those who passed the stimulus check with the example images, participants proceeded to read the cover story with cartoon illustrations designed to aid understanding. Participants then completed a study quiz that tested their understanding of task instructions, the aliens (e.g., have a different understanding of emotion as compared to humans), and the implementation of social information and different phases between planets. Participants were given a maximum of two attempts, and a completion rate of 100% was required to enter the actual study tasks. Participants first completed the emotion concept learning task, then the stimulus rating task so as to avoid being reinforced to impose a human understanding of emotion

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during the learning task. The questionnaire measures were completed at the end. Participants were required to review the instructions again before performing each specific task. At the end of the learning and rating tasks, we asked participants to indicate if they felt unwell because of the images, and they were given the opportunity to terminate the study if they wished to. The entire study took 50-55 minutes to complete on Gorilla (gorilla.sc).

Statistical Analyses

We first summarised the sample characteristics and descriptive statistics of the trait measures, task performance, and key parameters estimated via computational modelling. The computational modelling package was adopted from past studies (Behrens et al., 2007; Cook et al., 2014, 2019) in which participants' trial-by-trial responses were modelled under the Rescorla-Wagner framework in which changes in choice behaviour (here, choosing between the unfamiliar emotion concepts “noohy” and “zapro”) are driven by prediction errors. That is, the difference between expected outcome/value (V_i) and actual outcome (r_i), ($r_i - V_i$ in Equation 1). In narrative terms, it is assumed that participants use such sensory feedback to update their beliefs about outcomes (the perceptual model), and then to decide on the next action (the response model, see below). Following past studies (e.g., Cook et al., 2014, 2019; Rybicki et al., 2022), the current model comprised separate learning rates for direct/indirect learning and the stable/volatile phases, which resulted in four learning rate alpha estimates (α) (ranging between 0 and 1): $\alpha_{\text{stable_direct}}$, $\alpha_{\text{stable_indirect}}$, $\alpha_{\text{volatile_direct}}$, $\alpha_{\text{volatile_indirect}}$.

$$V_{(i+1)} = V_i + \alpha (r_i - V_i) \tag{1}$$

The response model computed two further parameters. Beta (β) represents the extent to which participants' actual choices were influenced by the estimated value of choices. Computationally, β is the inverse of decision temperature, whereby responses $y_{(i+1)}$ were

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coded as 1 when selecting “noohy” (Equation 2). Higher β values indicate that choices are more deterministic towards the higher valued option, whereas lower β values indicate more stochastic choices.

$$P(y_{(i+1)} = 1 | V_{direct(i+1)}) = \frac{V_{direct(i+1)}^\beta}{V_{direct(i+1)} + (1 - V_{direct(i+1)})^\beta} \quad (2)$$

Zeta (ζ) represents the extent to which participants’ actual responses were influenced by social information (indirect learning) relative to direct learning from task performance feedback. Computationally, ζ estimates the weighting of indirect social information relative to direct task feedback (Equation 3), which takes into account the alien word advised by the hypothetical group of participants (“advice” in Equation 4: “noohy” = 1 or “zapro” = 0) weighted by the probability of advice accuracy (Equation 4). Higher ζ values indicate that choices are more influenced by indirect learning from the social information relative to direct learning from task feedback, i.e., a bias to conform to the advice of the group of participants. In sum, this leads to a total of six key dependent variables for subsequent analyses.

$$V_{direct(i+1)} = \zeta(V_{social\ information(i+1)}) + (1 - \zeta)(V_{direct(i+1)}) \quad (3)$$

$$V_{social\ information(i+1)} = |advice - V_{indirect(i+1)}| \quad (4)$$

Model-fitting was performed using the TAPAS toolbox in Matlab R2021a (Diaconescu et al., 2014) (materials available at <https://tinyurl.com/b3c7d2zb>). Following the standard model validation procedures (e.g., Cook et al., 2014, 2019; Rybicki et al., 2022), the current model with separate learning rates for direct/indirect learning during the

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stable/volatile phases had an exceedance probability of almost 1, suggesting that it provided the best fit to the participants' behavioural data amongst alternative models. Follow-up data simulation and parameter recovery provided consistent evidence in favour of the current model (see **Supplementary Materials**, Figure S5.1).

To address our primary research question regarding the dimensional relationship between alexithymia and emotion concept learning, zero-order Pearson's correlations were performed between alexithymia (total and subscale scores) and the six computational parameters. These parameters were (inverse) square-root transformed when normality was severely violated. These multiple tests were corrected for using Bonferroni correction, such that correlations with p values $< .05/6$ parameters = .008 would be considered significant. Next, to adjust for the effects of co-occurring mood symptoms, DASS-21 subscale scores were entered as covariates alongside age and gender as control variables in a robust linear regression model (e.g., Hogeveen et al., 2021), using the `robustbase` package in R (Maechler et al., 2022; R Core Team, 2021). To reflect our hypothesis that alexithymia would be associated with suboptimal emotion concept learning – i.e., (i) lower learning rates as informed by emotional processing difficulties in alexithymic individuals (e.g., Cuve et al., 2021; Murphy et al., 2018), (ii) more stochastic choices with respect to outcome values (Hogeveen et al., 2021), and (iii) less indirect social learning relative to direct learning as informed by their interpersonal difficulties and increased propensity to disregard emotional information (e.g., Brewer et al., 2015; Gerber et al., 2019; Trevisan et al., 2021) – one-tailed tests were performed. All other statistical tests were two-tailed. To aid the interpretation of results, the correlation coefficients were considered small (.20), medium (.50), and large (.80) (Cohen, 1988).

Results

Descriptive Statistics

Table 5.1 presents the sample characteristics and descriptive summary of the computational parameters. The mean TAS-20 score was 43.49 ($SD = 10.92$, range = 25 to 69); six participants surpassed the clinical cutoff score of 61 or above for severe alexithymia (Parker et al., 2003). A wide range of co-occurring mood symptoms was present in this sample, amongst which 12 participants surpassed the clinically-relevant cutoff score for anxiety (15 or above on the DASS-21 anxiety subscale).

Stimulus Rating Task

Participants were generally reliable (mean = .70, $SD = .13$) in applying the correct emotion labels (sadness/disgust) to the test images selected from the well-validated databases. Accuracy was not correlated with TAS-20, $r(73) = .01$, $p = .91$. Participants on average rated the set of disgust images (mean = 48.03, $SD = 13.16$) as more arousing than the sad images (mean = 43.32, $SD = 10.53$), $t = 2.42$, $p = .02$, $d = 0.40$, and gave higher valence ratings to the sad images (mean = 30.34, $SD = 8.52$) than to the disgust images (mean = 26.69, $SD = 8.83$), $t = 2.58$, $p = .01$, $d = 0.58$. Altogether, this suggested that participants considered the two sets of sad and disgusted images conceptually and affectively different from each other, validating our choice of stimuli informed by the literature.

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Table 5.1*Sample Characteristics and Descriptive Summary of Computational Parameters*

<i>Experiment 1</i> (<i>N</i> = 75)	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>> Cutoff</i> <i>n</i>	<i>Experiment 2</i> (<i>N</i> = 138)	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>> Cutoff</i> <i>n</i>
Age (years)	25.08	7.51	18	45	--	Age (years)	28.87	7.07	19	45	--
% Female	58.7	--	--	--	--	% Female	49.3	--	--	--	--
AQ	18.80	7.39	3	38	3	AQ	20.39	6.99	3	42	6
TAS-20	43.39	10.92	25	69	6	TAS-20	43.91	11.98	21	71	12
DDF	12.72	4.67	5	23	--	DDF	12.14	4.58	5	24	--
DIF	13.83	5.14	7	27	--	DIF	13.64	5.42	7	27	--
EOT	16.84	4.34	8	26	--	EOT	18.13	4.93	8	30	--
DASS-21	25.57	22.47	0	98	--	DASS-21	26.84	22.00	0	84	--
Depression	7.28	7.65	0	32	6	Depression	8.42	9.23	0	42	18
Anxiety	7.09	7.70	0	34	12	Anxiety	6.81	7.60	0	32	19
Stress	11.20	9.32	0	38	7	Stress	11.61	8.70	0	38	11
<i>Computational parameters</i>	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>		<i>Computational parameters</i>	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	
Accuracy	0.53	0.06	0.35	0.65		Accuracy	0.53	0.06	0.37	0.68	
<u>Learning rate (α)</u>						<u>Learning rate (α)</u>					
Direct	0.15	0.10	0.02	0.53		Direct	0.15	0.10	0.01	0.52	

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Stable	0.15	0.12	0.01	0.55	Stable	0.15	0.11	0.01	0.61
Volatile	0.14	0.12	0.01	0.62	Volatile	0.15	0.12	0.01	0.64
Indirect	0.12	0.08	0.01	0.36	Indirect	0.12	0.07	0.01	0.31
Stable	0.14	0.10	0.01	0.50	Stable	0.12	0.09	0.00	0.45
Volatile	0.11	0.10	0.01	0.47	Volatile	0.11	0.09	0.01	0.43
β	2.19	1.63	0.55	8.41	β	2.26	1.91	0.53	15.51
ζ	0.52	0.33	0.00	1.00	ζ	0.51	0.33	0.00	1.00

Notes. The corresponding cutoff scores for the trait and symptom measures are: AQ (above 32), TAS-20 (61 or above), DASS-21 depression (21 or above), DASS-21 anxiety (15 or above), DASS-21 stress (26 or above). For descriptive purposes, direct and indirect learning rates are the average of learning rates during stable and volatile periods. Raw scores are presented here. AQ = Autism Spectrum Quotient; TAS-20 = 20-item Toronto Alexithymia Scale; DDF = Difficulty Describing Feelings; DIF = Difficulty Identifying Feelings; EOT = Externally-Oriented Thinking; DASS-21 = Depression Anxiety Stress Scale.

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Is Alexithymia Related to Suboptimal Emotion Concept Learning?

Correlation analyses suggested that amongst the four α estimates ($\alpha_{\text{stable_direct}}$, $\alpha_{\text{stable_indirect}}$, $\alpha_{\text{volatile_direct}}$, $\alpha_{\text{volatile_indirect}}$), difficulty identifying feelings was correlated with increased indirect learning rates when the learning environment was volatile, $r(73) = .27, p = .02$. Externally-oriented thinking was correlated with increased direct learning rates in the volatile period, $r(73) = .23, p = .046$. Note that two-tailed p values are reported here instead, as these relationships were in the opposite direction to our initial hypotheses. These tests did not survive Bonferroni correction.

As for the β and ζ parameters, difficulty identifying feelings was correlated with lower β values, $r(73) = -.22, p = .03$ (one-tailed), indicating that the choices of individuals with more difficulty were more stochastic. This correlation, however, did not survive Bonferroni correction. No significant correlations were found between the TAS-20 subscales and ζ (i.e., choices more/less influenced by indirect learning from social information relative to direct learning from feedback) ($r_s = -.01$ to $.04$), and between TAS-20 total score and the computational parameters ($r_s = -.06$ to $.17$). AQ, despite being correlated with TAS-20, $r(73) = .23, p = .04$, was not significantly correlated with any of the computational parameters ($r_s = 0$ to $-.20, p_s = .09$ to $.97$).

Next, we explored the contribution of co-occurring mood symptoms to the relationships between alexithymia and computational parameters. These correlations were exploratory and uncorrected. Of the three parameters that were correlated with alexithymia domains prior to Bonferroni correction, the DASS-21 subscale scores were correlated with increased indirect learning rates in the volatile period ($r_s = .27$ to $.34, p_s = .003$ to $.02$), whilst stress was also correlated with lower β values (more stochastic choices), $r(73) = -.24, p$

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= .04. This suggested that these co-occurring symptoms may partly explain the previous relationships found with difficulty identifying feelings.

These relationships were clarified by adding the respective DASS-21 scores to the linear regression models. Note that DASS-21 total score was used to avoid multi-collinearity for the model predicting indirect learning rates in the volatile period, due to their correlations with all three subscales mentioned above. As summarised in Table 5.2, DASS-21 total score was marginally associated with increased indirect learning rates in the volatile period (Estimate = 0.04 [-0.002; 0.08], SE = 0.02, $t = 1.88$, $p = .06$), whereas the effect of difficulty identifying feelings was no longer significant (Estimate = 0.02 [-0.03; 0.07], SE = 0.02, $t = 0.83$, $p = .41$). For the model predicting β values and adjusting for stress, difficulty identifying feelings remained significantly associated with more stochastic choices (Estimate = -0.06 [-0.12; 0.01], SE = 0.03, $t = -1.73$, $p = .04$, one-tailed); the effect of stress was not significant (Estimate = -0.03 [-0.09; 0.03], SE = 0.03, $t = -0.96$, $p = .34$). Moreover, age was significantly associated with lower β values (Estimate = -0.01 [-0.01; -0.001], SE = 0.003, $t = -2.18$, $p = .03$).

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Table 5.2*Summary of Robust Linear Regressions Adjusting for Co-Occurring Mood Symptoms in Experiment 1*

Outcome	Predictor	Estimate	2.5% CI	97.5% CI	SE	t	p	VIF
Learning rate-- Indirect (volatile)	(Intercept)	0.24	0.12	0.36	0.06	3.81	<0.001	--
	Age	0.00	0.00	0.01	0.00	0.64	0.526	1.35
	Sex (Female)	0.02	-0.04	0.07	0.03	0.58	0.564	1.07
	DIF	0.02	-0.03	0.07	0.02	0.83	0.409	1.61
	DASS-21	0.04	0.00	0.08	0.02	1.88	0.064	1.31
β	(Intercept)	-0.56	-0.74	-0.37	0.10	-5.81	<0.001	--
	Age	-0.01	-0.01	0.001	0.003	-2.18	0.033	1.26
	Sex (Female)	-0.08	-0.18	0.02	0.05	-1.51	0.135	1.07
	DIF	-0.06	-0.12	0.01	0.03	-1.73	0.089	1.71
	Stress	-0.03	-0.09	0.03	0.03	-0.96	0.343	1.43

Notes. Learning rates were square-root transformed, whilst β values were inverse square-root transformed. Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. For transparency, two-tailed p values are presented here. DIF = Difficulty Identifying Feelings; DASS-21 = Depression Anxiety Stress Scale.

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To serve as sensitivity analyses, the same linear regression models were re-run by restricting the study sample to participants who applied a similar conceptualisation of sadness and disgust as the past participants had in the image database validation studies. Specifically, this was defined as those who labelled the test images as sadness and disgust with at least 60% accuracy on the stimulus rating task. In this restricted sample ($n = 59$, four participants with severe alexithymia), a similar pattern of results emerged: difficulty identifying feelings was not significantly associated with increased indirect learning rates in the volatile period (Estimates = 0.03 [-0.04; 0.09], SE = 0.03, $t = 0.86$, $p = .39$) when adjusting for DASS-21 total score, but remained significantly associated with more stochastic choices (lower β values) (Estimate = -0.05 [-0.11; 0.01], SE = 0.03, $t = -1.73$, $p = .045$, one-tailed) when adjusting for stress. Likewise, when restricting the study sample to those with above 50% accuracy on the emotion concept learning task ($n = 51$, five participants with severe alexithymia), the non-significant effect of difficulty identifying feelings persisted when predicting indirect learning rates in the volatile period (Estimate = 0.02 [-0.03; 0.06], SE = 0.02, $t = 0.69$, $p = .50$), whilst its association with more stochastic choices remained significant (Estimate = -0.08 [-0.14; -0.02], SE = 0.03, $t = -2.80$, $p = .004$, one-tailed). These results are detailed in Table S5.1, **Supplementary Materials**. Figure S5.2 depicts the regression plots of the associations found in Experiment 1.

Experiment 2: Replication

Contrary to our prediction that alexithymia would be associated with a lower learning rate of unfamiliar emotion concepts, Experiment 1 suggested that these associations were not as reliable as previously thought and did not survive Bonferroni correction. Crucially, linear regression analyses provided preliminary evidence that co-occurring mood symptoms might

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account for some of the associations between emotion concept learning and alexithymia (specifically for difficulty identifying feelings). While the association between difficulty identifying feelings and stochastic choices seemed more consistent than findings on learning rates, a replication study would be useful to evaluate the robustness of this association. In light of these inconclusive findings, the primary aim of Experiment 2 was to seek to replicate the various relationships between alexithymia and emotion concept learning, and to clarify the potential role of co-occurring mood symptoms in these relationships. The same study measures, tasks, and procedures were employed.

Method

Participants

To determine the replication sample size, a power analysis was performed in G*power (Faul, 2007) based on the association between difficulty identifying feelings and stochastic choices found in Experiment 1, based on the fact that this association was more consistently found throughout the previous analyses. The power analysis indicated that an estimated sample size of 126 participants would achieve 80% power to detect the zero-order correlation of $-.22$ (one-tailed). A similar power analysis conducted under the simple linear regression framework suggested a sample size of 113 participants for 80% power to detect a slope of -0.05 (one-tailed) for difficulty identifying feelings. We therefore opted for the larger sample size estimate and recruited an independent sample of 138 participants (mean age = 28.97 years, $SD = 7.07$, range = 19-45, 49.3% female) on Testable. Note that the 12 additional participants were included in the study due to a temporary technical issue that was resolved at a later stage of data collection. The same exclusion criteria were applied.

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Statistical Analyses

As in Experiment 1, one-tailed zero-order Pearson's correlations were performed for the three relationships that showed some degree of statistical significance previously: (i) externally-oriented thinking and increased direct learning rates in the volatile period, (ii) difficulty identifying feelings and increased indirect learning rates in the volatile period, and (iii) difficulty identifying feelings and more stochastic choices overall. Informed by the exploratory analyses in Experiment 1, the correlations between DASS-21 subscales and computational parameters were conservatively kept at a two-tailed level of significance. A Bonferroni correction of $.05/6$ parameters = $.008$ was used to correct for multiple tests.

Additional robust linear regression models were used to evaluate the effects of autistic traits, alexithymia and co-occurring mood symptoms on the DASS-21, with age and gender entered as control variables. To better quantify the relative evidence for the (lack of an) effect of alexithymia and co-occurring mood symptoms on emotion concept learning, Bayesian linear regression was used to estimate the Bayes factors for the predictors with 95% credible intervals, which would allow one to infer at 95% chance level the expected range of change in emotion concept learning per unit change in alexithymia/mood symptoms given the data (Morey & Rouder, 2011; Heck et al., 2022). The inverse of Bayes factor was interpreted as anecdotal (1-3), substantial (4-10), and strong (11-30 or above) (Jarosz & Wiley, 2014). These Bayesian analyses were conducted using the R packages BAS (Clyde, 2022) and BayesFactor (Morey et al., 2022).

Finally, an overall analysis was conducted to compare the differences in computational parameters between participants who surpassed the clinical cutoff for severe alexithymia ($n = 18$) and the remaining participants ($n = 195$) in the full combined sample across Experiments 1 and 2 ($N = 213$). In these analyses, study variables were z-standardised

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again in the combined sample. Due to the relatively unbalanced subgroup sizes, these group comparisons were made using Welsh's t-tests (two-tailed) with 1,000 bootstrap samples to improve the reliability of estimates. A Bonferroni correction of $.05/6$ parameters = $.008$ was applied to these multiple comparisons. For descriptive purposes, the same group comparisons were performed for participants' sample characteristics, which were uncorrected. Cohen's d was reported as the effect size estimate, ranging from small (0.2), medium (0.5), to large (0.8) (Cohen, 1988). From a dimensional perspective, a path model was used to evaluate the potential pathways through which alexithymia, co-occurring mood symptoms, and emotion concept learning were linked. This model was computed using the lavaan package (Rosseel, 2012). We report standardised estimates and standard errors with 1,000 bootstrap samples.

Results

Descriptive Statistics

Table 5.1 (see page 276) summarises the sample characteristics and descriptive statistics of the computational parameters, both of which were highly comparable to participants in Experiment 1. The mean TAS-20 was 43.91 ($SD = 11.98$, range = 21 to 71); 12 participants were classified as severely alexithymic, providing more variance to test for the correlations of interest. Similarly, a wide range of co-occurring mood symptoms were present in this replication sample, 19 of whom surpassed the cut-off score for anxiety. TAS-20 was significantly correlated with AQ, $r(136) = .47$, $p < .001$.

Stimulus Rating Task

Similar to Experiment 1, participants were generally reliable in labelling the sad and disgusted images (mean = $.67$, $SD = .12$). Accuracy was correlated with anxiety ($r(136) = -.24$, $p = .004$), but not with TAS-20 ($r(136) = -.05$, $p = .57$). Importantly, we replicated the previous finding that participants gave higher arousal ratings to the disgusted images (mean =

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44.24, $SD = 14.12$) than to the sad images (mean = 39.87, $SD = 11.54$), $t = 2.81$, $p = .005$, $d = 0.41$, but gave higher valence ratings to the sad images (mean = 28.46, $SD = 9.63$) than to the disgusted images (mean = 24.76, $SD = 9.07$), $t = 3.30$, $p = .001$, $d = 0.41$.

Anxiety Is Linked with More Stochastic Choices Following Learning of Emotion Concepts

In this replication sample (almost twice as large as Experiment 1), the correlation between difficulty identifying feelings and indirect learning rates in the volatile period was almost non-existent, $r(136) = -.01$, $p = .47$ (one-tailed). The correlation between externally-oriented thinking and direct learning rates in the volatile period was also small and non-significant, $r(136) = .03$, $p = .34$ (one-tailed).

With respect to the parameters β and ζ , the previous correlation between difficulty identifying feelings and more stochastic choices (lower β) was reduced and not significant in the replication sample, $r(136) = -.10$, $p = .13$ (one-tailed). Intriguingly, among the DASS-21 subscales, co-occurring anxiety symptoms were correlated with more stochastic choices ($r(136) = -.25$, $p = .006$) which survived Bonferroni correction, as compared to depressive symptoms ($r(136) = -.11$, $p = .20$) and stress ($r(136) = -.16$, $p = .07$).

Indeed, linear regression suggested that anxiety remained significantly associated with more stochastic choices with respect to outcome values (Estimate = -0.06 [-0.11; -0.02], $SD = 0.02$, $t = -3.01$, $p = .003$) even after adjusting for TAS-20 total score (Estimate = 0.01 [-0.03; 0.05], $SE = 0.02$, $t = 0.23$, $p = .82$) and AQ (Estimate = 0.01 [-0.03; 0.05], $SE = 0.02$, $t = 0.42$, $p = .68$) with age and sex as control variables (Table 5.3, page 287). The effect of anxiety on stochastic choices was consistent when only analysing participants with a similar conceptualisation of sadness and disgust on the stimulus rating task as observed in the past validation studies ($n = 100$, nine participants with severe alexithymia) (Estimate = -0.05 [-0.10; -0.01], $SE = 0.02$, $t = -2.23$, $p = .03$) (TAS-20: Estimate = 0.03 [-0.02; 0.09], $SE = 0.03$,

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$t = 1.15, p = .25$), as well as amongst participants with above 50% accuracy on the learning task ($n = 93$, six participants with severe alexithymia) (Estimate = -0.07 [$-0.12; -0.01$], $SE = .03, t = -2.33, p = .02$) (TAS-20: Estimate = -0.0004 [$-0.05; 0.05$], $SE = .02, t = -0.02, p = .99$). Results are summarised in **Supplementary Materials** (Table S5.2). Consistent with Experiment 1, no relationships were found between alexithymia or mood symptoms and the extent to which one learned emotion concepts indirectly from social information relative to direct learning from task performance feedback (ζ) ($r_s = -.02$ to $.09$).

Complementing the frequentist approach with Bayesian statistics (Table 5.3), there was substantial evidence for the association between anxiety and stochastic choices overall (Posterior mean = -0.07 [$-0.12; -0.03$], Posterior $SD = 0.02$), with a Bayes factor of 9.48. In contrast, the data were consistent with the null hypothesis that alexithymia was not associated with stochastic choices (Posterior mean = 0.01 [$-0.05; 0.04$], Posterior $SD = 0.02$), with a Bayes factor of 0.43. Figure 5.2 (page 288) depicts the regression plots of Experiment 2.

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Table 5.3

Summary of Robust Linear Regression and Bayesian Linear Regression Predicting Parameter β in Experiment 2

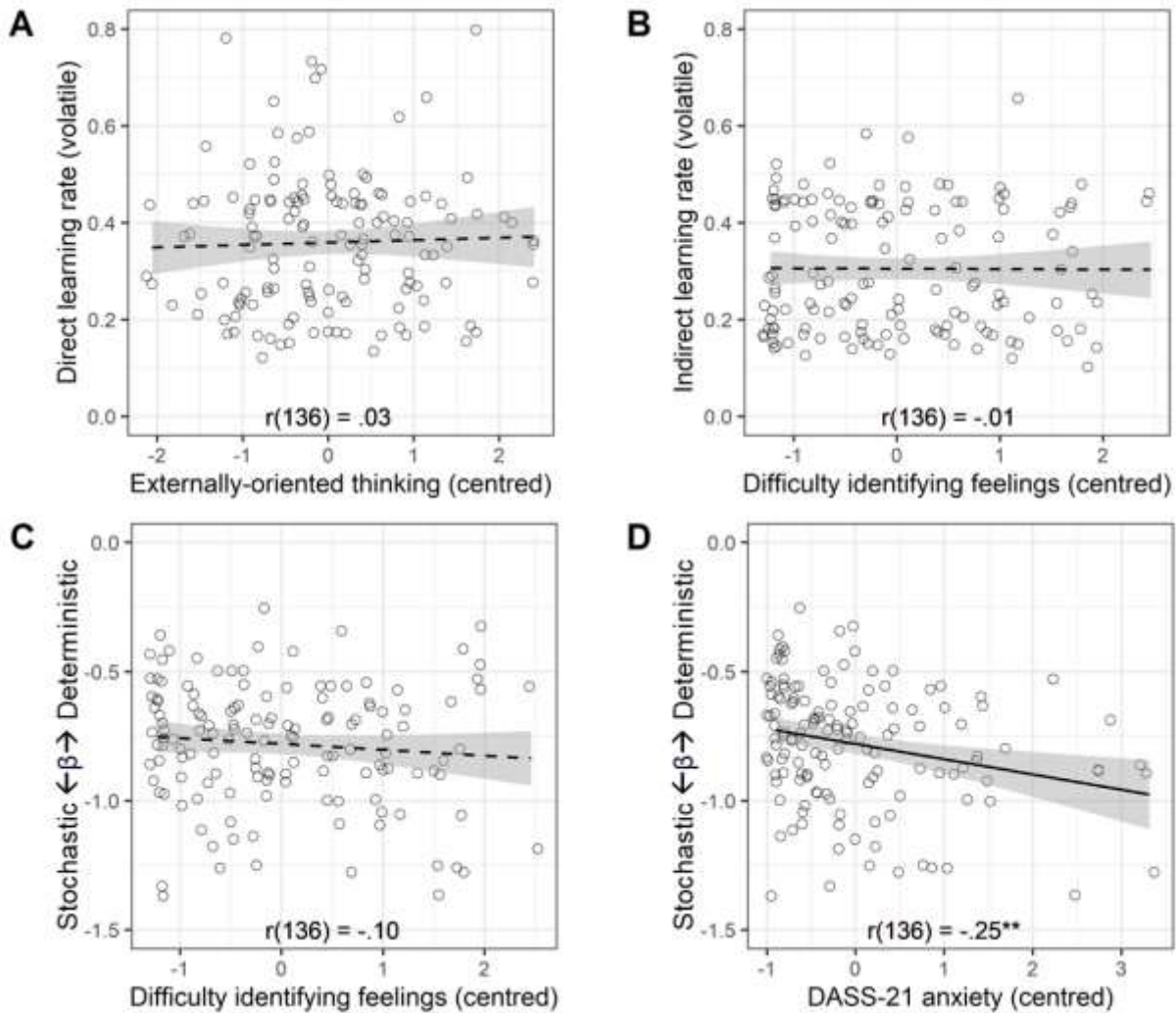
Outcome	Predictor	Estimate	2.5% CI	97.5% CI	SE	t	P	VIF
β	(Intercept)	-0.76	-0.95	-0.57	0.10	-7.97	<0.001	--
	Age	0.00	-0.01	0.01	0.00	-0.25	0.800	1.08
	Sex (Female)	0.02	-0.05	0.10	0.04	0.62	0.539	1.10
	Anxiety	-0.06	-0.11	-0.02	0.02	-3.01	0.003	1.25
	AQ	0.01	-0.03	0.05	0.02	0.42	0.679	1.42
	TAS-20	0.01	-0.04	0.05	0.02	0.23	0.816	1.43
Outcome	Predictor	Posterior mean	Posterior SD	2.5% CI	97.5% CI	Bayes factor		
β	(Intercept)	-0.78	0.02	-0.81	-0.73	--		
	Age	0.00	0.00	-0.01	0.00	0.37		
	Sex (Female)	0.02	0.04	-0.03	0.11	0.40		
	Anxiety	-0.07	0.02	-0.12	-0.03	9.48		
	AQ	0.00	0.02	-0.03	0.06	0.37		
	TAS-20	0.01	0.02	-0.05	0.04	0.43		

Notes. B values were inverse square-root transformed. Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. For robust linear regression, 95% confidence intervals are estimated. For Bayesian regression, 95% credible intervals are estimated. Two-tailed p values are presented here. AQ = Autism Spectrum Quotient; TAS-20 = 20-item Toronto Alexithymia Scale.

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Figure 5.2

Associations of Alexithymia and Anxiety with Computational Parameters in Experiment 2 (N = 138)



Notes. Learning rates were square-root transformed, whilst β values were inverse square-root transformed. (A) and (B) depict the associations between externally-oriented thinking and direct learning rate in the volatile period, and between difficulty identifying feelings and indirect learning rate in the volatile period, both of which were reduced to near zero in the replication sample. (C) The association between difficulty identifying feelings and more stochastic choices was largely reduced. (D) The association between co-occurring anxiety and more stochastic choices survived Bonferroni correction. $^{**} p < .01$, two-tailed.

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Overall Group Comparisons

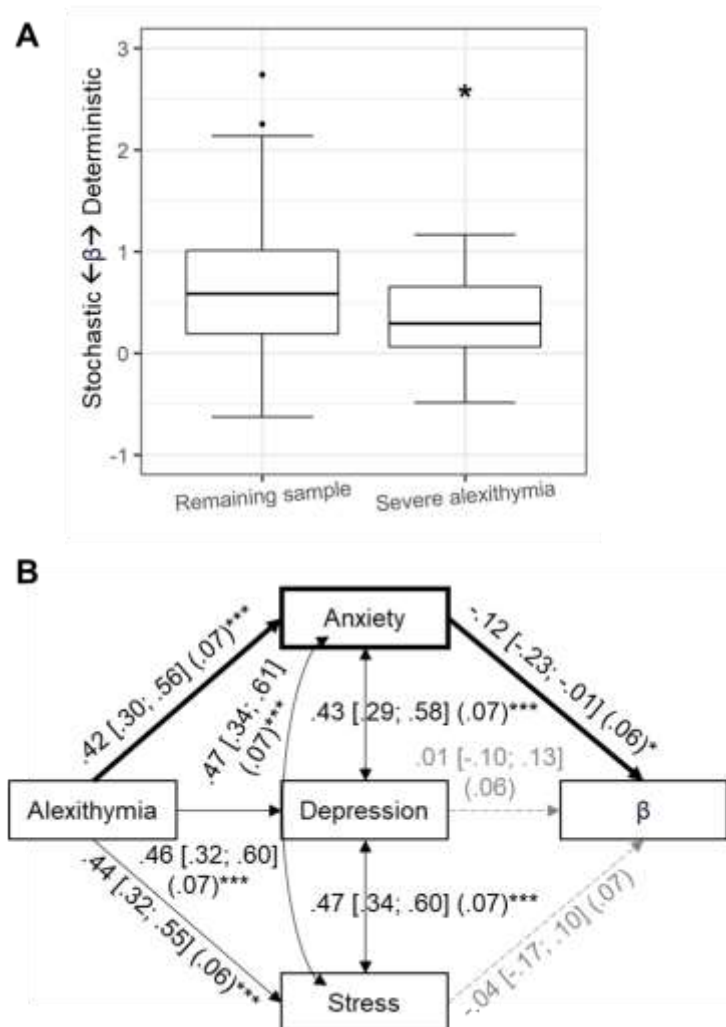
Due to space considerations, the group differences in sample characteristics and computational parameters between participants with severe alexithymia and the remaining participants in the combined sample ($N = 213$) are summarised in Table S5.3. While participants with severe alexithymia scored significantly higher on the TAS-20 and its subscales than others, as one would expect ($t_s = 6.95$ to 24 , $p_s < .001$, $d_s = 3.07$ to 6.52), alexithymic participants also reported significantly higher levels of co-occurring mood symptoms on the DASS-21 ($t_s = 2.38$ to 3.44 , $p_s = .005$ to $.02$, $d_s = 1.12$ to 1.57).

For computational parameters, alexithymic participants had comparable learning rates to other participants in both stable and volatile periods of the task ($t_s = -0.26$ to 0.52 , $p_s = .58$ to $.87$, $d_s = -0.25$ to -0.21). Alexithymic participants, however, made more stochastic choices with respect to outcome values than non-alexithymic participants, $t(23.22) = -2.33$ $[-0.51; -0.05]$, $p = .03$, $d = -0.97$) (Figure 5.3A). This group difference did not survive Bonferroni correction. No significant group difference was found for indirect learning of emotion concepts from social information relative to direct learning from task feedback, $t(20.39) = 0.42$ $[-0.11; 0.16]$, $p = .72$, $d = 0.19$.

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Figure 5.3

Overall Group Comparison and Path Model in the Full Combined Sample ($N = 213$)



Notes. In these pooled analyses, β values were log transformed in the full combined sample.

(A) Participants with severe alexithymia ($n = 18$) had significantly lower beta values than the remaining participants ($n = 195$), indicating that their choices were stochastic when learning unfamiliar emotion concepts. This group difference, however, did not survive Bonferroni correction. (B) Path model analysing the multivariate pathways amongst alexithymia, co-occurring mood symptoms, and stochastic choices. Standardised estimates and standard errors are shown here. * $p < .05$, ** $p < .01$, *** $p < .001$, two-tailed.

Path Model

Figure 5.3B (page 290) presents the multivariate pathways between alexithymia, co-occurring mood symptoms, and stochastic choices in the full combined sample. The non-significant chi-squared test suggested that there was good correspondence between the fitted and sample covariance matrices, $\chi^2(1) = .40, p = .53$. Specifically, while TAS-20 was significantly associated with more anxious (Estimate = .42 [.29; .56], SE = .07, $p < .001$), depressive (Estimate = .46 [.32; .60], SE = .07, $p < .001$) and stress symptoms (Estimate = .44 [.32; .55], SE = .06, $p < .001$), only anxiety symptoms were further associated with more stochastic choices following learning of emotion concepts (Estimate = -.12 [-.23; -.01], SE = .06, $p = .04$).

Experiment 3: Specificity of the Effect of Anxiety on Learning

Experiment 2 indicated that the associations between alexithymia and computational parameters found in Experiment 1 were not reliable, whilst the association between anxiety and more stochastic choices was robust and supported by both frequentist and Bayesian analyses. Further insights into the associations between these study variables were revealed by the pooled sample analyses: individuals with severe alexithymia reported significantly higher levels of co-occurring mood symptoms than others, amongst which anxiety was further and uniquely associated with more stochastic choices with respect to outcome values. A remaining question that is of broader theoretical importance in the affective sciences is to test if these same relationships would emerge in the context of learning about *abstract but non-emotion* concepts. Specifically, constructionist theories posit that emotion categories and their related concepts are, in essence, abstract categories that are defined in a context-specific manner and consist of a variable set of features (e.g., facial expressions and physiological

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signals) that do not necessarily inform a definitive boundary between categories/concepts (Hoemann et al., 2020). This account leads to the prediction that anxiety would be associated with more stochastic choices when learning about any abstract concept, and that the findings from Experiments 1 and 2 were not emotion-specific. To test this domain-general prediction, we present a final study that was structurally identical to Experiments 1 and 2, but comprised of a non-emotional version of the concept learning task.

Method

Participants

We performed a power analysis using the combined data from Experiments 1 and 2 ($N = 213$), which suggested that a sample size of 174 participants would provide 90% power to detect a zero-order correlation of $-.22$ (one-tailed) between anxiety and stochastic choices. A total of 176 participants were recruited independently on Testable, two of whom were excluded due to poor data quality and internet connection issue, leading to a final sample of 174 participants (mean age = 28.39 years, $SD = 6.84$, range = 18 to 45, 48.3% female) for subsequent analyses.

Measures

The same trait and mood symptom measures were used.

Non-Emotion Learning Task

A structurally similar concept learning task was completed, in which participants were told that they were travelling in space with the mission to learn the aliens' language to describe temperature. Importantly, participants were required to learn the temperature concept of the joint perception of hotness and coldness ("noohy" or "zapro"), which to our knowledge, does not exist in the languages of most human cultures and would be

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perceptually confusing to humans, resulting in an alternating perception between hotness and coldness, and/or pain (Casey et al., 1996; Tracey et al., 2000). Participants were not informed about the nature of this alien temperature concept throughout the task, but were only aware of the fact that the aliens had a very different understanding of temperature and would apply the same label to temperatures that appear different to humans. A total of 120 unique hot images and 120 unique cold images were gathered from online public-domain image libraries and presented in the same manner as described above for the emotional version, i.e., 120 unique pairs of images across 120 trials. The same probability schedules were used.

After completing the learning task, participants were asked to label a randomly selected subset of 60 test images (30 hot images and 30 cold images) using one of six labels: 2 temperature (hot/cold) x 3 physical state (solid/liquid/gas). Here, labelling accuracy could only be determined by the temperature labels that were initially tagged onto these images in the image libraries, whilst the three state labels were included for the sake of providing an identical structure to the task used in Experiments 1 and 2. Participants were also asked to rate the perceived temperature and state (0 to 100) of these images.

Statistical Analyses

Informed by Experiments 1 and 2 and constructionist theories of emotion, a zero-order Pearson's correlation (one-tailed) was conducted to test the relationship between anxiety and stochastic choices when learning abstract temperature concepts. β values were inverse square-root transformed. To serve as a more direct test of constructionist theories, a Fisher's r-to-z transformation was conducted to test if the size of the correlation between anxiety and more stochastic choices in this non-emotion concept learning task was significantly different from the same correlation found in the emotion concept learning task in Experiments 1 and 2 ($r = -.22$). Since constructionist theories posit that emotions are an

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instance of an abstract concept (e.g., Hoemann et al., 2020), a non-significant difference following r-to-z transformation would be expected. A Bayes factor testing of equality was further conducted to estimate the posterior probabilities for obtaining statistically equivalent versus non-equivalent correlations between anxiety and stochastic choices in the two versions of the task using the BCT software (Mulder & Gelissen, 2023). Finally, a path model was performed to quantify the multivariate associations between alexithymia, co-occurring mood symptoms as measured by the DASS-21, and stochasticity (β). The hypothesised path between anxiety and stochastic choices significance level was kept at $\alpha = .05$, one-tailed.

Results

Descriptive Statistics

The sample characteristics and descriptive statistics of the computational parameters of these participants were highly comparable to those who took part in Experiments 1 and 2 (see Table S5.4 in **Supplementary Materials**). Of the 174 participants, 18 participants were severely alexithymic (mean = 44.04, $SD = 11.71$, range = 21 to 76). Participants also showed a wide range of co-occurring mood symptoms, with 25 participants surpassing the cut-off score for anxiety.

Stimulus Rating Task

Participants were generally very accurate in labelling the temperature of the test images as hot or cold (mean = .96, $SD = .04$). This finding was also reflected in the profound difference between their dimensional ratings on the same hot images (mean = 87.73, $SD = 7.96$) and cold images (mean = 10.14, $SD = 7.43$), $t = 93.98$, $p < .001$, $d = 10.10$, suggesting a relatively categorical perception of temperature. When asked to rate the perceived state of these images, the hot images appeared to be significantly less “solid” (mean = 40.58, $SD = 15.5$) than the cold images (mean = 22.5, $SD = 13.64$), $t = 11.55$, $p < .001$, $d = 1.24$. Stimulus

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rating accuracy was not correlated with anxiety ($r(172) = -.11, p = .17$) or TAS-20 ($r(172) = -.06, p = .41$).

Anxiety Is Also Linked to More Stochastic Choices Following Learning of Non-Emotion Concepts

Our key planned analysis suggested that anxiety was significantly correlated with more stochastic choices following learning of abstract temperature concepts, $r(172) = -.16, p = .02$ (one-tailed) (see Figure S5.3A). This correlation remained significant after controlling for age differences in this sample, partial $r(172) = -.14, p = .03$ (one-tailed). The Fisher r -to- z test indicated that the correlation coefficient found between anxiety and stochastic choices in this non-emotion concept learning task was indeed not significantly different from that in the emotion concept learning task in Experiments 1 and 2, $z = -.60, p = .27$ (one-tailed). Bayes factor testing of equality also found much stronger evidence in favour of statistically equivalent correlations (Posterior probability = .83) than non-equivalent correlations (Posterior probability = .05) for anxiety and stochastic choices from the two concept learning tasks, supporting the constructionist theories. Finally, the path analysis, $\chi^2(1) = 1.48, p = .22$, revealed that while alexithymia was associated with higher co-occurring mood symptoms overall (Estimates = 0.37 to 0.54, SEs = 0.07 to 0.08, $ps < .001$), anxiety was additionally and uniquely associated with more stochastic choices following learning of temperature concepts (Estimate = -0.04 [-0.09; 0.01], SE = 0.02, $p = .04$, one-tailed) (see Figure S5.3B), although note that the confidence interval crossed the zero boundary slightly in this relatively smaller sample as compared to the combined sample from Experiments 1 and 2.

Overall Discussion

Through a series of three experiments, we investigated the relationship between alexithymia and computational parameters that quantified the rate of learning unfamiliar abstract concepts, the tendency to make deterministic/stochastic choices with respect to outcome values, and the extent to which one's choices were influenced by indirect learning from social information relative to direct learning from task feedback. These experiments utilised a computational framework from previous studies (Behrens et al., 2007; Cook et al., 2014, 2019), with the aim of elucidating basic learning processes that likely support the learning of abstract (emotion) concepts (Hoemann et al., 2020; Lindquist et al., 2022), offering novel insights into the link between alexithymia and potential deficits in emotion concept acquisition. Contrary to our initial predictions, associations between alexithymia and learning rates were unstable and not consistently replicable. Further insights regarding these associations were revealed when taking into account co-occurring mood symptoms: while alexithymic individuals reported elevated levels of mood symptoms, anxiety symptoms were consistently and uniquely associated with more stochastic choices following learning of unfamiliar abstract concepts.

Studies have shown that individuals with high anxiety symptoms and anxiety disorders showed atypical learning behaviours as compared to healthy individuals (see a meta-analysis of computational studies on this topic; Pike & Robinson, 2022). Here, we extend these findings to the context of choices following abstract concept learning. Co-occurring anxiety was consistently associated with lower β , indicating that actual choices were not strictly governed by the estimated value of choices. However, there was no evidence suggesting a relationship between anxiety and atypical learning rates, suggesting that the estimation of choice values *per se* is likely intact and not a process contributing to the stochastic choices. The tendency to make stochastic choices was not linked to a bias to conform to social

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information acquired from a hypothetical group of players who had had the experience of learning the same concepts (indicated by the non-significant associations with the ζ parameter throughout), meaning that anxious individuals were no more likely to utilise such social information relative to task performance feedback. Therefore, regardless of the type of learning information (direct task feedback / indirect social information) and environmental volatility (stable/volatile phases of the task), the above findings indicate that anxious individuals appear to have a general tendency to make choices that are not necessarily as informed by learned outcome values (Piray & Daw, 2021; Yamamori & Robinson, 2023). However, there is still a need to clarify the source(s) of stochastic choices in anxiety (see a critique of learning task-related computational parameters; Eckstein et al., 2021). Some possibilities are heightened risk perception / hypervigilance (which increases decision noise; Notebaert et al., 2016), metacognitive deficits that reduce one's confidence in tracking the outcome value of one's response (which leads to inflexible adjustment of behaviour: Rouault et al., 2018; see review by Seow et al., 2021), or a combination of both. Furthermore, other forms of learning imbalance in anxiety have been documented, including higher learning rates following punishment but lower learning rates after receiving a reward (Pike & Robinson, 2022), and reduced adaptability in reward contexts where the probability of encountering punitive agents is no longer volatile (Beltzer et al., 2019).

Regarding the null findings of alexithymia, we found no evidence for the proposal that low emotional self-awareness is directly linked to any of the (emotion) concept acquisition processes when controlling for co-occurring anxiety. Thus, despite findings that individuals with alexithymia have a less fine-grained perception of emotional experiences (Erbas et al., 2019; and as synthesised in Chapter 2), it is unlikely that reduced emotional granularity is due to difficulty learning a diverse range of emotion concepts (or abstract concepts in general) in these individuals in the absence of co-occurring anxiety. Perhaps more problematically, the

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modest association between alexithymia and emotional granularity found in the above studies may well be contributed to by co-occurring mood symptoms that were not measured in the majority of those student samples, which likely show elevated mood symptoms and poorer well-being when compared to the general population (Ichijo et al., 2019).

Convergent findings across the emotional and non-emotional versions of the concept learning task suggest that emotion concepts can be learned through similar learning processes as abstract non-emotion concepts (Hoemann et al., 2020). This domain-general perspective echoes the multi-route model of alexithymia, suggesting that emotional self-awareness is supported by basic psychological processes (e.g., social information processing, interoception, and language) that facilitate a broad range of cognitive and behavioural functions beyond the experience of emotions *per se* (Hobson et al., 2019). Although we found no evidence for a direct link between alexithymia and emotion concept learning, consideration of co-occurring mood symptoms (anxiety in this case) is crucial to rethinking the connections between these multiple routes and alexithymia. This has important clinical implications as it is common for individuals with alexithymia to struggle with emotion dysregulation, which is closely linked to mood disorders, including depression and anxiety (Preece et al., 2022). Randomised controlled trials attempting to improve emotional self-awareness and tolerance of emotion-related bodily sensations have demonstrated initial success in significantly reducing anxiety-related symptoms across a transdiagnostic range of patients with less attrition than conventional disorder-specific treatments (Barlow et al., 2017). Our findings suggest that focusing on these alexithymia-related targets alone may not necessarily promote adaptive choice behaviours in these individuals. Future research on the direct link between alexithymia and anxiety-related behaviours is warranted to enhance treatment specificity.

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Strengths and Limitations

To the best of our knowledge, this is one of the first empirical studies that tests the link between alexithymia and emotion concept learning. Concept learning was operationalised using a well-established paradigm that allows for the estimation of computational parameters that are pertinent to the underlying mechanisms of emotion concept learning, and we related these to clinically-relevant individual differences in alexithymia and mood symptoms. Moreover, we marry the strengths of computational modelling with statistical techniques such as Bayesian statistics and path analysis to shed light on the complex relationships between these individual differences and computational parameters. Although this study was not pre-registered, we systematically report the estimation of sample sizes, analytic strategies, and effect sizes in a transparent manner. A control experiment was also conducted to test the domain specificity of our findings, which addresses some broader theoretical issues in basic affective and cognitive sciences regarding the relevance of abstract concepts to psychological well-being.

Nonetheless, our findings should be interpreted in the context of several limitations. First, the current sample comprised healthy individuals who were not diagnosed with any psychiatric disorders and reported no significant mental health concerns (including those related to depression and anxiety). While participants reported a wide range of traits and mood symptoms across all three experiments, there is still a paucity of participants who are at the very extreme end of the alexithymia spectrum and those with symptoms that warrant a clinical diagnosis of anxiety. With reference to past computational work (Pike & Robinson, 2022), we speculate that some of the anxiety-related effects would be more pronounced when clinical groups are recruited. Second, anxiety symptoms were indexed using the DASS-21, which corresponds more closely to the diagnostic symptoms of clinical anxiety than state and trait anxiety. Studies have shown that state and trait anxiety are associated with different

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computational parameters on learning tasks (e.g., Browning et al., 2015; Hein et al., 2021), pointing to a potential source of heterogeneity in the relationship between anxiety and stochastic choices. In addition, the DASS-21 anxiety items do not assess social anxiety symptoms, which are associated with a negative bias to learn from punitive social agents (Beltzer et al., 2019), which may have implications for the development of alexithymia in social rejection and victimisation contexts. Lastly, although the use of cross-sectional data precludes the analysis of bi-directional effects, falsely discounting instances that could have aided one's emotion understanding may exacerbate some of the alexithymic features and contribute to further emotional distress in these individuals. Multi-session and longitudinal studies would help clarify the degree of reciprocity between individual differences and learning features.

Conclusions

In sum, the current study found no evidence for a direct link between alexithymia and emotion concept learning. Instead, an indirect pathway was found, demonstrating that individuals with alexithymia showed elevated levels of co-occurring mood symptoms, and that anxiety symptoms were uniquely associated with more stochastic choices with respect to outcome values. These findings suggested that individuals with high co-occurring anxiety demonstrated a reduced tendency to adapt to historic learning outcomes in the presence of environmental volatility. A control task testing the learning of abstract non-emotion concepts revealed the same pattern of results, supporting the constructionist account that emotion concepts are an instance of abstract concepts in general and learned in the same way as these other concepts.

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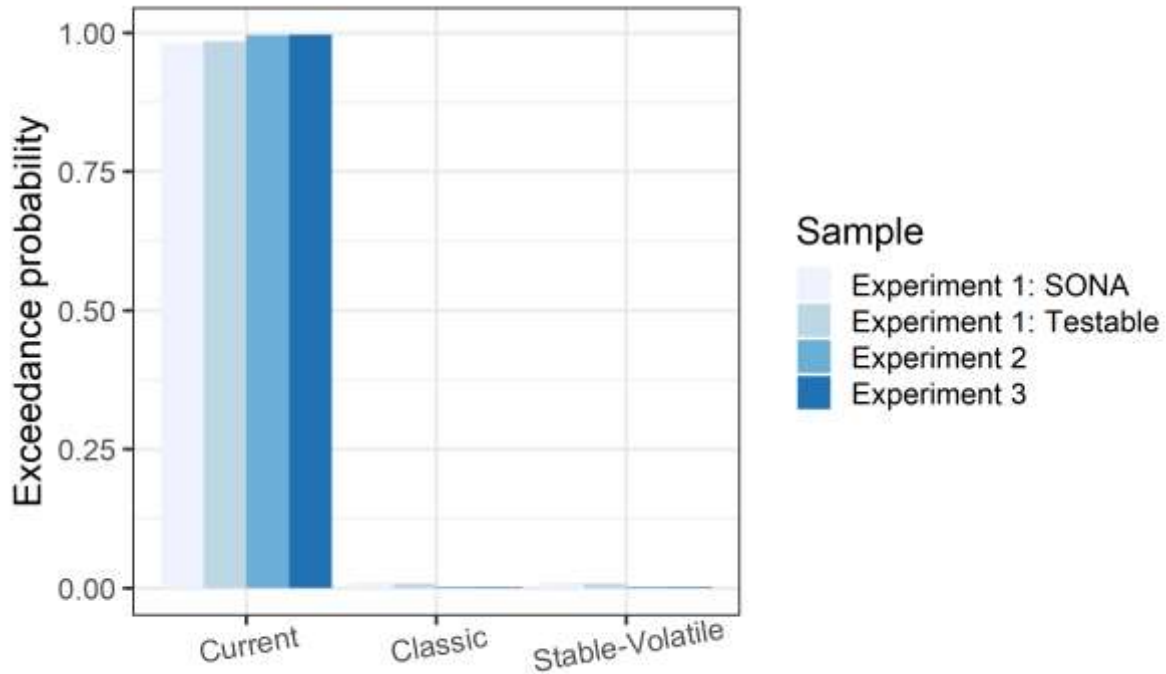
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Chapter 5**Supplementary Materials**

Figure S5.1*Model Comparison*

Notes. The current model that estimated separate learning rates (α) for direct and indirect learning during stable and volatile periods had exceedance probabilities of almost 1 across all study samples in Experiments 1 and 2. This suggested that there was compelling evidence that the current model was more frequent in generating the data for any randomly selected participants than the classic Rescorla Wagner model (with one single learning rate) and a model that only estimated two learning rates for stable and volatile periods, respectively. This Bayesian model selection procedure was performed using the VBA toolbox (Daunizeau et al., 2014). Using `tapas_simModel.m` with the parameter estimates, data simulation suggested that there was good correspondence between the simulated choices and participants' responses (Experiments 1 and 2: average $r = .66$; Experiment 3: $r = .68$).

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Table S5.1*Summary of Robust Linear Regressions Adjusting for Co-Occurring Mood Symptoms in Experiment 1 Selected Samples*

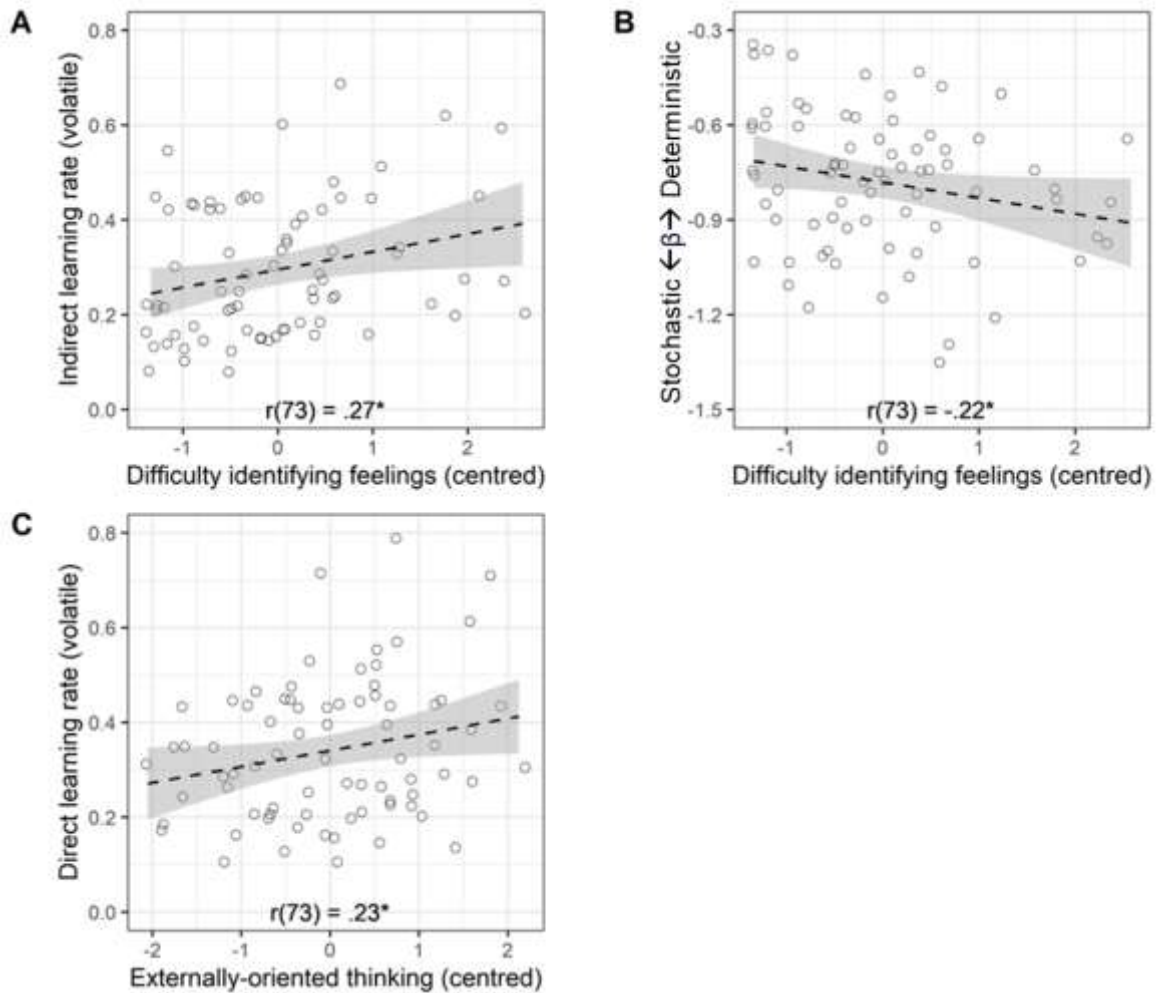
Outcome	Predictor	Estimate	2.5% CI	97.5% CI	SE	t	p	VIF
<i>Selected sample with at least 60% labelling accuracy on the stimulus rating task (n = 59)</i>								
Learning rate-- Indirect (volatile)	(Intercept)	0.22	0.07	0.37	0.08	2.92	0.005	--
	Age	0.00	0.00	0.01	0.00	0.79	0.435	1.34
	Sex (Female)	0.02	-0.05	0.09	0.04	0.63	0.534	1.14
	DIF	0.03	-0.04	0.09	0.03	0.86	0.392	1.90
	DASS-21	0.03	-0.02	0.08	0.03	1.08	0.285	1.68
β	(Intercept)	-0.59	-0.83	-0.36	0.12	-4.90	<0.001	--
	Age	-0.01	-0.01	0.00	0.00	-1.24	0.221	1.22
	Sex (Female)	-0.08	-0.21	0.05	0.07	-1.17	0.246	1.12
	DIF	-0.05	-0.11	0.01	0.03	-1.73	0.089	1.40
	Stress	-0.03	-0.10	0.03	0.03	-1.08	0.284	1.42
<i>Selected sample with >50% accuracy on the emotion concept learning task (n = 51)</i>								
Learning rate-- Indirect (volatile)	(Intercept)	0.26	0.13	0.38	0.06	4.04	<0.001	--
	Age	0.00	0.00	0.01	0.00	0.46	0.647	1.28
	Sex (Female)	-0.01	-0.08	0.05	0.03	-0.45	0.655	1.06

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	DIF	0.02	-0.03	0.06	0.02	0.69	0.495	1.63
	DASS-21	0.03	-0.03	0.09	0.03	0.85	0.399	1.36
β	(Intercept)	-0.62	-0.83	-0.41	0.11	-5.82	<0.001	--
	Age	0.00	-0.01	0.00	0.00	-1.18	0.242	1.11
	Sex (Female)	0.00	-0.09	0.08	0.04	-0.10	0.923	1.18
	DIF	-0.08	-0.14	-0.02	0.03	-2.80	0.007	1.42
	Stress	0.03	-0.03	0.09	0.03	0.86	0.393	1.30

Notes. The selected samples were not significantly different than the excluded participants in autistic traits, alexithymia, or co-occurring mood symptoms (at least 60% stimulus rating accuracy: $t_s = -0.24$ to 0.11 , $p_s = .815$ to $.934$; >50% learning accuracy: $t_s = -0.32$ to 1.61 , $p_s = .113$ to $.749$). Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. For transparency, two-tailed p values are presented here. DIF = Difficulty Identifying Feelings; DASS-21 = Depression Anxiety Stress Scale.

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Figure S5.2*Associations Between Alexithymia Domains and Computational Parameters in Experiment 1**(N = 75)*

Notes. Learning rates were square-root transformed, whilst beta values were inverse square-root transformed. Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. These zero-order correlations did not survive Bonferroni correction (denoted by the dotted regression lines).

* $p < .05$.

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Table S5.2*Summary of Robust Linear Regressions Adjusting for Co-Occurring Anxiety Symptoms in Experiment 2 Selected Samples*

Outcome	Predictor	Estimate	2.5% CI	97.5% CI	SE	t	p	VIF
<i>Selected sample with at least 60% labelling accuracy on the stimulus rating task (n = 100)</i>								
β	(Intercept)	-0.68	-0.87	-0.50	0.09	-7.38	<0.001	--
	Age	0.00	-0.01	0.00	0.00	-1.14	0.257	1.24
	Sex (Female)	0.03	-0.06	0.12	0.04	0.64	0.521	1.10
	Anxiety	-0.05	-0.10	-0.01	0.02	-2.23	0.028	1.38
	AQ	-0.04	-0.10	0.02	0.03	-1.40	0.166	1.56
	TAS-20	0.03	-0.02	0.09	0.03	1.15	0.252	1.72
<i>Selected sample with >50% accuracy on the emotion concept learning task (n = 93)</i>								
β	(Intercept)	-0.77	-0.98	-0.56	0.11	-7.19	<0.001	--
	Age	0.00	-0.01	0.01	0.00	0.03	0.975	1.05
	Sex (Female)	0.05	-0.04	0.14	0.05	1.05	0.298	1.15
	Anxiety	-0.07	-0.12	-0.01	0.03	-2.33	0.022	1.61
	AQ	0.02	-0.02	0.06	0.02	0.99	0.325	1.34
	TAS-20	0.00	-0.05	0.05	0.02	-0.02	0.988	1.42

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Notes. The selected samples were not significantly different from the excluded participants in autistic traits, alexithymia, or co-occurring mood symptoms (at least 60% stimulus rating accuracy: $t_s = -0.32$ to 0.74 , $p_s = .458$ to $.921$; >50% learning accuracy: $t_s = -0.64$ to 0.61 , $p_s = .525$ to $.845$). Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. For transparency, two-tailed p values are presented here. AQ = Autism Spectrum Quotient; TAS-20 = 20-item Toronto Alexithymia Scale.

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Table S5.3

Overall Group Comparisons Between Participants with Severe Alexithymia and Remaining Sample ($N = 213$)

Sample characteristics	Participants with severe alexithymia ($n = 18$)					Remaining sample ($n = 195$)					Comparison					
	<i>M</i>	<i>SD</i>	Min	Max	> Cutoff <i>n</i>	<i>M</i>	<i>SD</i>	Min	Max	> Cutoff <i>n</i>	<i>t</i> / χ^2	df	2.5% CI	97.5% CI	<i>p</i>	<i>d</i> / <i>V</i>
Age (years)	24.78	6.21	18	38	--	27.79	7.50	18	45	--	-1.93	21.85	-5.87	0.08	0.108	-0.83
% Female	61.1					51.8					0.77	--	--	--	0.719	0.06
AQ	23.94	8.61	6	37	3	19.45	6.91	3	42	6	2.15	19.08	0.41	8.38	0.064	0.99
TAS-20	66.33	3.22	62	71	--	41.64	9.71	21	60	--	24.00	54.22	22.68	26.70	<0.001	6.52
DDF	19.50	2.43	16	24	--	11.69	4.19	5	22	--	12.08	27.40	6.58	9.04	<0.001	4.61
DIF	22.56	2.62	18	27	--	12.89	4.73	7	27	--	13.74	28.55	8.31	11.01	<0.001	5.14
EOT	24.28	4.20	14	30	--	17.07	4.33	8	28	--	6.95	20.49	5.18	9.17	<0.001	3.07
DASS-21	46.11	25.77	6	84	--	24.57	20.91	0	98	--	3.44	19.12	9.69	33.45	0.002	1.57
Depression	14.67	12.69	0	38	7	7.41	8.01	0	42	17	2.38	18.27	1.54	13.08	0.023	1.12
Anxiety	13.44	10.24	2	32	6	6.31	7.06	0	34	25	2.89	18.52	2.57	12.04	0.004	1.34
Stress	18.00	8.60	2	38	3	10.86	8.71	0	38	15	3.37	20.36	3.18	11.14	0.003	1.49
Learning task	<i>M</i>	<i>SD</i>	Min	Max		<i>M</i>	<i>SD</i>	Min	Max		<i>t</i>	df	2.5% CI	97.5% CI	<i>p</i>	<i>d</i>
Learning rate (α)																
Direct	0.16	0.09	0.01	0.37		0.15	0.10	0.02	0.53							
Stable	0.16	0.09	0.01	0.33		0.15	0.12	0.01	0.61		0.52	21.56	-0.05	0.07	0.622	0.22
Volatile	0.16	0.15	0.02	0.64		0.14	0.12	0.01	0.62		0.51	19.78	-0.05	0.10	0.580	0.23
Indirect	0.11	0.06	0.02	0.20		0.12	0.08	0.01	0.36							
Stable	0.12	0.08	0.02	0.21		0.13	0.10	0.00	0.50		-0.15	21.45	-0.07	0.06	0.871	-0.06
Volatile	0.10	0.07	0.02	0.22		0.11	0.09	0.01	0.47		-0.26	21.78	-0.06	0.05	0.799	-0.11
β	1.55	0.72	0.61	3.20		2.30	1.87	0.53	15.51		-2.33	23.22	-0.51	-0.05	0.029	-0.97
ζ	0.54	0.32	0.00	0.97		0.51	0.33	0.00	1.00		0.42	20.39	-0.11	0.16	0.716	0.19

Notes. The corresponding cutoff scores for the trait and symptom measures are: AQ (above 32), TAS-20 (61 or above), DASS-21 depression (21 or above), DASS-21 anxiety (15 or above), DASS-21 stress (26 or above). For

descriptive purposes, direct and indirect learning rates are the average of learning rates during stable and volatile periods. Raw scores and two-tailed *p* values are presented here. Learning rates and ζ values were square-root

transformed, whilst β values were log transformed for the statistical comparisons. Higher β values indicate more deterministic choices with respect to outcome values, while lower β values indicate more stochastic choices. AQ =

Autism Spectrum Quotient; TAS-20 = 20-item Toronto Alexithymia Scale; DDF = Difficulty Describing Feelings; DIF = Difficulty Identifying Feelings; EOT = Externally-Oriented Thinking; DASS-21 = Depression Anxiety Stress

Scale.

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Table S5.4*Sample Characteristics and Descriptive Statistics of Computational**Parameters in Experiment 3 (N = 174)*

	<i>M</i>	<i>SD</i>	Min	Max	> Cutoff <i>n</i>
Age (years)	28.39	6.84	18	45	--
% Female	48.3				
AQ	20.68	7.09	6	40	10
TAS-20	44.04	11.71	21	76	18
DDF	12.64	4.90	5	25	--
DIF	13.28	5.29	7	30	--
EOT	18.12	4.45	8	35	--
DASS-21	25.75	20.34	0	104	--
Depression	8.18	8.69	0	42	16
Anxiety	6.63	6.63	0	30	25
Stress	10.93	8.21	0	42	12
	<i>M</i>	<i>SD</i>	Min	Max	
Accuracy	0.54	0.06	0.38	0.71	
<u>Learning rate (α)</u>					
Direct	0.15	0.09	0.02	0.48	
Stable	0.15	0.10	0.01	0.70	
Volatile	0.15	0.12	0.01	0.59	
Indirect	0.12	0.08	0.01	0.32	
Stable	0.12	0.09	0	0.40	
Volatile	0.12	0.10	0.01	0.51	
β	2.42	2.14	0.55	20.65	
ζ	0.51	0.32	0	1.00	

Notes. The corresponding cutoff scores for the trait and symptom measures are: AQ (above 32), TAS-20 (61 or above), DASS-21 depression (21 or above), DASS-21 anxiety (15 or above), DASS-21 stress (26 or above). For descriptive purposes, direct and indirect learning rates are the average of learning rates during stable and volatile periods. Raw scores are presented here. AQ = Autism Spectrum Quotient; TAS-20 = 20-

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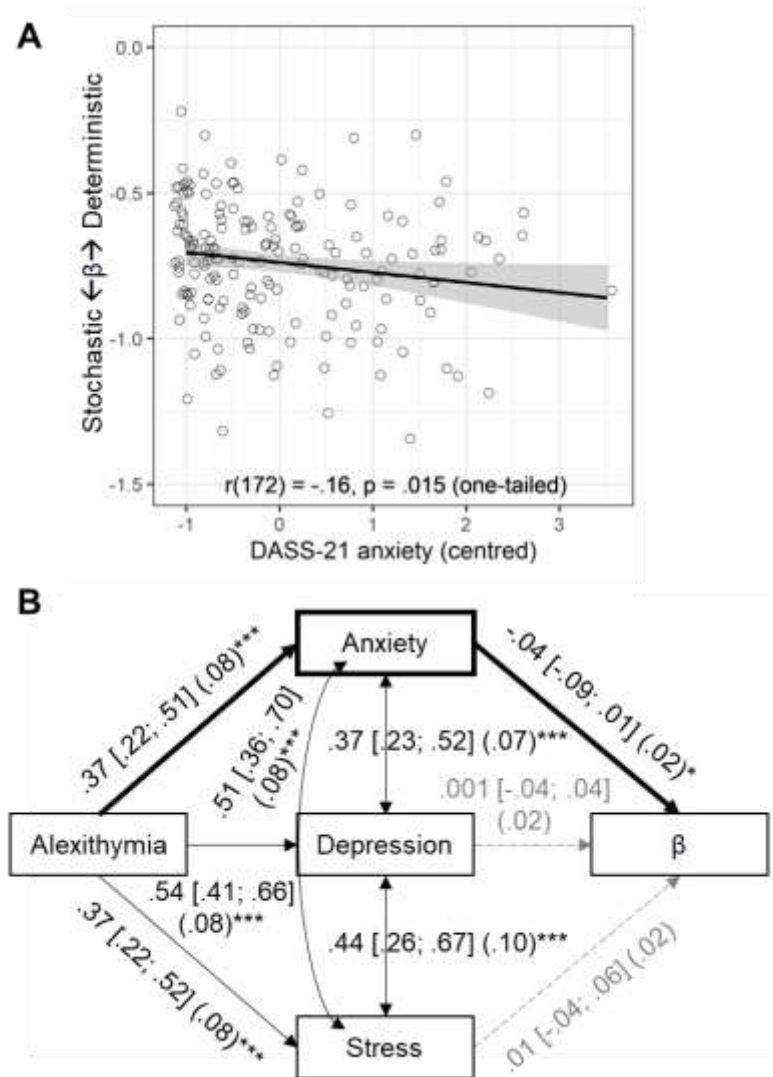
item Toronto Alexithymia Scale; DDF = Difficulty Describing Feelings; DIF = Difficulty Identifying

Feelings; EOT = Externally-Oriented Thinking; DASS-21 = Depression Anxiety Stress Scale.

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Figure S5.3

The Association Between Anxiety and More Stochastic Choices Following Learning of Temperature Concepts in Experiment 3 (N = 174)



Notes. (A) The relationship between anxiety and more stochastic choices (lower β values), supporting the constructionist theories that emotion concepts are in essence abstract concepts.

(B) The path model estimating the multivariate relationships between alexithymia, co-occurring mood symptoms, and more stochastic choices. Standardised estimates and standard errors are shown. Tests concerning anxiety and more stochastic choices are one-tailed.

* $p < .05$, ** $p < .01$, *** $p < .001$.

Chapter 6

Information Gathering:

Dissociable Effects of Autistic and Alexithymic Traits in Youths Aged 6 to 25 Years

Abstract

Autistic youths tend to react negatively to uncertain events. Little is known about the cognitive processes associated with this intolerance of uncertainty, most notably the tendency to actively gather information to minimise uncertainty. Past research has relied on self-report measures that may not allow investigation of the multifaceted processes associated with intolerance of uncertainty, including information gathering. Alexithymia (difficulties identifying and describing one's own emotions) commonly co-occurs with autistic traits, but its role in information gathering has rarely been considered. Accordingly, 97 typically-developing youths (aged 6-25 years) performed an information gathering task in which they were asked to gather information to infer socioemotional (emotional state) and non-social (clothing preference) information about another person, when information gathering was costly versus not costly. Dimensional autistic traits were associated with more information gathering regardless of costs and information type. Computational modelling suggested this is because of delayed emergence of subjective costs of information gathering in high autistic trait individuals, resulting in later guesses. Alexithymia was uniquely associated with inconsistent emotional responses to rewards and losses and to reduced information gathering about emotional states when assessed using parent-report measures. Future validations in youths diagnosed with autism are warranted to test the generalisability of the findings.

Information Gathering:**Dissociable Effects of Autistic and Alexithymic Traits in Youths Aged 6 to 25 Years**

The substantial heterogeneity present in the cognitive profile of individuals in the autistic population is well-recognised (Happé & Conway, 2016; Vivanti et al., 2011). Recent clinical evidence suggests that cognitive atypicalities experienced by some autistic individuals not only impact core autistic symptoms (Sasson et al., 2013), but also exacerbate co-occurring mood symptoms and emotional distress, including anxious and depressive symptoms (Hollocks et al., 2014; Milosavljevic et al., 2016) and irritability (Samson et al., 2015).

One cognitive difference associated with autistic traits is an increased need for information, a need that is thought to reflect intolerance of uncertainty (IoU)— a disproportionately negative or maladaptive reaction to situations and events characterised by uncertainty (Buhr & Dugas, 2009; Carleton et al., 2012). IoU predicts elevated anxiety in autistic youths (Boulter et al., 2014), and mediates the relationship between autistic symptom severity and anxiety (Neil et al., 2016; Wigham et al., 2015) and internalizing symptoms (Ozsivadjian et al., 2021). Recent debates point to the multifaceted nature of IoU, which includes (but is not limited to) the tendency to seek certainty and/or the feeling of being “paralysed” in the presence of uncertainty (Bervoets et al., 2021; Stark et al., 2021). While IoU is not defined as a need of information gathering, individuals who are averse to uncertain situations may actively engage in information gathering as a coping mechanism to minimise uncertainty. Excessive information gathering (i.e., it ceases to have informational value or becomes overly costly) may then constitute a maladaptive response to IoU. Studying information gathering in response to uncertainty and how it is affected by autistic traits may therefore prove to be of clinical relevance.

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Certain aspects of information gathering are assessed using the Intolerance of Uncertainty Scale (Carleton et al., 2007). In developmental studies, this scale assesses a parent's perception of how the child normally reacts to a lack of information ("*It frustrates my child not having all the information he/she needs*") and copes with unfamiliar and uncertain events ("*My child always wants to know what the future has in store for him/her*"). However, information gathering behaviours are not measured independently from other aspects of IoU on the scale, and it is unclear if these items would constitute a valid and reliable construct that can be analysed on its own. The parent's subjective evaluation of observable behaviours may also result in a reporting bias (De Los Reyes et al., 2015). More fundamentally, the measure captures limited information as to the various psychological processes that may underlie information gathering, precluding a mechanistic understanding as to *why* information gathering may become excessive, its relevance to IoU, and how to effectively intervene (Stark et al., 2021).

Another key research gap is the potential role of alexithymia in information gathering. Alexithymia is defined as the inability to identify and express one's own emotions, and is a subclinical dimensional trait that frequently co-occurs with autism (Griffin et al., 2016; Kinnaird et al., 2019; Milosavljevic et al., 2016). Notably, it has been consistently shown that alexithymia is more strongly associated with mood symptoms (e.g., Milosavljevic et al., 2016; Morie et al., 2019; Oakley et al., 2020; van der Crujisen et al., 2019) and socioemotional processing difficulties experienced by some autistic individuals (e.g., facial emotion perception: Cuve et al., 2021; multi-domain interoception: Murphy et al., 2018; and empathy: Bird et al., 2010) than autism or autistic traits/symptoms alone (see Bird & Cook, 2013 and Pisani et al., 2021 for reviews). These findings raise the important question of whether atypical affective and socioemotional processes previously attributed to autism/high autistic traits are in fact explained by co-occurring alexithymia. Measuring both autistic and

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alexithymic traits would be hence crucial to inform their relative contributions to information gathering given its relevance to IoU and anxiety. However, only a few studies have considered the potential contribution of alexithymia to IoU in individuals with autism/high autistic traits, and none have investigated the link with information gathering in any detail. Using the parent-report Intolerance of Uncertainty Scale, one study found that parent-reported alexithymia in autistic children was moderately associated with higher parent-reported IoU, which was in turn associated with more emotional problems (Ozsivadjian et al., 2021). Two studies reported that alexithymia predicted self-reported IoU in autistic adults (Gaigg et al., 2020; Maisel et al., 2016), and to a lesser degree also in a further cohort of autistic adults (Moore et al., 2021).

One potential mechanism by which alexithymia may increase information gathering, is via its potential to increase uncertainty due to its negative impact on the consistency of emotional responses (Hogeveen et al., 2021; Huggins et al., 2021). If alexithymia leads to inconsistent emotional responses, then even frequently-encountered situations will involve a greater degree of emotional uncertainty than experienced by non-alexithymic individuals, as alexithymic individuals will be less able to predict how the situation will make them feel. Thus, one might expect alexithymia to increase IoU in individuals with high autistic traits and therefore more information gathering. The mechanism, however, is not by changing the relationship between contextual uncertainty and the extent of any emotional reaction, but by increasing the degree of emotional uncertainty itself. Relatedly, the use of the IoU scale in past studies did not allow for clarifying if alexithymia would affect the gathering of emotional information or information gathering in general. While one study has demonstrated that higher alexithymic traits were associated with smaller framing effects on an emotional decision-making task in neurotypical individuals (Shah et al., 2016), an additional non-

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emotional condition would be necessary to conclude an emotion-specific effect. Relevant experimental work on information gathering is not available.

To address the above research gaps, the focus of this experimental study is to gain a deeper understanding of the relationship between autistic traits and cognitive processes associated with information gathering, and to identify whether alexithymia contributes to information gathering. As compared to self-report questionnaires, experiments are better suited to elucidate the cognitive mechanisms involved in information gathering. For example, information gathering tasks (e.g., Clark et al., 2006) ask participants to determine the predominant internal colour (yellow/blue) of a number of closed boxes by opening any number of those boxes under two conditions – (i) when boxes could be opened at no cost, and (ii) in a costly condition where points were deducted for each box opened. Note that while self-reported IoU predicts information gathering on this task (Hauser et al., 2017b), the number of boxes opened on this task is not a direct measure of IoU (there are several processes thought to influence the degree of information gathering before participants make a choice) but it allows measurement of several parameters that are useful in characterising the cognitive correlates of aversion to uncertainty and information gathering. One relevant response pattern is when participants continue to open boxes when the probability of one colour being predominant approaches (or equals) 1. For example, if a participant has opened 13 yellow boxes in a grid of 25 boxes, yellow must be the predominant colour as there are only a maximum of 12 boxes which could remain closed. Even if all closed boxes are blue, yellow will be the predominant colour. If participants continue to open boxes after finding 13 boxes of one colour, then this may indicate an aversion to uncertainty surrounding the colour of the closed boxes. In these tasks, the measure of information gathering is the number of boxes opened before a choice is made. Using this paradigm, autistic adults have been shown to gather more information (but not significantly so; Vella et al., 2018), and autistic

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adolescents have also been shown to gather more information in a similar paradigm (Brosnan et al., 2014).

Computational modelling has also been applied to responses on this task to identify parameters underpinning information gathering (Bowler et al., 2021; Hauser et al., 2017a). For example, one relevant parameter is the point at which subjective (“internal”) costs associated with continuing to gather information (i.e., open more boxes) arises, even in the condition where no external cost to information gathering exists. These internal costs are thought to represent a constellation of subjective factors, such as perception of time costs, boredom, and cognitive effort (Hauser et al., 2017a, 2017b). If someone is averse to uncertainty, then internal costs of information gathering are likely to emerge later as they are balanced by the gains achieved by reducing uncertainty, thereby promoting a later decision. If uncertainty is not completely aversive, then subjective costs of information gathering will emerge earlier, producing an earlier decision (Bowler et al., 2021; Hauser et al., 2017a).

Therefore, to investigate processes related to information gathering, we administered a modified version of the information gathering task in a youth sample aged 6-25 years while also measuring autistic and alexithymic traits. The information gathering task was modified such that in addition to the manipulation of information gathering costs (with/without external costs) as in previous studies (Bowler et al., 2021; Hauser et al., 2017a), the task was reframed such that participants were asked to make a guess about two types of information: another person’s clothing preference or their emotional state. The comparison between participants’ behaviour when gathering non-emotional vs emotional information allowed it to assess whether there were any selective effects of alexithymia for emotional information. Following each round of information gathering, we asked participants to rate their own emotional experiences in response to the points they had lost or gained, which allowed for any effect of alexithymia on the consistency of emotional responses to be identified. Further,

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research has pointed out that atypical psychological processes that underlie IoU emerge early in development, such as threat conditioning (anxiety: Morriss et al., 2021) and sensory processing (autism: South & Rodgers, 2017; Wigham et al., 2015), as well as information gathering (obsessive-compulsiveness: Hauser et al., 2017b). The inclusion of children, adolescents, and young adults would thus serve as an important first step to examine the developmental trends in the relationships between autistic and alexithymic traits and information gathering.

Based on the wealth of clinical and empirical evidence that youths with high autistic symptoms/traits are averse to uncertain situations, it was hypothesised that there would be a positive association between autistic traits and information gathering. Whether and how the association between autistic traits and information gathering would differ across information gathering costs and information type were not known. Moreover, it was hypothesised that alexithymia would be associated with less consistent emotional responses, with the possibility of a specific effect of alexithymia with emotional information. If increased information gathering is found in individuals with higher autistic and/or alexithymic traits, it was hypothesised that this may be related to reduced subjective costs of information gathering.

Method

Participants

A total of 107 typically-developing participants were recruited, of which nine were involved in piloting the study tasks, and 98 took part in the reported study. One participant was excluded due to technical issues, which resulted in a final sample of 97 participants. Informed by data simulation using prior work (Bowler et al., 2021), and a correlation power analysis in G*Power 3 (Faul et al., 2007) using the effect size of .498 and an alpha of .05

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(one-tailed) (Hauser et al., 2017a), a sample size of 23 to 30 participants for each age group would provide 80% power to detect medium effects on information gathering behaviours in developmental samples. Because of public health restrictions and ethical issues related to online recruitment during the pandemic, children aged 6 to 10 ($n = 30$, 40% female, mean age = 8.20 years, $SD = 1.37$), adolescents aged 11 to 15 ($n = 32$, 56.3% female, mean age = 13.12 years, $SD = 1.54$), and their parents were recruited remotely via museums, existing contact with schools, and parent support groups in the Oxford city community. Young adults aged 18 to 25 ($n = 35$, 34.3% female, mean age = 20.86 years, $SD = 1.79$) were recruited from Prolific (prolific.co). See Table 6.1 for full sample characteristics. All participants were fluent in English and declared no past, current, or recent diagnosis of a mental health condition (including autism), no intellectual/language disability, no history of head injury, were taking no long-term psychiatric medications, and had normal or corrected-to-normal vision. These eligibility criteria were confirmed in the online intake meetings with child and adolescent participants and their parents, and via the initial registration information provided by young adult participants on Prolific. Prior to participating in the study, young adult participants gave informed consent, whilst children and adolescents were asked to assent as their parents gave informed consent. All participants received an honorarium of £8/hour. Children and adolescents also received a certificate as a token of thanks. This study was approved by the Medical Sciences Interdivisional Research Ethics Committee, University of Oxford (Reference: R74857/RE001).

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Table 6.1*Sample Characteristics (N = 97)*

	Children (<i>n</i> = 30)			Adolescents (<i>n</i> = 32)			Young adults (<i>n</i> = 35)		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Age (years)	8.20	1.37	6 to 10	13.12	1.54	11 to 15	20.86	1.79	18 to 25
% Female	40.00	--	--	56.25	--	--	34.29	--	--
Autistic traits	16.83	8.51	2 to 38	18.66	6.62	7 to 37	18.66	5.67	7 to 30
Alexithymic traits-- self-report	36.37	6.41	26 to 47	36.28	6.31	25 to 51	48.71	13.21	24 to 79
DIF	--	--	--	--	--	--	16.20	6.36	7 to 30
DDF	--	--	--	--	--	--	13.31	4.46	5 to 21
EOT	--	--	--	--	--	--	19.20	4.68	9 to 28
Alexithymic traits-- parent-report	10.47	8.76	1 to 33	12.12	8.61	0 to 30	--	--	--

Notes. DIF = Difficulties Identifying Feelings; DDF = Difficulties Describing Feelings; EOT = Externally-Oriented Thinking. Raw autistic traits (Autism Spectrum Quotient) and alexithymia scores (20-item Toronto Alexithymia Scale for young adults; Children's Alexithymia Measure for children and adolescents) are presented. Four children and two adolescents surpassed the cutoff score on their AQ (≥ 76 and ≥ 30 , respectively), while all young adults fell within the range of AQ scores as commonly reported in neurotypical adults (< 32). Eight young adults surpassed the clinical cutoff for severe alexithymia on the TAS-20 (≥ 61). Clinical cutoff scores for the parent- and child self-report alexithymia questionnaires were under research and not available.

Measures

Autistic Traits

The Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001) was administered to young adults, which comprises 50 items assessing five domains of autistic traits, namely social skill, attention switching, attention to detail, communication, and imagination. The child (Auyeung et al., 2008) and adolescent versions (Baron-Cohen et al., 2006) of the AQ were completed by the parents of child and adolescent participants. Participants rated each item on a four-point Likert scale (“Definitely agree” to “Definitely disagree”). Binary scoring was used for all versions, i.e., endorsement of an autistic-like behaviour scored one point. Higher scores indicate higher levels of autistic traits. The internal consistency of the AQ was $\alpha = .88$ in children, $\alpha = .77$ in adolescents, and $\alpha = .69$ in young adults. A comprehension check item “How well do you think you understand the questions?” was added to the end of the AQ, and the mean level of understanding was high (4.51 out of 5) in the study sample. The age groups did not differ in mean AQ scores, $F(2,94) = .71, p = .49$. The means and standard deviations of autistic traits in the current sample were comparable to the original findings in the UK (children: Auyeung et al., 2008; adolescents: Baron-Cohen et al., 2006; young adults: Baron-Cohen et al., 2001). Sum scores were therefore standardised as T-scores within each age group and combined in the analyses. Four children and two adolescents scored above the cutoff scores on the respective version of AQ (Auyeung et al., 2008: ≥ 76 based on its scoring method for deriving cutoff scores in children; Baron-Cohen et al., 2006: ≥ 30). None of the young adult participants surpassed the cutoff for adults (Baron-Cohen et al., 2001: ≥ 32).

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Alexithymic Traits

Young adults completed the 20-item Toronto Alexithymia Scale (TAS-20) (Parker et al., 2003), which assesses core aspects of alexithymia including difficulties in identifying feelings, difficulties in describing feelings, and externally-oriented thinking. Responses on the TAS-20 were rated on a five-point Likert scale (“Strongly disagree” to “Strongly agree”). The internal consistency of the TAS-20 was $\alpha = .89$ in the young adults, eight of whom surpassed the clinical cutoff for severe alexithymia on the TAS-20 (≥ 61).

Children and adolescents completed the 20-item Children’s Alexithymia Questionnaire (CAQ) (Rieffe et al., 2006), a child-friendly adaptation of the TAS-20. Responses on the CAQ were rated on a three-point Likert scale (“Not true”; “A bit true”; “True”). Higher scores on both the TAS-20 and CAQ questionnaires reflect higher alexithymic traits. The CAQ has demonstrated good internal consistency $\alpha > .75$ in children aged 9 to 15 (Rieffe et al., 2006). In the current sample, the internal consistency of CAQ was $\alpha = .79$ in children and $\alpha = .79$ in adolescents, respectively. Children and adolescents did not differ in mean CAQ scores, $t(60) = .05$, $p = .96$. A similar comprehension check item as for the AQ was added to the TAS-20 and CAQ, and the mean level of understanding was high (4.30 out of 5) across the three age groups. The means and standard deviations of self-reported alexithymic traits were comparable to past findings in larger young adult samples (Cuve et al., 2021) and similar developmental groups (e.g., Griffin et al., 2016; Speyer et al., 2022) in the UK. Sum scores were therefore converted to T-scores for each age group for analysis.

Parents of child and adolescent participants completed the 14-item Children’s Alexithymia Measure (CAM) (Way et al., 2010). Responses were rated on a four-point Likert scale (“Almost never” to “Almost always”). Higher scores reflect higher parent-perceived

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levels of alexithymic traits in their children. The CAM has shown good internal consistency $\alpha > .85$ in children aged 3 to 13 (Costa et al., 2017; Speyer et al., 2022). In this sample, the internal consistency of CAM was $\alpha = .92$ in children and $\alpha = .93$ in adolescents, respectively. The parents' responses on the CAM correlated with their children's and adolescents' responses on the CAQ moderately, $r(28) = .46, p = .01$ and $r(30) = .33, p = .06$, respectively. Children and adolescents did not differ in mean CAM scores, $t(60) = -.75, p = .46$. The mean level of understanding was high among parents (4.48 out of 5). While there has been limited data on the distribution of CAM scores in large UK samples, sum scores were standardised and analysed as T-scores for consistency. Note that clinical cutoff scores for the parent- and child self-report alexithymia questionnaires were not available yet.

Task***Information Gathering***

A modified information gathering task was used (Bowler et al., 2021; Hauser et al., 2017a) in the format of a guessing game comprising 2 types of information (emotional/non-emotional) x 2 cost conditions (with/without external costs) (Figure 6.1, page 338). In each version of the game, participants were asked to gather information about other people by revealing between one and 25 diary entries, according to their choice, from a 5 x 5 grid of diary entries with no time constraint. In the emotional condition, participants were instructed to guess what emotion (happy/sad) the other person mainly feels by revealing diary entries showing either a happy or sad emoji. In the non-emotional condition, participants were instructed to guess what colour of t-shirt (orange/blue) the other person mainly wears by revealing diary entries showing either an orange or blue t-shirt. Having revealed their chosen number of diary entries, the diary entries remained on the screen and participants could make their choice of how the other person mainly feels or their usual colour of t-shirt by choosing

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the corresponding options (happy/sad face emoji, or orange/blue t-shirt). The face emojis (the exact same ones are shown in Figure 6.1, page 338) are gender-neutral and comprise no sociodemographic characteristics to avoid biasing the perception of emotional valence. Participants then received feedback regarding the accuracy of their choice and earned points based on their performance. In the no-cost condition, participants always earned 100 points if they made the correct judgement and lost 100 points otherwise. In the costly condition, however, participants began from a maximum of 250 points, and had 10 points deducted for each diary entry they chose to reveal. Therefore, the number of points a participant could win for a correct guess was dependent on the number of diary entries revealed during information gathering. Participants always lost 100 points for a wrong guess. Together, participants played 15 rounds of each combination of the four conditions, resulting in a total of 60 rounds. The game sequences used in the current study were adopted from previous studies using the same paradigm and were relatively challenging with a generative probability close to 50% (Bowler et al., 2021; Hauser et al., 2017a). Participants were reminded that they had to guess the typical emotion/t-shirt colour of a new person each round, to minimize the chance that participants would base their judgment on previous rounds. To minimise working memory load, the chosen diary entries remained open until the participant made a judgment. While thorough IQ assessments (such as reasoning) were not possible amid the pandemic, all participants declared normal intellectual and language functioning, which would help rule out potential confounds due to related impairments/disabilities.

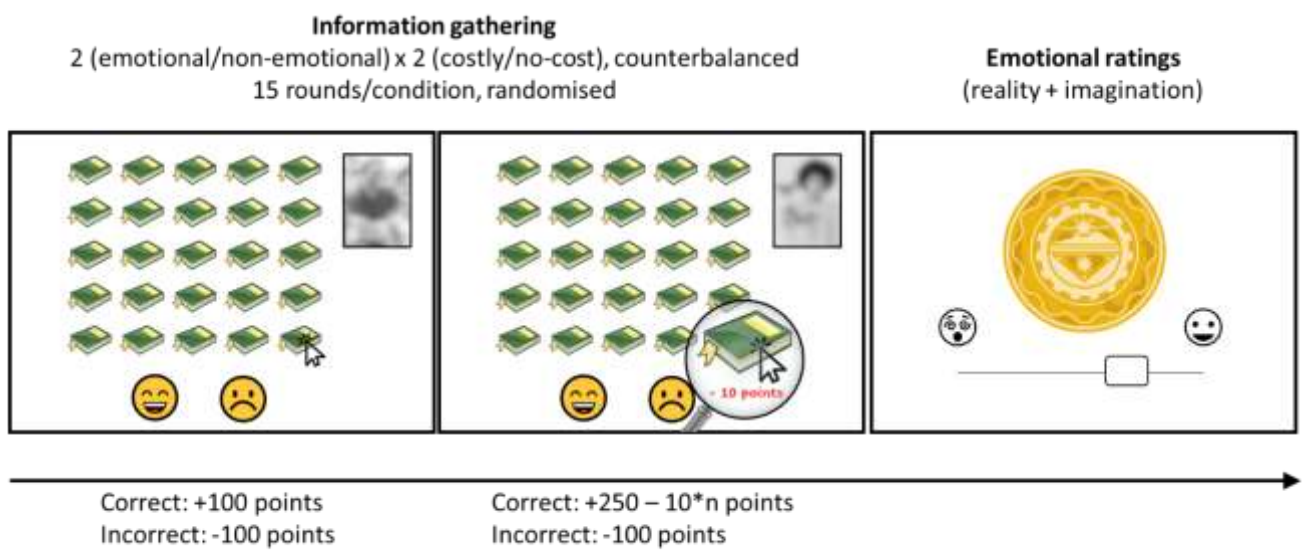
At the end of each round of information gathering, participants were asked to first rate (0 = Very upset; 100 = Very happy) how they felt about the number of points they had just won/lost in that round of the game, and then imagine how they would feel about winning/losing the same number of points in the opposite scenario. For instance, if a participant earned 100 points in a particular round, they would first rate how they felt about

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the 100 points they had just won, and then rate how they would feel about *losing* the 100 points if they had made an incorrect guess instead. Participants were reminded that they were allowed to use the full range of the rating scales.

Figure 6.1

Modified Information Gathering Task



Notes. The emotional information gathering task is presented here as a schematic illustration.

In the no-cost condition, participants are free to reveal as many diary entries as they want until they feel certain enough to guess what emotion (happy/sad) the person (greyed out portrait in the top-right corner) mainly feels. In the costly condition, 10 points are deducted for each diary entry revealed. For the non-emotional tasks, participants have to guess what colour of t-shirt (orange/blue) the person mainly wears. n = number of diary entries revealed.

Procedure

Given that the study was conducted remotely amid the COVID-19 pandemic, various briefing procedures were carried out to cater to the needs of child and adolescent participants and their parents (Sheskin et al., 2020). An online face-to-face (via videocall) intake meeting was arranged with each family, in which the study procedures were reviewed and clarified in child-friendly language. Prior to the start of the study tasks, participants reviewed the study instructions again with the aid of cartoon illustrations and example images. Participants then performed two practice rounds requiring correct answers; failure on these rounds meant that they would not be allowed to proceed to the actual study tasks. Participants also completed short comprehension quizzes about the different types of information and costs, and the emotional rating scales (actual and imaginative rewards/losses) until they got all questions correct before each condition. There were short breaks throughout the study. Participants were frequently reminded that they were allowed to reveal as many diary entries as they wanted, and the goal of the game was to make as many correct guesses and earn as many points as possible. Participants, however, were not informed about the strategy that revealing 13 diary entries of the same emoji/colour would constitute the point of certainty on the task. Parents were asked to be present while the children were performing the study tasks in case there were technical issues to be reported to the research team, and were instructed not to direct their child's task performance in any way. The information gathering task was hosted on Gorilla (gorilla.sc), with condition order and game sequences randomised. Questionnaires were completed at the end of the game. Young adults underwent the same study procedures on their own, without the intake meeting. The entire study task (excluding the consent meeting) lasted for approximately 50mins.

Statistical Analyses

The study was conducted amid the second wave of the COVID-19 pandemic in the UK (March to July 2021). Data were analysed using R (R Core Team, 2021). This study's design and its analysis were not preregistered.

Total Draws

Total draws refer to the number of diary entries a subject revealed prior to making a guess about another person's most frequent emotion or t-shirt colour. Given that total draws were non-normally distributed, generalised linear mixed models with negative binomial distribution were used for analysis, using the *glmmTMB* package in R (Brooks et al., 2022). For model parsimony, and to better gauge the variance in autistic traits that was uniquely associated with total draws, we analysed residualised AQ scores when autistic traits were the key trait of interest in the models unless otherwise specified (e.g., Hogeveen et al., 2016; Hobson et al., 2018, 2020). Specifically, residualised AQ scores were computed from a regression predicting AQ T-scores from alexithymia T-scores. This approach allows identification of variance in information gathering uniquely attributable to autistic traits and not co-occurring alexithymia (correlation between autistic and alexithymic traits: $r(95) = .44$, $p < .001$). For models with alexithymia as the key trait of interest, the raw alexithymia T-scores were used. These residualised AQ scores and raw alexithymia T-scores were then each used to construct two- and three-way interaction terms with the information type (emotional/non-emotional) and cost condition (with/without external costs) variables in the separate sets of mixed models for autistic traits and alexithymia. A nested model comparisons approach was performed to specify the most appropriate model structure, starting from a maximal model comprising all possible random intercepts and random slopes then a one-step-down model with one random slope and/or one random intercept removed (Bates et al.,

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2015). Informed by model comparisons using the `anova` function in the `lmerTest` package (Kuznetsova et al., 2017), the best random-effects structure consisted of random slopes for the cost conditions for each participant (indexed by IDs) and random intercepts for game sequences. Age (years) and sex were included as control variables in the models. Using the `lmerTest` package's `anova` function, these hypothesised models were then compared with the null model that included the same covariates, but which did not include the terms of interest (trait main effect and interactions). The main effects and interactions were reported using omnibus Type III χ^2 Wald tests, which estimate the effect of a variable or interaction term on the outcome given all other variables in the model (e.g., Moses-Payne et al., 2022). Significant effects were further probed via planned and post-hoc pairwise comparisons with Tukey's method to correct for multiple tests using the `emmeans` package (Lenth et al., 2020). All statistical tests were two-tailed with $\alpha = .05$, except for one-tailed tests performed to test the hypothesised positive association between AQ and increased information gathering given that studies have consistently reported this effect (e.g., Neil et al., 2016; Ozsivadjian et al., 2021; Stark et al., 2021). Given that the associations of autistic traits and alexithymia with information gathering was of chief interest, we focus on the main effects of AQ and alexithymia, and their interactions with information type and cost condition. As parent reports have been shown to more reliably assess youth affective symptoms associated with alexithymia and autistic symptoms (e.g., Blakeley-Smith et al., 2012; Storch et al., 2012), the main results reported here were produced by analysis of residualised AQ scores and alexithymia T-scores derived from parent reports of alexithymia for children and adolescents. Table S6.1 summarises the model structures.

Computational Modelling

Computational models were adopted from previous studies, which have revealed the mechanisms by which age and clinical traits impact information gathering (see Hauser et al.,

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2017a, 2017b, 2018 for a detailed discussion of the model; the mathematical description is presented in the **Supplementary Materials**). In brief, the model used assumes that an agent decides between three possible options: choose option A, choose option B, or continue sampling (continue to gather information). To make a choice, the agent assigns a subjective value to each of the choice options. The computed value for choosing option A or B depends on the agent's current belief that the given option (e.g., happy) is likely correct, multiplied by the number of points one could potentially earn or lose. Importantly, the agent forms this current belief based on the diary entries they have already revealed.

A key parameter that influences the decision to make a guess is the emergence of costs (cs_p) associated with information gathering. It has been empirically demonstrated that participants represent the internal cost of continuous information gathering based on a number of subjective factors (e.g., time costs, boredom, effort), even when there is no externally imposed cost for information gathering, such as in the no-cost condition of the current study (Bowler et al., 2021; Hauser et al., 2017a, 2017b, 2018). These internal (subjective) costs increase with time in a sigmoidal fashion (denoted as c ; cs refers to cost of sampling), where cs_p indexes the point at which these internal costs arise over the course of information gathering. It has been demonstrated that cs_p is the primary parameter sensitive to the manipulation of information gathering costs (with/without external costs) (Hauser et al., 2017a, 2017b). A low cs_p indicates that the subjective costs of information gathering emerge early in the trial, driving an earlier decision to make a guess.

$$c = \frac{cs}{1 + e^{-10(n - cs.p)}}$$

The computational model was fitted to each participant and the parameter of interest, i.e., cs_p , was estimated separately for each of the four conditions. The model fitting procedures were the same as those reported in previous studies (e.g., Bowler et al., 2021). For

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brevity, an out-of-sample prediction with five-fold cross-validation was used to assess the predictive likelihood of the models, a measure that aims to achieve an optimal balance between model complexity and accuracy (Figure S6.1). The model parameters were optimised with *fmincon*, which utilises multiple starting points to overcome local minima.

Linear mixed models were used to examine the relationships between *cs_p* and residualised AQ scores and alexithymia T-scores. Since the parameters were not trial-level estimates, calculating random effects of game sequence would be inappropriate, so only a random slope for the cost conditions for each participant was included in the model (Table S6.1). Omnibus Type III ANOVA tests and pairwise comparisons were reported.

Emotional Consistency

As in previous studies (Hogeveen et al., 2021; Huggins et al., 2021), emotional consistency regarding *actual reward* was calculated as the within-person rank-ordered correlation coefficient across the number of points earned and emotional ratings for each participant. Only correct trials across the emotional and non-emotional costly conditions were used given that participants always earned 100 points in the no-cost conditions and had 100 points deducted for an incorrect guess in all conditions. Emotional consistency regarding *imagined losses* was calculated similarly, using emotion ratings for the imagined losses. To ease interpretation, the signs of the coefficients were flipped for imaginative loss, such that higher emotional consistency scores reflect higher agreement between emotional ratings and actual reward/imaginative loss. For consistency, emotional consistency scores were standardised as T-scores within each age group. A robust multiple linear regression approach with M-type estimators was used to investigate the dimensional relationships between alexithymia T-scores and emotional consistency. Separate models were performed for actual reward and imaginative loss. We conducted one-tailed tests to test the hypothesis that there

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was a negative relationship between alexithymia and emotional consistency, informed by consistent findings in the literature (Hogeveen et al., 2021; Huggins et al., 2021).

Supplementary Analyses

Four sets of supplementary analyses are presented. First, to gain further insights into whether the hypothesised relationship between higher autistic traits and increased information gathering would have an impact on reward rate on the study task, a linear mixed model for AQ was performed using reward rate as the dependent variable, which was calculated as the number of points one earned in each round over the maximum possible points (i.e., no-cost = 100; costly = 240), and then divided by the total amount of time (seconds) taken to make a guess in that round. The same reward rate analysis was performed for alexithymia (see Table S6.2). Second, the main mixed models predicting total draws and computational parameters were re-run using residualised AQ scores derived from self-reported alexithymia T-scores for children and adolescents, and raw alexithymia T-scores for models with alexithymia as the key trait of interest (Tables S6.3-6.6). This differs from the primary analyses in that those analyses used parent-reported alexithymia T-scores for children and adolescents. Results remained largely the same, except for mixed models with alexithymia as the key predictor (see discussion of multi-informant assessment of alexithymic traits in youths). Third, instead of analysing age as a covariate, participants' age group was added to the mixed models as a four-way interaction term with AQ/alexithymia, and the information type and cost conditions (Tables S6.7-6.8). For models analysing residualised AQ scores as the main trait of interest, children with higher autistic traits tended to gather more information in the no-cost condition than in the costly condition, whilst young adults gathered marginally more information in the emotional condition than in the non-emotional condition. Children with higher autistic traits also showed a later emergence of internal costs in the no-cost condition than in the costly condition. For the alexithymia models, children with higher alexithymic traits gathered more

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information in the no-costly condition than in the costly condition. No alexithymia-related effects were found for emergence of internal costs. These results, however, should be interpreted with caution, as more strategic sampling within age groups / developmental stages are warranted.

Results

Information Gathering

On average, participants revealed 8.60 out of 25 diary entries ($SD = 3.54$) prior to making a guess across trials and conditions, with a mean accuracy of .83 ($SD = .07$). A repeated-measures ANOVA indicated that there was a significant main effect of cost condition on total draws, $F(1,96) = 99.24, p < .001, \eta_p^2 = .25$. Specifically, participants revealed significantly fewer diary entries when information gathering was penalised in the costly condition (mean = 5.76, $SD = 2.75$) than when it was not in the no-cost condition (mean = 11.44, $SD = 6.32$), replicating previous findings (e.g., Bowler et al., 2021; Hauser et al., 2017a) (Figure S6.2).

Obtaining 13 of the same type of T-shirt or emoji provides a definitive answer to the task ('point of certainty'), and participants revealed 7.25 less diary entries ($SD = 2.16$) than this number across trials and conditions (guessing when approximately six of the same type had been revealed). Repeated-measures ANOVA indicated a significant main effect of cost condition on same-type draws, $F(1,96) = 100.56, p < .001, \eta_p^2 = .26$, where participants had a higher number of same-type draws in the no-cost condition (average number of same-type draws relative to point of certainty = -5.5, $SD = 3.81$, range = -11.73 to 2.8) than in the costly condition (average number of same-type draws relative to point of certainty = -8.99, $SD = 1.7$, range = -12.47 to -3.07).

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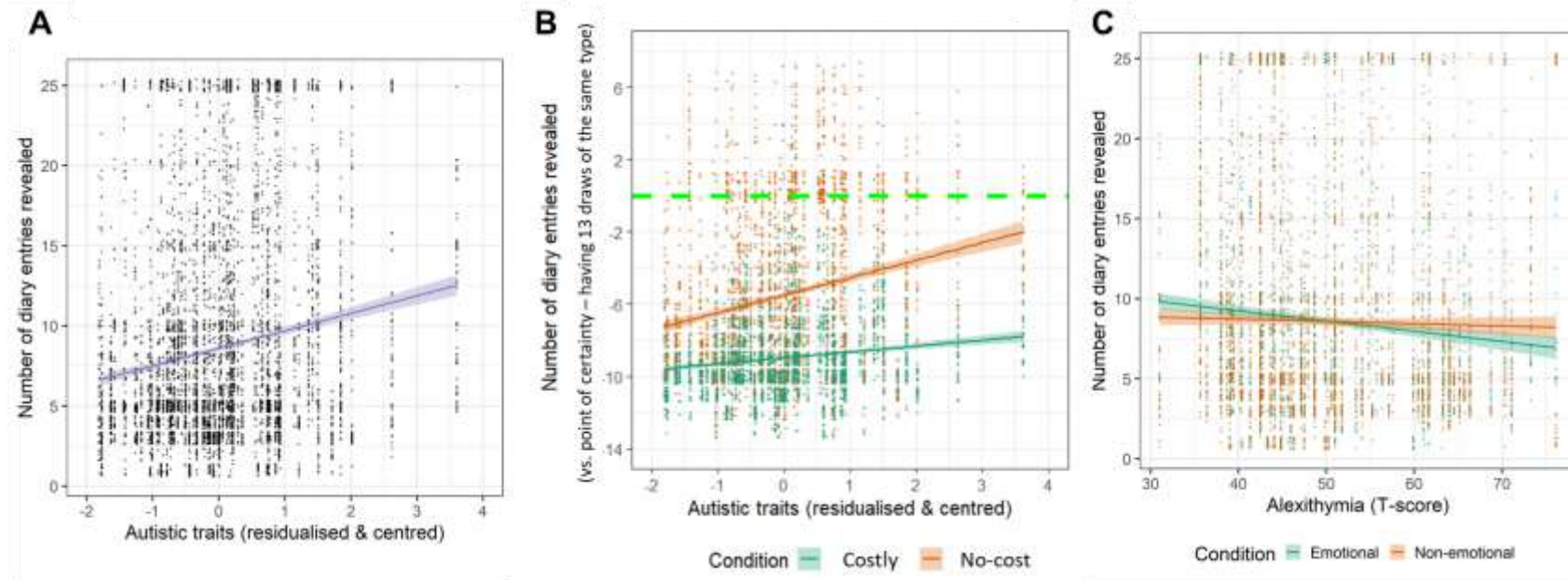
Regarding the correlations between traits and total draws, zero-order Spearman correlations indicated that there was a significant positive association between AQ T-scores and total draws, $r(95) = .22, p = .02$ (one-tailed), providing initial support for the hypothesis of autistic traits being associated with increased information gathering. Total draws were negatively related to alexithymia T-scores, $r(95) = -.15, p = .15$, but this did not reach statistical significance. The same dissociation emerged when considering the number of draws relative to the point of certainty, $r(95) = .22, p = .02$ (one-tailed) for AQ, and $r(95) = -.14, p = .16$ for alexithymia.

Autistic Traits

The AQ model (i.e., using residualised AQ scores as a main trait regressor of interest) significantly outperformed the null model ($\chi^2(7) = 83.44, p < .001$), suggesting that the inclusion of the AQ main effect and interaction terms provided a better fit to the observed information gathering behaviour (Table 6.2, page 348). There was a significant main effect of AQ on total draws ($\chi^2(1) = 5.60, p = .009$, one-tailed) (Figure 6.2A). No significant interactions between AQ and condition or AQ and information type were observed, $\chi^2 = 0.22-2.19, ps > .14$. Participants with higher AQ scores had a higher number of draws in all combinations of information type and condition (emotional no-cost: Slope = 0.12 [0.01; 0.22], SE = 0.05; emotional costly: Slope = 0.09 [0.001; 0.18], SE = 0.05; non-emotional no-cost condition: Slope = 0.13 [0.02; 0.23], SE = 0.05; non-emotional costly condition (Slope = 0.06 [-0.03; 0.15], SE = 0.05). There was a significant two-way interaction between costs and information type ($\chi^2(1) = 6.82, p < .01$).

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Figure 6.2

AQ and Alexithymia Mixed Models Predicting Total Draws

Notes. (A) AQ main effect on total draws. (B) Two-way interaction between AQ and costs (no-cost/costly) on number of same-type draws relative to the point of certainty of having 13 same-type draws where the probability of making a correct judgement based on that colour/emotion is 1 (green dashed line). (C) Two-way interaction between alexithymia and information type (emotional/non-emotional) on total draws (main models using parent reports for children and adolescents). To reflect the random-effects structure of the models, trial-level data are presented here. AQ = Autism-Spectrum Quotient.

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Table 6.2

Summary of Mixed Model Results Predicting Total Draws from Autistic Traits and Alexithymia

AQ model	χ^2	df	<i>p</i>
(Intercept)	298.13	1	<0.001
Age	5.17	1	0.023
Sex: Male	1.44	1	0.230
AQ	5.60	1	0.018
Cost conditions	102.15	1	<0.001
Information type	1.90	1	0.168
AQ x Cost conditions	0.92	1	0.337
AQ x Information type	0.22	1	0.638
Cost conditions x Information type	6.82	1	0.009
AQ x Cost conditions x Information type	2.19	1	0.139
Alexithymia model	χ^2	df	<i>p</i>
(Intercept)	290.36	1	<0.001
Age	6.85	1	0.009
Sex: Male	1.53	1	0.216
Alexithymia	1.47	1	0.225
Cost conditions	102.19	1	<0.001
Information type	2.49	1	0.115
Alexithymia x Cost conditions	0.06	1	0.803
Alexithymia x Information type	9.40	1	0.002
Cost conditions x Information type	7.20	1	0.007
Alexithymia x Cost conditions x Information type	0.11	1	0.742

Notes. Two-tailed *p* values are presented here for consistency. To reflect our

hypothesis, one-tailed *p* value is reported for the main effect of AQ in text. AQ

= Autism-Spectrum Quotient.

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When repeating the analyses by recalculating the number of same-type draws relative to the point of certainty, there was a significant main effect of AQ on draws ($\chi^2(1) = 24.51, p < .001$, one-tailed), along with a significant two-way interaction between AQ and costs ($\chi^2(1) = 7.35, p = .007$) (Table 6.3). Specifically, relative to the point of certainty, participants with higher AQ scores had a higher number of same-type draws in the no-cost condition (Slope = 0.02 [0.01; 0.02], SE = 0.003) than in the costly condition (Slope = 0.005 [-0.0003; 0.01], SE = 0.003, Contrast (costly – no-cost) = -0.01, SE = 0.004, $t = -3.41, p < .001$). Note that the best-fitting regression line for AQ in the no-cost condition does not intersect the point of certainty (where $y = 0$) (Figure 6.2B, page 347), suggesting that participants with higher autistic traits were not completely averse to the uncertainty presented on the task, and did not gather more information than necessary even when such a behaviour was not penalised.

Alexithymic Traits

The alexithymia model significantly outperformed the null model ($\chi^2(7) = 94.92, p < .001$), which suggested that the inclusion of alexithymia terms provided a better fit to the data. The main effect of alexithymia on total draws was not significant ($\chi^2(1) = 0.05, p = .82$). There was a significant two-way interaction between alexithymia and information type ($\chi^2(1) = 13.16, p = .001$), in that participants with higher alexithymia revealed *fewer* diary entries in the emotional condition (Slope = -0.01 [-0.01; 0.0004], SE = 0.004) than in the non-emotional condition (Slope = -0.002 [-0.01; 0.01], SE = 0.004, Contrast (emotional – non-emotional) = -0.01, SE = 0.001, $t = -4.29, p < .001$ (Figure 6.2C, page 347)). No other significant interactions with alexithymia were found, $\chi^2 = 0.03-0.09, ps > .77$. There was a significant two-way interaction between costs and information type ($\chi^2(1) = 7.20, p < .01$). Analysing the number of same-type draws relative to the point of certainty yielded no significant main effect ($\chi^2(1) = 0.25, p = .62$), or interactions with alexithymia ($\chi^2 = 0.07-2.60, ps > .11$).

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Table 6.3

Summary of Mixed Model Results Predicting Number of Draws Relative to the Point of Certainty from Autistic Traits and Alexithymia

AQ model	χ^2	df	<i>p</i>
(Intercept)	295370.00	1	<0.001
Age	24.51	1	<0.001
Sex: Male	35.39	1	<0.001
AQ	24.51	1	<0.001
Cost conditions	226.99	1	<0.001
Information type	0.78	1	0.377
AQ x Cost conditions	7.35	1	0.007
AQ x Information type	0.02	1	0.898
Cost conditions x Information type	1.03	1	0.311
AQ x Cost conditions x Information type	0.18	1	0.670
Alexithymia model	χ^2	df	<i>p</i>
(Intercept)	32813.78	1	<0.001
Age	29.00	1	<0.001
Sex: Male	49.87	1	<0.001
Alexithymia	0.25	1	0.619
Cost conditions	7.28	1	0.007
Information type	1.98	1	0.159
Alexithymia x Cost conditions	0.07	1	0.785
Alexithymia x Information type	2.60	1	0.107
Cost conditions x Information type	0.12	1	0.734
Alexithymia x Cost conditions x Information type	0.30	1	0.582

Notes. Two-tailed *p* values are presented here for consistency. To reflect our hypothesis, one-tailed *p* value is reported for the main effect of AQ in text. AQ = Autism-Spectrum Quotient.

Computational Modelling

Inspection of the model fitting procedures suggested that the predictive likelihood of 78 out of 97 (80%) participants was of at least 80% accuracy in predicting the cross-validated held-out data. The remaining participants had less accurate task performance (mean = 74%, $SD = 12$) than the rest of the study sample (mean = 82%, $SD = 13$), $p = .02$ [-.14; -.02].

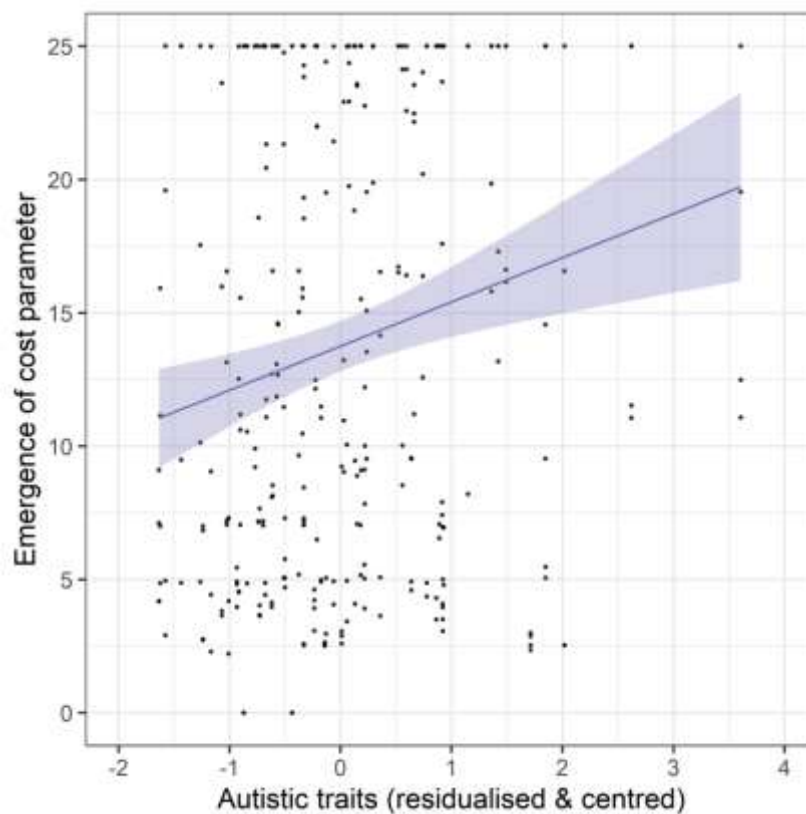
Below we present the more conservative set of results, where participants with the lower mean predictive likelihood were excluded to improve inference about the underlying cognitive processes (full-sample results see **Supplementary Materials**, Table S6.9).

Emergence of Cost

The cost emergence parameter cs_p indexes the point at which the internal cost of further sampling of diary entries rises to promote the decision to make a choice based on diary entries revealed. The mean of the cost emergence parameter was 13.69 ($SD = 4.94$). The AQ model significantly outperformed the null model ($\chi^2(7) = 82.52, p < .001$), indicating that the inclusion of AQ and its interactions provided a better fit to the cost emergence data. In the AQ model (Table 6.4, page 353), there was a significant main effect of AQ on cs_p ($F(1,77.6) = 6.51, p = .01$). Specifically, the internal costs of gathering more information arose later in participants with higher autistic traits, which delayed their decision to make a guess. This AQ main effect was more apparent in the emotional no-cost condition (Slope = 2.35 [0.68; 4.02], $SE = 0.85$) as compared to other conditions (Slopes = 0.94 to 1.27, $SEs = 0.72$ to 0.85) (Figure 6.3), but no significant interactions between AQ and either costs or information type were observed, $F_s = 0.53$ -1.77, $p_s > .19$. There was a significant main of costs on cs_p ($F(1,78) = 117.90, p < .001$), where participants delayed their guesses more in the no-cost conditions (mean = 18.43, $SD = 8.06$) than in the costly conditions (mean = 9.22, $SD = 6.46$).

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The alexithymia model significantly outperformed the null model ($\chi^2(7) = 78.14, p < .001$). However, the main effect of alexithymia on cs_p was not significant ($F(1,77.3) = 2.21, p = .14$) (Table 6.4), and no significant interactions with alexithymia were observed, $F_s = 0.05-1.36, p_s > .25$.

Figure 6.3*AQ Main Effect on Cost Emergence*

Notes. To reflect the random-effects structure of the model, data are aggregated by conditions here. AQ = Autism-Spectrum Quotient.

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Table 6.4

Summary of Mixed Model Results Predicting Cost Emergence from Autistic Traits and Alexithymia

AQ model	Num df	Den df	F	p
Age	1	78	1.67	0.200
Sex: Male	1	78	2.98	0.088
AQ	1	77.6	6.51	0.013
Cost conditions	1	78	117.90	<0.001
Information type	1	156	0.23	0.633
AQ x Cost conditions	1	78	0.84	0.364
AQ x information type	1	156	0.53	0.469
Cost conditions x information type	1	156	2.07	0.152
AQ x Cost conditions x information type	1	156	1.77	0.185
Alexithymia model	Num df	Den df	F	p
Age	1	78	1.92	0.170
Sex: Male	1	78	4.57	0.036
Alexithymia	1	77.3	2.21	0.141
Cost conditions	1	78	2.55	0.114
Information type	1	156	0.02	0.893
Alexithymia x Cost conditions	1	78	0.29	0.593
Alexithymia x information type	1	156	0.05	0.821
Cost conditions x information type	1	156	0.76	0.384
Alexithymia x Cost conditions x information type	1	156	1.36	0.246

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. AQ = Autism-Spectrum Quotient.

Alexithymia and Consistency of Emotional Responses

Across the emotional and non-emotional costly conditions, the mean emotional consistency score for actual reward was 69.03 ($SD = 10.92$), whilst that for imagined loss was 34.22 ($SD = 9.21$). Higher emotional consistency scores indicate greater consistency of emotional response given the points earned or imagined as lost. There were no significant differences in emotional consistency scores for actual reward, $t(192) = -0.06, p = .95$, nor imaginative loss $t(185) = -1.05, p = .29$, between the conditions. Participants earned comparable numbers of points in each round in the emotional (mean = .56, $SD = .16$) and non-emotional costly conditions (mean = .56, $SD = .15$), $t(191) = .05, p = .96$.

Robust multiple regression indicated a significant negative association between alexithymia and emotional consistency for actual reward (Estimate = -0.17 [-0.33; -0.01], $SE = 0.08, t = -2.08, p = .02$, one-tailed) while adjusting for AQ scores and controlling for age and sex differences (Table S6.10). AQ was not significant (Estimate = 0.09 [-0.08; 0.26], $SE = 0.09, t = 1.04, p = .30$). Alexithymia remained a significant predictor of emotional consistency when analysing self-reported, rather than parent-reported, alexithymia scores for all participants (Estimate = -0.16 [-0.29; -0.03], $SE = 0.07, t = -2.36, p = .01$, one-tailed) (Table S6.11).

A separate multiple regression revealed a significant negative association between alexithymia and emotional consistency for imagined loss (Estimate = -0.20 [-0.36; -0.05], $SE = 0.08, t = -2.58, p = .006$, one-tailed) when adjusting for all covariates (Table S6.10). AQ was not significant (Estimate = 0.07 [-0.10; 0.24], $SE = 0.09, t = .80, p = .43$). Alexithymia remained significantly associated with lower emotional consistency when analysing self-reported alexithymia scores (Estimate = -0.21 [-0.37; -0.05], $SE = 0.08, t = -2.51, p = .01$, one-tailed) (Table S6.11).

Discussion

This experimental study investigated the effect of autistic and alexithymic traits on information gathering in typically-developing youths (aged 6-25 years) using a modified information gathering task (Hauser et al., 2017a; Bowler et al., 2021). Extending past literature, we experimentally manipulated the cost of information gathering (with/without external costs) and the type of information gathered (another person's emotional state/clothing preference), to test whether variable environmental costs and information type exert differential effects on the relationships between information gathering and autistic and alexithymic traits.

Supporting our hypothesis, we reported that youths with higher autistic traits had an overall increased propensity to gather information regardless of cost and information type, when either total number of draws or number of draws in relation to the point of certainty was analysed (see also Brosnan et al., 2014 and Vella et al., 2018, though the effect was only a statistical trend in the latter). Increased information gathering was evident regardless of whether the uncertain scenario required the gathering of emotional or non-emotional information, suggesting a general tendency. Computational modelling suggested that increased information gathering may stem from the fact that the internal costs of information gathering arise later for those with higher autistic traits, which promotes a delayed decision regardless of costs and information type. Given the overall total number of same-type draws made, even in those with high autistic traits, it is clear that any IoU experienced by these individuals was not severe enough to make them consistently persist in making draws beyond the point of certainty. Having a greater tendency to gather information *per se* does not constitute an aversion to uncertainty, instead it could reflect, for example, increased curiosity or a desire to make a better-informed decision, although it did result in a lower reward rate (when analysing parent-report data). Of course, a tendency for increased information

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gathering may be pathological if it is due to, or results in, an intolerance of uncertainty. An increased tendency to gather information on related tasks has been found in those with anxiety (Cardinale et al., 2021) and obsessive-compulsive symptoms (Hauser et al., 2017a, 2017b), both of which are prevalent in the autistic population.

Alexithymia was related to a *reduced* tendency to gather information about another person's emotional state when analysing parent reports of youth alexithymia, although this association was not significant using self-report data. It is unclear how this relates to previous reports of a positive association between alexithymia and self-report IoU measures that also include information gathering tendencies in autistic individuals (Gaigg et al., 2020; Maisel et al., 2016; Ozsivadjian et al., 2021). Further work separating the many cognitive and affective components of IoU is necessary in order to gain a clear picture of the factors responsible for any increased tendency to experience IoU in alexithymia and autistic traits (Stark et al., 2021).

The discrepancy between results obtained using parent- and child-report measures of alexithymia are not unique to this study (Hobson & van den Bedem, 2021) and call for a methodological framework guiding the measurement of alexithymia in developmental populations. Some suggest that parent reports may be more reliable than child reports of alexithymic traits (e.g., Griffin et al., 2016; Ozsivadjian et al., 2021; Speyer et al., 2022), but this hypothesis is yet to be tested empirically. Other potentially contributing factors are the parent's ability to make reliable inferences about their child's alexithymic traits (given that alexithymic children are more likely to have alexithymic parents; e.g., Szatmari et al., 2008), and contextual effects on parent-child interactions (including the presence of co-occurring psychiatric conditions in either the child, parent, or both).

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Despite the above, both self- and parent-report measures of alexithymia revealed an association between alexithymia and the consistency of emotional responses to both real and imagined wins and losses. These findings add further support for the idea that alexithymia produces variability in the evaluation of emotional experiences (Hogeveen et al., 2021; Huggins et al., 2021), which is present in the context of information gathering. This would result in an increased degree of uncertainty in any situation with the potential to induce an emotional reaction in those with alexithymia, and therefore exacerbate any IoU.

Limitations and Constraints on Generalisability

Despite the contribution of these results to understanding of information gathering and how it is related to autistic and alexithymic traits, several limitations of the study must be acknowledged. First, we were unable to obtain measures of other co-occurring mood symptoms that may be relevant to information gathering (e.g., anxiety and obsessive-compulsiveness) due to ethics restrictions amid the pandemic. Nevertheless, the study was conducted in accordance with guidelines on online developmental studies at that time, such as arranging individual meetings with families, and the use of a gamified design with youth-friendly illustrations. It is not known if pandemic-related stress (e.g., school closure and increased caregiving responsibilities) would have an impact on participants' perception of levels of autistic traits and alexithymia; further studies would be useful to provide information as to the reliability of these findings. Second, given the need to use separate measures suitable for each developmental stage, different measures of alexithymia for the three age groups were combined in a standardised manner for subsequent analyses. However, whether the standardised scores necessarily represent the same degree and/or manifestation of alexithymia between the younger participants and young adults is an open question. Future studies with a more strategic sampling of age groups may investigate if key developmental stages (e.g., puberty) would moderate the associations between information gathering and

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autistic traits and/or alexithymia. Third and relatedly, regarding the AQ, individuals with low introspective abilities may not score high on the AQ, which may limit the range of AQ scores available in our typically-developing sample. Using a larger sample size, such as a mixed sample that combines both typically-developing participants and those diagnosed with autism, would be of good use for validating the current associations with greater power.

Conclusion

In sum, the current study reported experimental evidence for the association between information gathering and autistic and alexithymic traits in typically-developing youths. In addition, alexithymia was shown to be associated with reduced consistency of emotional responses to both real and imagined wins and losses. Both findings are of relevance to IoU, and demonstrate that fractionating IoU into its cognitive and affective components is likely to be of clinical relevance. Finally, further evidence of dissociable effects of autistic traits and alexithymia highlights the need to consider co-occurring alexithymia when examining emotion processing related to autistic traits.

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Chapter 5

Supplementary Materials

Table S6.1*Mixed Model Structures*

Trait of interest	Alexithymia informant for children and adolescents	Dependent variable	Fixed effects	Random effects
Autistic trait (residualised)	Parent	Total draws	Age + Sex + AQ*Information type*Cost conditions	Cost conditions Participants + Game sequences
		Emergence of cost (<i>cs_p</i>)		Cost conditions Participants
		Reward rate		Cost conditions Participants + Game sequences
Alexithymia (raw T- scores)	Parent	Total draws	Age + Sex + Alexithymia*Information type*Cost conditions	Cost conditions Participants + Game sequences
		Emergence of cost (<i>cs_p</i>)		Cost conditions Participants
		Reward rate		Participants + Game sequences
Autistic trait (residualised)	Self	Total draws	Age + Sex + AQ*Information type*Cost conditions	Cost conditions Participants + Game sequences
		Emergence of cost (<i>cs_p</i>)		Cost conditions Participants
		Reward rate		Cost conditions Participants + Game sequences
Alexithymia (raw T- scores)	Self	Total draws	Age + Sex + Alexithymia*Information type*Cost conditions	Cost conditions Participants + Game sequences
		Emergence of cost (<i>cs_p</i>)		Cost conditions Participants
		Reward rate		Cost conditions Participants + Game sequences

Notes. Self-reported alexithymia T-scores were used for young adults throughout. For models predicting number of same-type draws relative to the point of certainty, only game sequences were included as random effects for the sake of convergence. These models were compared to the null models comprising only the fixed effects of age and sex and the random effects of participants and game sequences. The alexithymia model (parent reports) predicting reward rate had the random slopes for cost conditions removed due to singularity. AQ = Autism-Spectrum Quotient.

Description of Computational Modelling

Here we present a detailed description of the key features and related mathematical specifications of the computational modelling package (Hauser et al., 2017a, 2017b, 2018).

A key assumption of the model is that the agent makes inference about what emotional state (face emoji) / outfit preference (colour of T-shirt) constitutes the majority among the 25 diary entries $P(MH | n_h, N)$. Using the emotional condition as an example here, MH denotes the majority being happy faces, given the current number of happy face emojis (n_h) out of N number of diary entries revealed thus far. Since $P(MH)$ concerns the current number of diary entries, it infers the generative probability the agent believes has likely caused this proportion of happy face emojis. Mathematically, this belief is used to estimate the value (Q) of making a judgment (i.e., choosing H: happy or S: sad), weighted by potential rewards ($R_{correct}$: +100) and losses ($R_{incorrect}$: -100), as in a no-cost condition as an example:

$$Q(H | n_h, N) = R_{correct} P(MH | n_h, N) + R_{incorrect} P(MS | n_s, N)$$

The value of not deciding, i.e., further information gathering ($Q(ND)$), is estimated as the sum of the Q values of future states ($V(s')$), weighted by the likelihood of ending up in that state given the diary entries revealed so far ($P(s' | n_h, N)$). Furthermore, a cost per step, c , is incurred, which represents the internal subjective costs for gathering more information, such as time and effort spend on the task, and rewards/losses (when information gathering is costly).

$$Q(ND | n_h, N) = \sum_{s' = \binom{n_h+i}{N+1}}^{i=[0,1]} P(s' | n_h, N) V(s') + c$$

As mentioned in the main text and visualised below in Figure S6.1, the best fitting model is one that models these internal costs (c) in a sigmoidal form, which increase over the

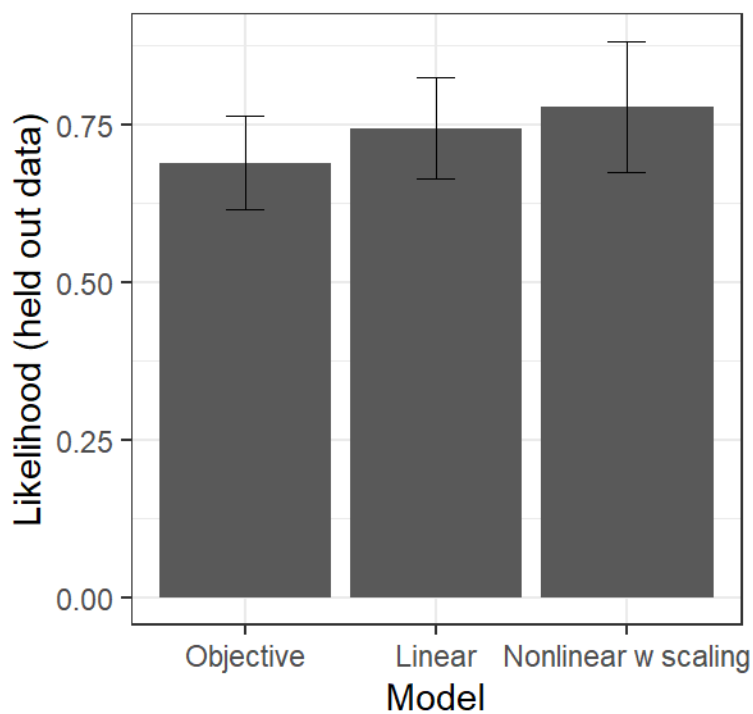
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course of information gathering. It comprises the scaling parameter cs determining the magnitude of the maximal costs of information gathering, and relevant to the current study, the intercept cs_p , which refers to the number of diary entries (n) after which those internal costs emerged.

$$c = \frac{cs}{1 + e^{-10(n-cs.p)}}$$

Figure S6.1

Summary of Predictive Likelihood across Computational Models



Notes. Resembling previous studies (Bowler et al., 2021; Hauser et al., 2017a, 2017b), the model with a nonlinear increase in subjective information gathering cost was found to fit the participants' task performance best, and that these subjective costs did not seem to follow either the external costs on the task (i.e., the objective model: 0 points in the no-cost

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condition and -10 points in the costly condition), or a linear increase (i.e., the linear model).

Means and standard deviations of predictive likelihood across conditions are shown. The objective model is treated as the reference model.

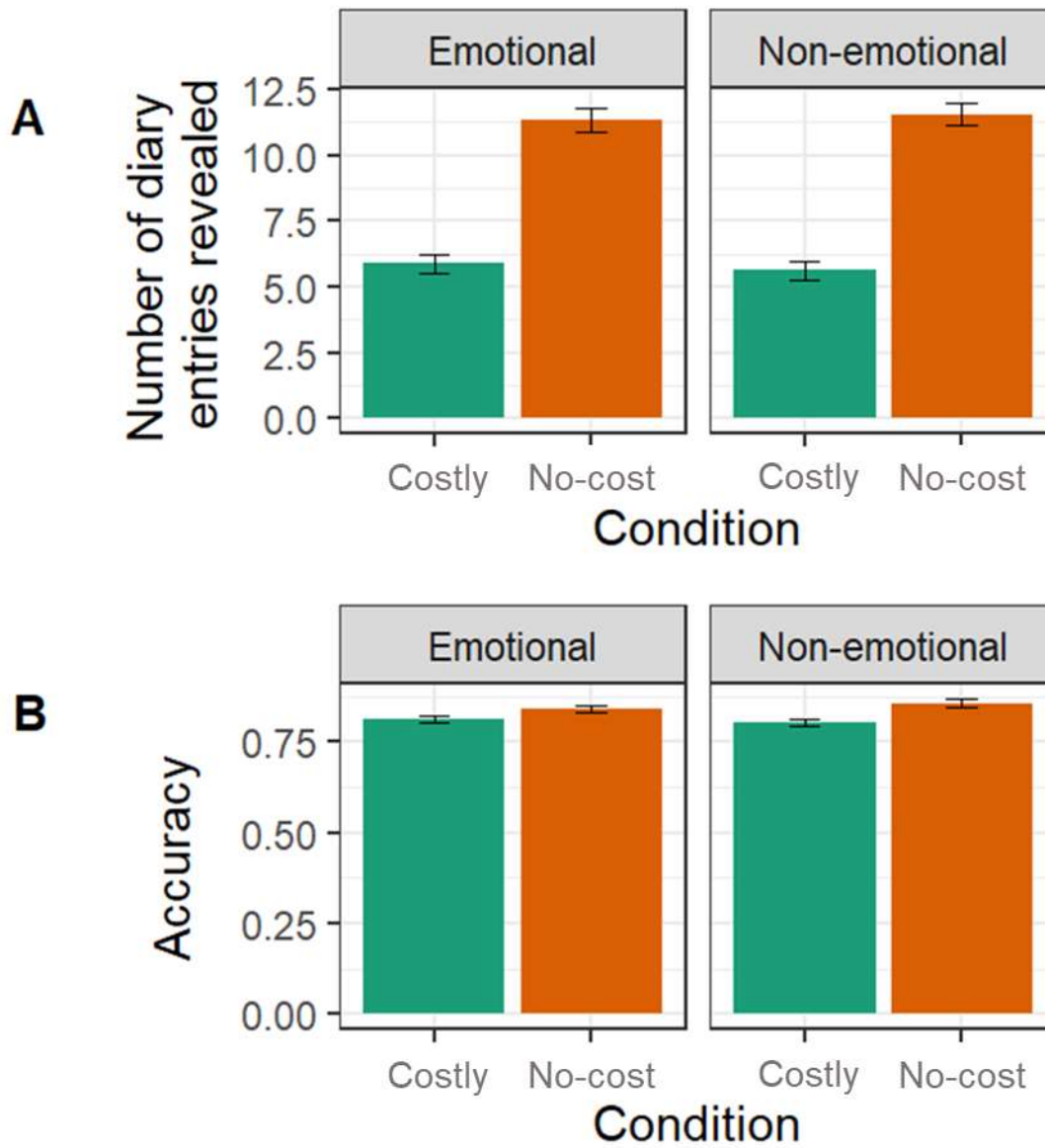
Reward Rate Mixed Models Analysing Parent-Reported Alexithymia

Linear mixed models showed that there was a significant main effect of AQ on reward rate ($F(1,96.3) = 7.63, p = .007$), in that participants with higher AQ earned fewer points per unit time across conditions (Slopes = -0.01 to -0.02, SEs = 0.005). No effects of interest were observed for alexithymia (F s = 0.19 to 1.55, p s > .22). Table S6.2 summarises the reward rate model results.

Table S6.2*Summary of Mixed Model Results Predicting Reward Rate from Autistic Traits and Alexithymia*

AQ model	Num df	Den df	F	p
Age	1	96.3	56.26	<0.001
Sex: Male	1	96.3	0.85	0.358
AQ	1	96.3	7.63	0.007
Cost conditions	1	5708.9	19.79	<0.001
information type	1	5708.9	5.83	0.016
AQ x Cost conditions	1	5708.9	0.00	0.968
AQ x information type	1	5708.9	1.88	0.170
Cost conditions x information type	1	5708.9	0.19	0.660
AQ x Cost conditions x information type	1	5708.9	1.72	0.189
Alexithymia model	Num df	Den df	F	p
Age	1	96.4	50.72	<0.001
Sex: Male	1	96.4	0.20	0.658
Alexithymia	1	96.4	1.55	0.216
Cost conditions	1	5708.9	3.48	0.062
information type	1	5708.9	0.80	0.370
Alexithymia x Cost conditions	1	5708.9	1.02	0.311
Alexithymia x information type	1	5708.9	0.19	0.667
Cost conditions x information type	1	5708.9	0.69	0.407
Alexithymia x Cost conditions x information type	1	5708.9	0.87	0.351

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Both models used parent-reported alexithymia T-scores as described in the main text. Self-reported alexithymia T-scores were used for young adults throughout. AQ = Autism-Spectrum Quotient.

Figure S6.2*Descriptive Summary of Information Gathering Task Performance*

Notes. (A) Total draws defined by the number of diary entries the participant revealed before making a guess by information type and cost conditions. (B) Accuracy by information type and cost conditions. Participants had significantly fewer draws when information gathering was penalised in the costly condition than when it was not in the no-cost condition ($F(1,96) = 99.24, p < .001, \eta_p^2 = .25$), replicating past studies (Bowler et al., 2021; Hauser et al., 2017a, 2017b). Means and standard errors are shown here.

Mixed Models Analysing Self-Reported Alexithymia***Information Gathering***

The AQ model significantly outperformed the null model ($\chi^2(7) = 85.01, p < .001$). There was a significant main effect of AQ on total draws ($\chi^2(1) = 5.93, p = .008$, one-tailed) (Table S6.3), where participants with higher AQ revealed more diary entries before making a guess. There was a significant interaction between AQ and information type ($\chi^2(1) = 6.20, p = .01$), such that participants with higher AQ tended to reveal more diary entries in the non-emotional (Slope = 0.09 [0.02; 0.17], SE = 0.04) compared to emotional (Slope = 0.07 [-0.002; 0.14], SE = 0.04) condition. The difference in slope of total draws as a function of autistic traits between the two conditions, however, was non-significant, Contrast (emotional – non-emotional) = -0.02, SE = 0.01, $t = -1.66, p < .10$. No other significant interactions with AQ were found, $\chi^2 = 1.28$ to $2.90, ps > .15$.

When aggregated across trials and conditions, a Spearman correlation suggested that total draws were negatively related to self-reported alexithymia T-scores, $r(95) = -.13, p = .21$, although it did not reach statistical significance. The self-reported alexithymia model significantly outperformed the null model ($\chi^2(7) = 79.88, p < .001$). The main effect of self-reported alexithymia on total draws was not significant ($\chi^2(1) = 2.19, p = .14$) (Table S6.3). No significant interactions with alexithymia were observed, $\chi^2 = 0.07$ to $2.10, ps > .15$.

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Table S6.3

Summary of Mixed Model Results Predicting Total Draws from Autistic Traits and Self-Reported Alexithymia

AQ model	χ^2	df	<i>p</i>
(Intercept)	289.50	1	<0.001
Age	1.57	1	0.210
Sex: Male	5.56	1	0.018
AQ	5.93	1	0.015
Cost conditions	102.39	1	<0.001
information type	1.55	1	0.213
AQ x Cost conditions	1.28	1	0.258
AQ x information type	6.20	1	0.013
Cost conditions x information type	6.81	1	0.009
AQ x Cost conditions x information type	2.09	1	0.148
Alexithymia model	χ^2	df	<i>p</i>
(Intercept)	70.09	1	<0.001
Age	1.78	1	0.182
Sex: Male	7.36	1	0.007
Alexithymia	2.19	1	0.138
Cost conditions	6.93	1	0.008
information type	2.89	1	0.089
Alexithymia x Cost conditions	0.43	1	0.511
Alexithymia x information type	2.10	1	0.148
Cost conditions x information type	0.07	1	0.785
Alexithymia x Cost conditions x information type	0.07	1	0.791

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Two-tailed *p* values are presented here for

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consistency. To reflect our hypothesis, one-tailed p value is reported for the main effect of AQ in text. AQ = Autism-Spectrum Quotient.

Analysing the number of same-type draws relative to the point of certainty as the dependent variables yielded similar results. For the AQ model (Table S6.4), there was a significant main effect of AQ on number of draws ($\chi^2(1) = 38.36, p < .001$, one-tailed). There was a significant two-way interaction between AQ and cost conditions ($\chi^2(1) = 11.75, p < .001$), in that participants with higher autistic traits had a higher number of same-type draws relative to the point of certainty in the no-cost condition (Slope = 0.02 [0.01; 0.02], SE = 0.003) than in the costly condition (Slope = 0.004 [-0.002; 0.009], SE = 0.003, Contrast (costly – no-cost) = -0.01, SE = 0.004, $t = -3.43, p = .006$).

For the alexithymia model (Table S6.4), there was a significant main effect of alexithymia on same-type draws ($\chi^2(1) = 8.24, p = .004$), but inspecting this main effect more closely in each condition suggested that the seemingly significant simple slopes in the no-cost conditions were in fact not significantly different from the non-significant simple slopes in the costly conditions (Contrast (costly – no-cost) = 0.0006, SE = 0.0004, $t = 1.45, p = .15$), suggesting that this main effect of alexithymia was not robust.

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Table S6.4

Summary of Mixed Model Results Predicting Number of Same-Type Draws Relative to Point of Certainty from Autistic Traits and Self-Reported Alexithymia

AQ model	χ^2	df	<i>p</i>
(Intercept)	352128.82	1	<0.001
Age	26.16	1	<0.001
Sex: Male	39.11	1	<0.001
AQ	38.36	1	<0.001
Cost conditions	406.41	1	<0.001
AQ x Cost conditions	11.75	1	<0.001
Alexithymia model	χ^2	df	<i>p</i>
(Intercept)	33480.42	1	<0.001
Age	28.66	1	<0.001
Sex: Male	53.46	1	<0.001
Alexithymia	8.24	1	0.004
Cost conditions	15.95	1	<0.001
Information type	0.36	1	0.550
Alexithymia x Cost conditions	1.11	1	0.291
Alexithymia x Information type	0.19	1	0.664
Cost conditions x Information type	0.06	1	0.812
Alexithymia x Cost conditions x Information type	0.00	1	0.968

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Due to non-convergence and the lack of interaction between AQ and information type as informed by the main model (see main text), information type was removed from this supplementary AQ model. Decomposing the main effect of alexithymia suggested that although the 95% confidence intervals of the simple slopes of alexithymia in the no-cost conditions did not cross zero, these slopes were

not significantly different from those in the costly conditions, suggesting that the main effect of alexithymia was not robust. Game sequences were included as random effects in both the AQ and alexithymia models. AQ = Autism-Spectrum Quotient.

Emergence of Cost

The AQ model significantly outperformed the null model ($\chi^2(7) = 79.37, p < .001$). In the AQ model (Table S6.5), there was a significant main effect of AQ on the cost emergence parameter cs_p ($F(1,77.6) = 4.02, p < .05$). Although no interaction with AQ was found, participants with higher autistic traits had a later emergence of internal costs delaying the decision to make a guess in the emotional no-cost condition (Slope = 1.97 [.28; 3.7], SE = .86) than in other conditions (Slopes = 0.58 to 1.27, SEs = 0.74 to 0.86). No other significant interactions with AQ were found, $F_s = 0.17$ to 1.08, $p_s > .30$.

The self-reported alexithymia model significantly outperformed the null model ($\chi^2(7) = 79.11, p < .001$). However, the main effect of alexithymia was not significant ($F(1,77.6) = 2.39, p = .13$) (Table S6.5). No significant interactions with alexithymia were observed, $F_s = 0.07$ to 2.18, $p_s > .13$.

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Table S6.5

Summary of Mixed Model Results Predicting Cost Emergence from Autistic Traits and Self-Reported Alexithymia

AQ model	Num df	Den df	F	p
Age	1	78	1.67	0.199
Sex: Male	1	78	3.30	0.073
AQ	1	77.6	4.02	0.048
Cost conditions	1	78	117.84	<0.001
Information type	1	156	0.22	0.640
AQ x Cost conditions	1	78	1.08	0.302
AQ x Information type	1	156	0.17	0.685
Cost conditions x Information type	1	156	2.05	0.154
AQ x Cost conditions x Information type	1	156	1.08	0.301
Alexithymia model	Num df	Den df	F	p
Age	1	78	1.99	0.162
Sex: Male	1	78	5.25	0.025
Alexithymia	1	77.6	2.39	0.126
Cost conditions	1	78	3.18	0.078
Information type	1	156	0.57	0.453
Alexithymia x Cost conditions	1	78	0.07	0.792
Alexithymia x Information type	1	156	0.46	0.498
Cost conditions x Information type	1	156	1.41	0.237
Alexithymia x Cost conditions x Information type	1	156	2.18	0.142

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. AQ = Autism-Spectrum Quotient.

Reward Rate

The AQ model significantly outperformed the null model ($\chi^2(7) = 19.04, p < .01$). The main effect of AQ was marginally significant ($F(1,97) = 3.61, p = .06$), in that participants with higher AQ had lower reward rate across conditions (Slopes = -0.004 to -0.01, SEs = 0.005 to 0.006). The alexithymia model also significantly outperformed the null model ($\chi^2(7) = 15.79, p = .03$). However, the main effect of alexithymia on reward rate was not significant ($F(1,96.7) = 0, p = 1$). No significant interactions with alexithymia were observed (F s = 0.03 to 2.21, p s > .14). These reward rate model results are summarised in Table S6.6.

Table S6.6

Summary of Mixed Model Results Predicting Reward Rate from Autistic Traits and Self-Reported Alexithymia

AQ model	Num df	Den df	<i>F</i>	<i>p</i>
Age	1	96.3	55.89	<0.001
Sex: Male	1	96.3	0.68	0.413
AQ	1	96.8	3.61	0.060
Cost conditions	1	97	6.29	0.014
Information type	1	5611.9	6.06	0.014
AQ x Cost conditions	1	97	0.00	0.983
AQ x Information type	1	5611.9	2.11	0.146
Cost conditions x Information type	1	5611.9	0.20	0.654
AQ x Cost conditions x Information type	1	5611.9	0.59	0.443
Alexithymia model	Num df	Den df	<i>F</i>	<i>p</i>
Age	1	96.3	52.07	<0.001
Sex: Male	1	96.3	0.26	0.613

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Alexithymia	1	96.7	0.00	0.995
Cost conditions	1	97	2.30	0.133
Information type	1	5611.9	3.77	0.052
Alexithymia x Cost conditions	1	97	1.09	0.300
Alexithymia x Information type	1	5611.9	2.21	0.137
Cost conditions x Information type	1	5611.9	0.06	0.800
Alexithymia x Cost conditions x Information type	1	5611.9	0.03	0.866

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. AQ = Autism-Spectrum Quotient.

Mixed Models Accounting for Age Group Interaction Effects

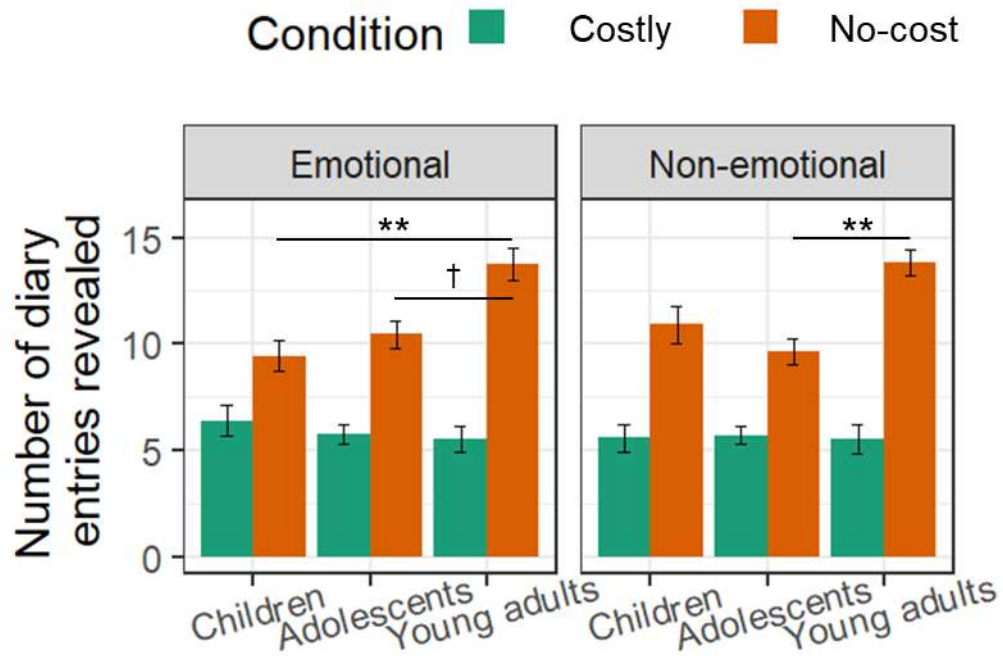
Instead of analysing continuous age (years), we introduced a four-way interaction term to the same set of mixed models by adding participants' age group (childhood/adolescents/young adults) to the three-way interaction term between autistic traits/alexithymia and the information type (emotional/non-emotional) and cost conditions (no-cost/costly) as presented in the main text. Since the purpose of these supplementary analyses is to explore if our primary interaction of interest between traits and study conditions would vary between age groups, we focus on reporting the interaction effects with age group below. Nevertheless, these results should be interpreted with caution as they do not necessarily imply specific developmental stage differences, which would require more strategic sampling in future studies. Summary of model results can be found in Tables S6.7-6.8. These supplementary analyses are significant at $\alpha = .05$, two-tailed.

Information Gathering

To explore if our current study found a similar pattern of results that children would gather significantly more information than older age groups when information gathering was

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not costly as reported in the previous study (Bowler et al., 2021), we first performed a repeated-measures ANOVA (cost conditions as the within-subjects factor) in the aggregated data (Figure S6.3). Specifically, when analysing data in the non-emotional conditions (which better approximated the study design in Bowler et al, 2021), there was a significant interaction between age group and cost conditions, $F(2,188) = 3.77, p = .02, \eta_p^2 = 0.04$. However, pairwise Tukey tests revealed that children only had slightly more draws than adolescents in the no-cost condition (Difference = 1.25 [-2.18; 4.67], $p = .90$), which did not reach statistical significance. Additionally, young adults were found to reveal significantly more diary entries than adolescents (Difference = 4.16 [0.86; 7.45], $p = .005$). No age group differences were found when information gathering was costly in the costly condition (Differences = -0.18 to 0.12, $ps = .99$ to 1) (Bowler et al., 2021). Likewise, when analysing data in the emotional conditions, there was a significant interaction between age group and cost conditions, $F(2,188) = 5.02, p = .008, \eta_p^2 = 0.05$. Young adults revealed significantly more diary entries than children (Difference = 4.33 [0.87; 7.79], $p = .005$) and adolescents (Difference = 3.31 [-0.09; 6.71], $p = .06$) in the no-cost condition, although the latter reached marginal significance only. No age group differences were found in the costly condition (Differences = -0.88 to -0.25, $ps = .98$ to .99) (Bowler et al., 2021).

Figure S6.3*Descriptive Summary of Number of Draws by Age Groups*

Notes. To provide a more direct comparison with the previous study (Bowler et al., 2021), the current study showed that children (aged 6-10) revealed slightly more diary entries than adolescents (aged 11-15) in the non-emotional no-cost condition, but this did not reach statistical significance. Additionally, young adults (aged 18-25) were found to have more draws than children and adolescents (especially in the emotional conditions). No significant differences were found between age groups in the costly conditions, which were consistent with the previous study. Means and standard errors are shown here.

† $p < .10$, ** $p < .01$.

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In the mixed models using trial-level data, the AQ model with the four-way interaction term significantly outperformed its null model without the interaction term, $\chi^2(23) = 178.69, p < .001$ (Table S6.7). In particular, there was a significant four-way interaction between age group and AQ and the information type and cost conditions, $\chi^2(2) = 21.63, p < .001$. To ease the interpretation of results, we first decomposed its three-way interaction with the cost conditions ($\chi^2(2) = 9.32, p < .01$), and then that with the information type conditions ($\chi^2(2) = 31.23, p < .001$). Specifically, children with higher autistic traits were found to draw significantly more diary entries in the no-cost condition than in the costly condition, Contrast (costly – no-cost) = -0.27, SE = 0.13, $t = -2.15, p = .03$. Such differences, however, were neither found in adolescents (Slope = -0.02, SE = 0.09, $p = .86$) nor in young adults (Slope = 0.06, SE = 0.10, $p = .52$). Regarding the information type conditions, young adults with higher autistic traits seemed to draw more diary entries in the emotional condition than in the non-emotional condition, Contrast (emotional – non-emotional) = 0.03, SE = 0.02, $t = 1.57, p = .12$, although this contrast was only observed at a trend level. No differences were observed in children (Slope = -0.04, SE = 0.03, $p = .15$) and adolescents (Slope = 0.02, SE = 0.02, $p = .22$).

When analysing alexithymia as the key trait of interest, the four-way interaction model significantly outperformed the null model, $\chi^2(23) = 164.35, p < .001$. Specifically, there was a significant three-way interaction between age group and alexithymia and cost conditions ($\chi^2(2) = 8.63, p = .01$), in that children with higher alexithymia were found to draw more diary entries in the no-cost condition than in the costly condition, Contrast (costly – no-cost) = -0.02, SE = 0.01, $t = -2.24, p = .03$. No differences were observed in adolescents (Slope = 0.005, SE = 0.01, $p = .64$) and young adults (Slope = 0.01, SE = 0.01, $p = .15$).

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Table S6.7*Summary of Mixed Models Predicting Total Draws with Age Group Interaction Terms*

AQ model	χ^2	df	<i>p</i>
(Intercept)	578.02	1	<0.001
Sex: Male	5.07	1	0.024
AQ	1.07	1	0.301
Cost conditions	85.72	1	<0.001
Information type	0.46	1	0.496
Age group	10.29	2	0.006
AQ x Cost conditions	0.73	1	0.394
AQ x Information type	4.87	1	0.027
Cost conditions x Information type	0.28	1	0.598
AQ x Age group	4.68	2	0.096
Cost conditions x Age group	11.69	2	0.003
Information type x Age group	28.73	2	<0.001
AQ x Cost conditions x Information type	1.32	1	0.251
AQ x Cost conditions x Age group	9.32	2	0.009
AQ x Information type x Age group	31.23	2	<0.001
Cost conditions x Information type x Age group	30.09	2	<0.001
AQ x Cost conditions x Information type x Age group	21.63	2	<0.001
Alexithymia model	χ^2	df	<i>p</i>
(Intercept)	41.17	1	<0.001
Sex: Male	5.87	1	0.015
Alexithymia	0.59	1	0.444
Cost conditions	11.13	1	0.001
Information type	3.28	1	0.070
Age group	11.64	2	0.003
Alexithymia x Cost conditions	2.33	1	0.127
Alexithymia x Information type	3.83	1	0.050

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Cost conditions x Information type	0.53	1	0.469
Alexithymia x Age group	11.36	2	0.003
Cost conditions x Age group	10.68	2	0.005
Information type x Age group	0.53	2	0.766
Alexithymia x Cost conditions x Information type	0.38	1	0.535
Alexithymia x Cost conditions x Age group	8.63	2	0.013
Alexithymia x Information type x Age group	3.59	2	0.166
Cost conditions x Information type x Age group	0.27	2	0.875
Alexithymia x Cost conditions x Information type x Age group	2.36	2	0.308

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Both models used parent-reported alexithymia T-scores as described in the main text. Self-reported alexithymia T-scores were used for young adults throughout. AQ = Autism-Spectrum Quotient.

Emergence of Cost

The AQ model with the age group interaction term outperformed its null model, $\chi^2(23) = 107.78, p < .001$ (Table S6.8). There was a significant three-way interaction between age group and AQ and cost conditions, $F(2,78) = 5.05, p < .01$. Specifically, children with higher autistic traits had a later emergence of internal costs of information gathering in the no-cost condition than in the costly condition (where more information gathering was penalised), Contrast (costly – no-cost) = -5.68, SE = 1.72, $z = -3.29, p = .001$. No such differences were found in adolescents (Slope = 0.48, SE = 1.15, $p = .68$) and young adults (Slope = 0.40, SE = 1.29, $p = .76$).

For the alexithymia model, although being statistically superior to its null model ($\chi^2(23) = 96.12, p < .001$), none of the interaction terms between age group and alexithymia reached statistical significance (F s = 0.18 to 1.76, p s = .18 to .83).

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Table S6.8*Summary of Mixed Models Predicting Emergence of Cost with Age Group Interaction Terms*

AQ model	NumDF	DenDF	F	p
Sex: Male	1	78	2.84	0.096
AQ	1	77.8	6.64	0.012
Cost conditions	1	78	132.57	<0.001
Information type	1	156	0.17	0.684
Age group	2	77.8	1.23	0.297
AQ x Cost conditions	1	78	3.86	0.053
AQ x Information type	1	156	0.81	0.370
Cost conditions x Information type	1	156	2.83	0.094
AQ x Age group	2	77.8	0.36	0.699
Cost conditions x Age group	2	78	3.93	0.024
Information type x Age group	2	156	0.30	0.743
AQ x Cost conditions x Information type	1	156	0.97	0.327
AQ x Cost conditions x Age group	2	78	5.05	0.009
AQ x Information type x Age group	2	156	0.25	0.783
Cost conditions x Information type x Age group	2	156	1.33	0.266
AQ x Cost conditions x Information type x Age group	2	156	1.71	0.184
Alexithymia model	NumDF	DenDF	F	p
Sex: Male	1	78	3.66	0.069
Alexithymia	1	77.9	1.31	0.255
Cost conditions	1	78	1.65	0.203
Information type	1	156	0.01	0.927
Age group	2	77.9	1.24	0.296
Alexithymia x Cost conditions	1	78	0.78	0.380
Alexithymia x Information type	1	156	0.00	0.973
Cost conditions x Information type	1	156	0.97	0.327
Alexithymia x Age group	2	78	1.01	0.369

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Cost conditions x Age group	2	78	2.58	0.082
Information type x Age group	2	156	0.84	0.432
Alexithymia x Cost conditions x Information type	1	156	1.75	0.187
Alexithymia x Cost conditions x Age group	2	78	1.76	0.179
Alexithymia x Information type x Age group	2	156	1.09	0.340
Cost conditions x Information type x Age group	2	156	0.07	0.931
Alexithymia x Cost conditions x Information type x Age group	2	156	0.18	0.834

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Both models used parent-reported alexithymia T-scores as described in the main text. Self-reported alexithymia T-scores were used for young adults throughout. AQ = Autism-Spectrum Quotient.

Computational Mixed Models in the Full Sample***Emergence of Cost***

Consistent with the main text, the AQ model with the three-way interaction was superior to the null model, $\chi^2(7) = 87.52, p < .001$ (Table S6.9). Similarly, there was a significant main effect of AQ on the computational parameter cs_p , $F(1,96.8) = 5.17, p = .03$. By decomposing this main effect, it was found that participants with higher autistic traits considered the act of gathering more information less costly and delayed their decision to make a guess (Slopes = 0.67 to 2.05, SEs = .70 to .79), especially in the emotional no-cost condition (Slope = 2.05 [0.50; 3.59], SE = .79). However, no interactions with AQ were observed.

The alexithymia model was also superior to the null model, $\chi^2(7) = 82.63, p < .001$. However, none of the main effects or interaction terms of interest reached statistical significance (Table S6.9).

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Table S6.9*Summary of Mixed Models Predicting Emergence of Cost in the Full Sample*

AQ model	NumDF	DenDF	F	p
Age	1	97	2.14	0.147
Sex: Male	1	97	1.70	0.195
AQ	1	96.8	5.17	0.025
Cost conditions	1	97	117.10	<0.001
Information type	1	194	0.02	0.901
AQ x Cost conditions	1	97	0.55	0.460
AQ x Information type	1	194	2.40	0.123
Cost conditions x Information type	1	194	2.81	0.095
AQ x Cost conditions x Information type	1	194	0.68	0.411
Alexithymia model	NumDF	DenDF	F	P
Age	1	97	2.36	0.128
Sex: Male	1	97	2.73	0.102
Alexithymia	1	96.5	1.34	0.251
Cost conditions	1	97	1.60	0.208
Information type	1	194	0.54	0.465
Alexithymia x Cost conditions	1	97	0.76	0.384
Alexithymia x Information type	1	194	0.60	0.441
Cost conditions x Information type	1	194	0.03	0.860
Alexithymia x Cost conditions x Information type	1	194	0.26	0.608

Notes. Residualised AQ scores were analysed in the AQ model, whilst raw alexithymia T-scores were analysed in the alexithymia model. Both models used parent-reported alexithymia T-scores as described in the main text. Self-reported alexithymia T-scores were used for young adults throughout. AQ = Autism-Spectrum Quotient.

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Table S6.10*Summary of Robust Multiple Regressions Predicting Emotional Consistency from Alexithymia*

Emotional consistency	Coefficient	Estimate	SE	t	p	Lower 95% CI	Upper 95% CI	VIF
Actual reward	Intercept	53.09	4.38	12.12	<0.001	44.50	61.67	--
	Age	0.04	0.13	0.31	0.758	-0.22	0.30	1.21
	Sex: Male	-0.71	1.61	-0.44	0.659	-3.87	2.44	1.47
	AQ	0.09	0.09	1.04	0.300	-0.08	0.26	1.64
	Alexithymia	-0.17	0.08	-2.08	0.041	-0.33	-0.01	1.42
Imaginative loss	Intercept	56.46	5.17	10.92	<0.001	46.32	66.59	--
	Age	0.03	0.15	0.18	0.856	-0.26	0.31	1.12
	Sex: Male	-0.61	1.72	-0.35	0.726	-3.99	2.77	1.13
	AQ	0.07	0.09	0.80	0.426	-0.10	0.24	1.22
	Alexithymia	-0.20	0.08	-2.58	0.012	-0.36	-0.05	1.12

Notes. Raw AQ T-scores and alexithymia T-scores were used. Models were adjusted for age in years, sex, and AQ scores.

Two-tailed *p* values are reported here for consistency. To reflect our hypotheses, one-tailed *p* values are reported for alexithymia in text. AQ = Autism-Spectrum Quotient.

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Table S6.11*Summary of Robust Multiple Regressions Predicting Emotional Consistency from Self-Reported Alexithymia*

Emotional consistency	Coefficient	Estimate	SE	t	p	Lower 95% CI	Upper 95% CI	VIF
Actual reward	Intercept	54.04	4.53	11.94	<0.001	45.17	62.91	--
	Age	0.03	0.13	0.25	0.800	-0.22	0.29	1.20
	Sex: Male	-0.39	1.59	-0.25	0.807	-3.50	2.72	1.46
	AQ	0.06	0.08	0.77	0.444	-0.09	0.21	1.36
	Alexithymia	-0.16	0.07	-2.36	0.021	-0.29	-0.03	1.11
Imaginative loss	Intercept	58.67	5.80	10.12	<0.001	47.31	70.03	--
	Age	0.02	0.14	0.14	0.886	-0.26	0.30	1.10
	Sex: Male	-0.22	1.85	-0.12	0.906	-3.85	3.41	1.10
	AQ	0.03	0.09	0.37	0.714	-0.14	0.20	1.16
	Alexithymia	-0.21	0.08	-2.51	0.014	-0.37	-0.05	1.05

Notes. Self-reported alexithymia scores were analysed for all participants. Two-tailed *p* values are reported here for consistency. AQ = Autism-Spectrum Quotient.

Chapter 7
General Discussion

General Discussion

This thesis aimed to investigate the potential contribution of factors other than interoception to alexithymia, with the aim of refining the multi-route model of alexithymia (Hobson et al., 2019). The development of the multi-route model is at an early stage, and requires both old and new conceptual and methodological issues to be addressed, a matter that is common with other emerging areas of emotion research (Barrett, 2017; Barrett et al., 2007b). Through a series of five research projects, I have first focused on the language hypothesis of alexithymia and employed a question-word framework – *who*, *which*, *when*, and *how* – to help identify key knowledge gaps that would further specify the role of language impairments in the development of alexithymia. These include synthesising the empirical evidence for the relationship between multi-domain language deficits and alexithymia, testing their prospective relationship in a longitudinal cohort of children with and without language impairments, and examining the role of language talents in emotional self-awareness. I have also described these findings in the context of the theory of constructed emotion (Barrett, 2017; Barrett et al., 2007a), and further investigated if alexithymia is associated with atypical learning of abstract emotion concepts. Finally, I have investigated the relationship between alexithymia and autistic trait-related information gathering, and highlighted the importance of studying the negative impact of alexithymia on decision making and its related emotional processes, which have clinical implications for supporting a transdiagnostic range of individuals with alexithymia.

In this final chapter, I will first summarise the key findings of each empirical chapter and the relevant questions they were designed to address. This is then followed by a general discussion of the theoretical implications of these empirical findings and their broader connections with the multi-route model of alexithymia and the theory of constructed emotion. From an epistemological point of view, I will then revisit various analytic strategies used in

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these chapters and describe how these strategies would benefit the building of a multi-route model of alexithymia and their limitations. I will end with an overall discussion of the clinical implications of the findings, providing recommendations for improving clinical support for individuals with alexithymia.

Key Findings

The language hypothesis of alexithymia posits that language impaired groups are predisposed to an elevated risk of developing alexithymia due to language impairments rather than interoceptive deficits. Synthesising data from all empirical studies published to date, **Chapter 2** found that while alexithymia was dimensionally linked to multi-domain language impairments to a modest degree, cross-sectional studies could not test the hypothesis that language impairments would lead to elevated alexithymic traits rather than elevated alexithymic traits leading to language impairments. Only a few studies have directly compared alexithymic traits between language impaired groups and those with typical language, and it is this comparison which is most directly relevant for the alexithymia hypothesis. Using data from the SCALES cohort, **Chapter 3** found longitudinal support for the prediction that boys with low language function at ages 4-5 reported more difficulties differentiating emotions at ages 12-13, and children who later fulfilled the diagnostic criteria for language disorders at ages 5-6 reported paying less attention to others' emotions at ages 12-13. Both groups of children, however, reported similar levels of bodily awareness as peers with typical language, proving no evidence that interoception plays a role in the development of alexithymia in language impaired groups. These findings highlight the importance of considering developmental timing (*when*), as although prospective group differences were detected, the alexithymic trait domain in which these group differences emerged might not necessarily correspond to the alexithymia construct as defined in the adult literature. This relates to the methodological issues of when the initial language assessment took place, what

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aspects of language deficits were assessed, and when and what alexithymic traits were assessed in later years. It might therefore be more appropriate to conceptualise reduced motivation to attend to others' feelings and low emotion recognition accuracy (as found in Griffiths et al., 2020 in the SCALES cohort) as developmental correlates of alexithymia, which are widely documented in alexithymic adults (e.g., Cuve et al., 2021, also see a review by Pisani et al., 2021). Relevant to the *which* question is the relative contribution of different language domains to alexithymia: while Chapter 2 found no significant differences in effect sizes between structural language, pragmatics, and natural use of language, Chapter 3 revealed that early structural language impairments, notably difficulties using grammar and understanding syntax, were most robustly linked to elevated alexithymic traits in early adolescence.

Chapter 4 revisited the *who*-question from a positive angle, using professional writers as a model of language talents to investigate the role of language in emotional self-awareness. While professional writers indeed showed a very low level of alexithymic traits as compared to non-writers, this was related to the fact that writers also reported being more accurate in perceiving their internal bodily signals than non-writers, which was in turn associated with high emotional self-awareness. This interoceptive accuracy pathway was independent of the marginal effect of having better knowledge of emotion vocabulary in writers than non-writers, and there was no evidence suggesting that high emotional self-awareness in writers was directly related to their extensive reading and writing experience. These data are, strictly speaking, orthogonal to the predictions of the language hypothesis of alexithymia which were specific to the impact of language deficits on the likelihood of developing alexithymia. However, they suggest that the link between language talents and emotional self-awareness may be more complex than the simple model outlined in the language hypothesis of alexithymia. Future studies are warranted to determine if the lack of a

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direct effect of language strengths on emotional self-awareness is also observed with respect to language gifts that emerge in early years. Overall, these findings highlight that the relative importance of each of the multiple processes underlying alexithymia is likely different across study populations and clinical groups (Hobson et al., 2019).

In light of the Chapter 2 finding that alexithymia was associated with reduced emotional granularity, **Chapter 5** focused on testing the rudimentary link between alexithymia and emotion concept learning, a potential mechanism (*how*) informed by the constructionist literature. Through a series of three experiments, it was found that alexithymia was not robustly associated with lower learning rates of abstract unfamiliar emotion concepts. However, there existed an indirect pathway where alexithymic individuals had higher levels of co-occurring anxiety symptoms, which were in turn associated with more stochastic choices with respect to outcome values (i.e., lower β estimates), suggestive of a choice characteristic that was not strictly governed by learning history, and/or a potential insensitivity to environmental volatility (Piray & Daw, 2021; Yamamori & Robinson, 2023). This indirect pathway through co-occurring anxiety was also found in Experiment 3 where participants were asked to learn non-emotion concepts about temperature, suggesting a general learning deficit that was not specific to emotion. These findings suggest that the modest link between alexithymia and reduced emotional granularity in Chapter 2 might be confounded by co-occurring mood symptoms in those study samples.

Finally, **Chapter 6** investigated the interplay between autistic and alexithymic traits and information gathering, a decision-making process (*how*) that is associated with aversion to uncertainty as commonly observed in individuals with high autistic traits (Boulter et al., 2014; Stark et al., 2021), obsessive-compulsive traits (Hauser et al., 2017), and anxiety (Carleton et al., 2012). While past studies have shown mixed results concerning the role of co-occurring alexithymic traits in information gathering (e.g., Ozsivadjian et al., 2021; Maisel

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et al., 2016), in the present study, high autistic traits were consistently associated with an increased propensity to gather information regardless of information type and costs of information gathering. This association was related to the fact that there was a delayed emergence of subjective cost of information gathering, promoting later guesses in those with high autistic traits. Alexithymic traits, on the other hand, were uniquely associated with inconsistent emotional responses to rewards and losses on the task. These findings provide some of the first experimental evidence that clarifies the unique link between autistic traits and information gathering, and are consistent with past studies that demonstrated emotional inconsistency in alexithymic adults.

Theoretical Implications and Future Considerations

Incorporating a Developmental Perspective

A greater developmental focus in the field would be key to understanding the factors contributing to alexithymia. In particular, the language hypothesis of alexithymia has a strong emphasis on the idea of predisposition – a developmental prediction concerning the long-term effects of early language deficits on alexithymia. However, research on alexithymia has primarily been conducted in adults and in cross-sectional settings; issues concerning the early presentation of alexithymic traits and the developmental milestones of related emotional abilities are limited to theoretical discussions thus far (e.g., Hoemann et al., 2019, 2020b). This paucity of developmental knowledge also relates to some long-standing methodological issues regarding the measurement of alexithymic traits in developmental populations. These issues include the lack of parent-child agreement in self-report measures (e.g., Hobson & van den Bedem, 2021) and the need to clarify the alexithymia construct in children (e.g., whether externally-oriented thinking is a feature of alexithymia or not in youths; Rieffe et al., 2006), both of which hamper research efforts that seek to track the developmental trajectory of

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alexithymia and its contributing factors in early years. Another key area for future research would be to demonstrate how various developmental correlates, such as reduced attention to others' emotions and atypical processing of emotional cues as mentioned previously, would eventually lead to the onset of alexithymia as seen in adults. It is perhaps unsurprising that these developmental correlates of alexithymia are also common in its highly co-occurring mood disorders, such as anxiety and depression (e.g., atypical attention in clinically anxious and depressed youths; Hankin et al., 2010; Harrison & Gibb, 2015). It is therefore crucial for future research to dissociate the early developmental trajectory of alexithymia from other cognitive-affective processes that underly the emergence of these co-occurring mood symptoms, which may help elucidate the longitudinal link between low emotional awareness and affective psychopathology (Weissman et al., 2020). Incorporating a developmental perspective has important clinical implications, as it provides direct evidence informing early screening for, and prevention of, alexithymia as compared to interventions that target the symptoms of alexithymia.

Reflecting on the Theory of Constructed Emotion and the Role of Language

The theory of constructed emotion and the multi-route model of alexithymia share the view that multiple neurobiological and psychological systems are involved in the experience of emotions (including emotional self-awareness) (Barrett, 2017; Hoemann et al., 2021; Lindquist & Barrett, 2008; Lindquist et al., 2012). These processes not only involve the ability to make inferences about an emotional state based on continuous monitoring of interoceptive signals (Barrett, 2017; Barrett et al., 2007b), but also language skills that allow one to apply linguistic symbols to make sense of and communicate vague affective signals as discrete and specific emotion categories (Barrett et al., 2007a; Lindquist et al., 2015; Lindquist, 2017). This link between language and emotion introduces novel avenues for research, testing the representation and acquisition of emotion concepts in alexithymic

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individuals. Intriguingly, although Chapter 2 found a modest association between alexithymia and less fine-grained representation of emotion concepts in the literature, Chapter 4 revealed that similarity judgements of emotion concepts did not predict the alexithymic traits of writers and non-writers well. Chapter 4 also found no evidence for a direct link between interoceptive abilities and general/emotional vocabulary knowledge when predicting individual differences in alexithymic traits, suggesting that there could be a ceiling effect at which further increases in language abilities do not provide for increased emotional awareness (Lindquist et al., 2015; Lindquist, 2017). While it was thought that disrupted acquisition of emotion concepts would contribute to reduced availability of linguistic labels for identifying and describing emotions (Lindquist et al., 2015; Shablack & Lindquist, 2019), Chapter 6 likewise found no direct links between alexithymia and atypical learning of emotion and non-emotion concepts.

The above null findings underscore the need for explanation of the specific language processes that are thought to play a role in emotional experience under the theory of constructed emotion, and the roles that they play. In particular, most behavioural evidence presented in relevant literature stems from studies that demonstrate the capability of emotion words to alter subsequent perception of facial expressions (e.g., Gendron et al., 2012; Nook et al., 2015; also see a commentary by Lindquist & Gendron, 2013). These study designs are essentially priming paradigms that employ emotion word cues as stimuli: while they demonstrate an effect of emotional words on subsequent perception of emotional stimuli, they do not demonstrate a role of language in either the development or use of emotional categories. Instead, emotion words may affect perception in the same way that abstract shapes can cause fear following a fear conditioning paradigm – with the associated emotion category biasing perception. Consideration of this point highlights a potential difference in the conceptualisation and operationalisation of the role of language in emotion between the

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theory of constructed emotion and the language hypothesis of alexithymia. Theories of constructed emotion suggest language plays a role via individual linguistic labels which represent abstract concepts (including emotion words and their associated emotion categories; Hoemann et al., 2020b), whereas researchers testing the language hypothesis of alexithymia have focused on language functions that are clinically used to define and diagnose language impaired groups, such as structural language and pragmatics (Hobson et al., 2019).

Conceptual differences between theories are not uncommon, and could foster the mutual exchange of empirical data and theoretical principles (Borsboom et al., 2021). For example, a recent study has demonstrated that children aged four and five years old were able to learn unfamiliar emotion concepts using syntactic features that signal an emotion-related word (e.g., *feel* and *feel...about*) and contextual details concerning the causes and consequences of the emotion experienced by a cartoon character (Shablack et al., 2020), demonstrating emotion concept acquisition which is scaffolded by structural language skills. Another possible area for knowledge exchange is to provide more direct behavioural evidence that illustrates the interplay between multiple psychological processes and emotional experience. Theorists of constructed emotion have pointed to a shared neural network supporting interoception and language function (Barrett, 2017; Oosterwijk et al., 2012), there is yet the need to distinguish between the method (self-report beliefs vs. objective performance) and target (accuracy vs. attention) of their interoceptive measurement (Murphy et al., 2019), which may interact differently with language in supporting emotional self-awareness. Conversely, studies testing the language hypothesis of alexithymia have primarily tested self-reported interoceptive abilities. It would be crucial to conduct objective performance tasks of interoception (along with physiological recording of interoceptive signals) in language impaired individuals, which would serve as key evidence for evaluating the significance of interoception to alexithymia in language impaired groups (Hobson et al.,

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2019). Interoceptive tests can now be conducted outside the laboratory using smartphone-based sampling technologies that send biological triggers based on multi-modal signals, including electrocardiography, impedance cardiography, and accelerometry (Hoemann et al., 2020a). As compared to existing sampling methods that trigger prompts randomly (such as studies reviewed in Chapter 2), these novel techniques can capture meaningful changes of emotional experiences more accurately and be more sensitive to their real-time interactions with interoceptive signals across daily situations (Hoemann et al., 2023).

Studying the Social Pathways of Alexithymia

As mentioned in previous chapters, clinical populations with high co-occurring alexithymia often experience interpersonal problems and social rejection (e.g., autism: Rowley et al., 2012; developmental language disorder (DLD): van den Bedem et al., 2018). However, past studies have not illustrated the underlying mechanisms that would put alexithymic individuals at elevated risks of experiencing such social difficulties and if these difficulties could exacerbate alexithymia in return. A proposal that is relevant to this social pathway has been raised from studies in children with DLD. Specifically, it is hypothesised that the persistent language impairments in these children would limit their capacity to communicate and interact with peers, which would in turn compromise their social learning opportunity to acquire the linguistic skills and labels to identify and express their emotions (Hobson & van den Bedem, 2021). However, there remains the need to specify what social learning processes are involved in the development of alexithymia, as Chapter 5 found no evidence that individuals with high alexithymic traits showed atypical learning of social information about unfamiliar emotional or non-emotion concepts, suggesting that some aspects of social learning may be intact in alexithymic individuals (it of course should be noted that Chapter 5 did not test individuals with DLD). Nonetheless, since those experiments did not involve actual social interactions with other participants, these findings

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may not generalise well to social learning contexts in real life. Future studies may also investigate if co-occurring anxiety symptoms in language impaired groups would contribute to difficulties learning abstract concepts in social situations that require prompt responses, such as when having real-time conversations about emotions with others. After all, various psychological processes considered in the multi-route model of alexithymia serve key social purposes (e.g., language for communication, face processing for inferring others' emotional states). A more in depth understanding of their impact on social functioning would help understand interpersonal difficulties in alexithymic individuals in more mechanistic terms.

Analytic Considerations for Building a Multi-Route Model of Alexithymia

Models have the unique property to describe the workings of a psychological system, illustrating the complex relationships and interactions between multiple psychological processes and their outcomes (Haslbeck et al., 2021). This systemic focus is highly relevant to building a multi-route model of alexithymia, as one could conceptualise alexithymia as a psychological system of low emotional self-awareness which arises from the complex interplay between several cognitive processes and social-environmental factors (Hobson et al., 2019). However, it is evident in various reviews (Hobson et al., 2019; Luminet et al., 2021) and Chapter 2 that past studies have primarily tested small-scale predictions about alexithymia (such as the univariate relationship between interoception and alexithymia; Trevisan et al., 2019), which have not put forth a model-oriented understanding of the development of alexithymia. In the following sections, I will describe how various analytic strategies used in this thesis – namely data synthesis, structural equation modelling, and computational modelling – may serve as a tool kit to help build a multi-route model of alexithymia.

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Data Synthesis

Conducting a systematic review and meta-analysis represents an important first step in model building, as it characterises the psychological phenomena of interest with an overview of the current research practices and findings (Brosboom et al., 2021). In particular, quantitative syntheses provide summary estimates (e.g., standardised mean difference and aggregated correlation coefficient) that can be weighted by sample sizes and the number of tests conducted, which can reduce statistical biases introduced by smaller, underpowered studies (Carter et al., 2019; Schmidt, 1992). When combined with a systematic review, the summary estimates can be more critically evaluated in the context of individual study methodologies and sample characteristics. Data synthesis can also provide preliminary insights into the hypothesised relationship among constructs, such as the finding that alexithymia was associated with both language impairments and reduced emotional granularity (Chapter 2), supporting the idea of considering the theory of constructed emotion in subsequent work. This integrated approach can therefore deliver a framework for identifying knowledge gaps and guiding future study designs in young fields of research, including the language hypothesis of alexithymia (Siddaway et al., 2019).

However, it is important to note that a significant effect size synthesised across studies does not confirm that the alexithymia theory of interest is true. Importantly, the interpretability of these synthesised results is highly dependent on the quality of individual studies (Siddaway et al., 2019). An example would be the meta-analysis of Trevisan and colleagues (2019), where past invalid measurement and operationalisation of interoceptive abilities have resulted in correlations that were drastically different in strength and directions, rendering the relationship between interoception and alexithymia inconclusive. Likewise in the language literature (Chapter 2), studies on pragmatics and natural use of emotional language have not ruled out the possibility that those were in fact language-based theory of

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mind tests and autobiographical memory tests, respectively. Although the emotional granularity literature is relatively homogenous in its methods and study samples (which mostly involved stimulus rating and experience sampling in students), its modest relationship with alexithymia might be confounded by co-occurring mood symptoms in their student samples (Ichijo et al., 2019). Ideally, meta-analysts are encouraged to obtain raw data from the study authors and implement a synthesis pipeline that could allow for independent re-screening of data quality and re-calculation of effect sizes (Polanin et al., 2020; Siddaway et al., 2019). This ideal scenario would require a collaborative effort to share individual data sets and provide transparent information on sample characteristics and study limitations (Polanin et al., 2020). Together, these practices would help the overall evaluation of the most robust and interpretable evidence in the field on a regular basis, and refine empirical questions and paradigms that coherently elucidate factors contributing to alexithymia.

Structural Equation Modelling

Structural equation modelling (SEM) is well-suited for testing hypotheses concerning longitudinal changes and development of alexithymia (*when*). Specifically, SEM is itself a model building technique that allows researchers to mathematically specify and test a hypothesised series of regression-based relationships among a large set of study constructs (see a seminal introduction by MacCallum & Austin, 2000). For instance, the researcher could specify the directionality of these structural relationships (e.g., language → alexithymia, or alexithymia ↔ emotional granularity), and the resulting paths presented as a model-like diagram that depicts the interplay of the alexithymia constructs of interest. A relevant proposal mentioned in Chapter 3 is to use cross-lagged panel modelling to estimate bi-directional influences between language and alexithymia over time (i.e., language → alexithymia → language and vice versa; see Griffiths et al., 2022 for an example between language and non-verbal reasoning). This specific class of SEM allows for testing

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prospective relationships between multiple cognitive variables and alexithymia, while simultaneously controlling for their contemporaneous and prior associations at previous time points (see Hamaker et al., 2015 and Mulder & Hamaker, 2021 for new variants of the model, which can be useful for testing how within-person changes in language abilities predict within-person changes in alexithymia over time). In experimental settings, researchers could apply SEM to test the multivariate relationships between alexithymia, co-occurring mood symptom, and task performance variables (as demonstrated in Chapter 5). As the structural diagrams of SEM are the direct expression of the underlying theoretical model specified with standardised symbols and equations (Borsboom et al., 2021; MacCallum & Austin, 2000), researchers could easily carry out tests of validity and generalisability in other study samples, progressively building on existing structural models of alexithymia.

SEM can also be used for subtyping purposes (*who*). Chapter 3 utilised latent profile analysis (LPA) to empirically identify subgroups of children using their subscale scores on the Child Communication Checklist. The use of LPA allows for testing alexithymic trait differences in children with at-risk language profiles, such as subtypes of children displaying varied abilities in different language domains, who were often overlooked in past research that analysed conventional diagnostic categories of language disorders. Similar latent grouping techniques can be extended to longitudinal data, such as with the use of latent growth curve analysis to identify children with distinct trajectories of language development based on their longitudinal *changes* in early language abilities (Chapter 3). This longitudinal approach may be more advantageous than detecting language difficulties at a single time point, as in some cases the latter may simply reflect transient variations in early language development instead of a robust language marker that is diagnostic of future alexithymia. To extract a variety of distinct profiles, the application of these classification techniques would ideally require a large sample with considerable heterogeneity in their language development

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data. Some examples would be the use of administrative data that allow linkages to participants' language-related records (e.g., school records and diagnosis of language disorders), and epidemiological samples that are socioeconomically and demographically representative of a population of interest. As compared to data sets curated by smaller independent laboratories, these large data sources provide a better buffer to high attrition rates in clinical samples and reduce sample selection bias based on researcher-imposed criteria.

Computational Modelling

Computational modelling refers to modelling techniques that compute estimates through the programmatic execution of mathematical equations that are hypothesised to represent the underlying cognitive mechanisms of an observed task behaviour (*how*) (Hauser et al., 2022). Since these equations can be expressed algebraically and accept multiple input variables (while constrained by mathematical rules), they provide a mathematically logical and traceable framework for generating and testing hypotheses about the interplay of cognitive processes underlying alexithymia. Applying these estimation procedures may be more advantageous than only analysing observed task behaviour, as conventional task performance variables are overly generic (e.g., measuring accuracy and reaction time in a classic facial emotion recognition study in alexithymic individuals; Pisani et al., 2021), which may not capture their mechanistic interactions with other alexithymia constructs. Moreover, most narrative theories have issues of conceptual redundancy and ambiguity about the statistical relationships between constructs (Fried, 2020; van Dongen et al., 2022). These model building issues open up huge degrees of freedom regarding the measurement and operationalisation of these constructs (e.g., interoception; Trevisan et al., 2019), thereby increasing the odds of obtaining inconsistent results that are not assimilable with efforts that seek to build a coherent model of alexithymia. Computational models, on the other hand, can

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evaluate how well the output estimates are captured by the models (such as through the evaluation of model fit, model comparisons, or even simulations), which can facilitate model building in a systematic manner (Hauser et al., 2022; Nassar & Frank, 2016).

Chapters 5 and 6 have presented some of the first attempts at applying computational modelling in the study of alexithymia, but these attempts are not without limitations. In particular, there have been suggestions that researchers should consider formalising psychological theories whenever possible through computational modelling, with the idea that expressing theoretical constructs and their relationships in mathematical terms would avoid the issue of construct ambiguity in narrative theories and increase the fidelity of the communication of these theories (Farrell & Lewandowsky, 2010; Guest & Martin, 2021). However, recent studies have found that overly-restricted mathematical assumptions may lack relevance with the cognitive process of interest, which may bias the estimation and mislead the interpretation of computational parameters (Nassar & Frank, 2016). Relevant to research on alexithymia are several computational models of interoception, which are primarily formulated within the Bayesian (i.e., aberrant integration of prior knowledge/experience into the current perception and prediction of internal bodily signals) and predictive coding (i.e., mismatch between the predicted and actual interoceptive output) frameworks (e.g., Petzschner et al., 2021; Suksasilp & Garfinkel, 2022). These same frameworks, however, are also applied in models that seek to explain perceptual experiences in autistic individuals (Pellicano & Burr, 2012) and interoceptive inference in depressed individuals (Barrett et al., 2016). There is hence the need to test the generalisability of these mathematical assumptions and whether a shared computational framework would necessarily imply a common computational marker that is attributable to co-occurring alexithymia across these clinical groups. For future research testing the language hypothesis of alexithymia, besides computational models that allow for investigating atypical language acquisition

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(Erickson & Thiessen, 2015; Gupta & MacWhinney, 1997; Thomas & Karmiloff-Smith, 2003), thoughtful study design remains key to the reliable and valid estimation of underlying computational processes (Erickson & Thiessen, 2015). To ultimately build a multi-route model of alexithymia, researchers would have to consider how these existing computational models of language acquisition could merge with competing models of emotion that show promise to explain the development of alexithymia (e.g., Barrett et al., 2016 and Barrett, 2017 from a constructed emotion perspective; Seth, 2013 and Seth & Friston, 2016 with an emphasis on predictive coding principles of interoceptive inference).

Clinical Implications

In all, building a multi-route model of alexithymia holds the great promise of improving the diagnosis, prevention, and treatment of alexithymia. This holistic approach highlights the importance of mechanism-driven research that has a translational impact on identifying specific mechanisms of change for the wide array of alexithymic individuals.

The value of prevention is increasingly recognised in mental health, as it shows great promise in preventing the onset of psychiatric conditions when there is greater room for change and is generally less costly than clinical treatments (Fusar-Poli et al., 2021). While studies have shown that low emotional self-awareness is associated with increased risks of affective psychopathology (Albantakis et al., 2020; Preece et al., 2022; Weissman et al., 2020), targeting the developmental correlates of alexithymia in early years may be a promising approach to prevent the onset of common mood disorders and alexithymia itself. Curriculum-based activities that encourage regular sharing of emotions with peers and teaching valence-arousal mapping of bodily signals and emotion words have been shown to improve emotional literacy (i.e., better abilities to define and explain the causes of emotions, and be able to evaluate actions that make one feel in a certain way) (Brackett et al., 2019;

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Hoffmann et al., 2020; Reyes et al., 2012), which seem to correspond well with the developmental correlates of alexithymia found in Chapter 3. However, more research is warranted to test if adjunct speech and language support would be necessary for language impaired groups, such as teaching verbs and syntactic frames for the extraction of emotional information and expression of emotions. Relevant to Chapter 4 is the idea of creative writing, which has been used as a novel approach to enhance emotion regulation skills in mental health patients (e.g., King et al., 2013). However, the treatment mechanism may not be directly related to language, as we found no evidence that extensive reading/writing experience had a direct link with high emotional self-awareness in writers. While this could mean that there are extraneous cognitive processes involved in these literary activities that might indirectly enhance emotional self-awareness over time, it is possible that engaging in creative activities in general increases self-perceived social support, thereby promoting mental well-being (Mundy et al., 2022).

The few existing interventions for alexithymia have been based on the logic that promoting interoceptive abilities would increase emotional self-awareness (such as increasing one's attentional focus on heart and breathing rates through meditative practices; Norman et al., 2019; Silveira et al., 2023). While this approach may be useful in individuals whose pathway to alexithymia is underpinned by interoceptive deficits, we call for treatment strategies that also consider the *negative outcomes* of alexithymia. One potential impairment highlighted in Chapter 5 is that of anxiety symptoms, which are elevated in alexithymic individuals and may lead to insensitivity to volatility in learning contexts (Pike & Robinson, 2022). This again highlights that past symptom-focused interventions aimed at enhancing emotional self-awareness *per se* might not necessarily translate to more adaptive behaviours supportive of better emotional abilities. Another impairment found in Chapter 6 is the lack of emotional consistency in alexithymic individuals, which has been shown to be associated

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with less economical decision-making behaviours (Hogeveen et al., 2021). Emotional inconsistency may explain aberrant reward valuation in alexithymia-related mood disorders (e.g., depression; Halahakoon et al., 2020) and substance misuse and addictions (Morie et al., 2016; Pinard et al., 1996). Given that cognitive-behavioural therapy is particularly effective in facilitating mindful decision-making in these clinical groups (Baker et al., 2010; Riper et al., 2014), it delivers a promising framework for exploring if alexithymic individuals are aware of such inconsistency in their emotional responses and its potential impact on decision making.

Conclusion

Moving beyond a single interoceptive account of alexithymia, a holistic understanding of the pathway to alexithymia requires a rich description and mechanism-based explanation of its underlying psychological processes. Importantly, atypicalities in these processes do not function in isolation but represent a product of the disrupted interplay between multiple psychological systems, as well as their interactions with early developmental factors and the social environment for emotion understanding. Consideration of the theory of constructed emotion has provided the unique opportunity to raise novel empirical questions about the representation and acquisition of emotion concepts in alexithymic individuals, fostering the mutual exchange of empirical knowledge and improvement of study methods with researchers aiming to build a multi-route model of alexithymia. The model underlines a coherent framework for elucidating the complex cognitive, affective, and social processes that contribute to low emotional self-awareness and its consequences, with the ultimate goal of informing mechanisms of change for the wide array of alexithymic individuals.

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