On not knowing the music:

Disruptions to synchrony of affect in the vocal channel between mothers and their children with callous-unemotional (CU) traits

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A thesis submitted for the degree of Doctor of Philosophy of
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DECLARATION

This thesis describes original research undertaken at the Research School of Psychology at the Australian National University. It contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no content previously published or written by another person except where due reference is made in the text.

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ABSTRACT

Examining mechanisms for the transmission of emotion between caregivers and their children is a growing concern for theories of child psychological development. One established mechanism for such transmission is biobehavioural synchrony, a phenomenon that is considered normative in early childhood and has been associated with the child's capacity for empathy across development. Yet very little is known about synchrony on features of vocal affect between mothers and their children beyond infancy or about characteristics of the child that might disrupt such processes. This thesis proposes callous-unemotional (CU) traits as one such characteristic due to impairments in emotion arousal and empathy that characterise this population.

Study 1 used a novel integrative paradigm of clinical psychological assessment, speech signal feature analysis, and the dynamic time series method of cointegration to test the hypothesis that synchrony of vocal affect is a prevalent phenomenon in the interactions of mothers and their children aged 4 to 8 years (M = 6.04; SD = 1.50). Studying a large number of vocal parameters in a large sample of dyads (N = 79 dyads; 66% male children), synchrony was found to be a widespread occurrence during mother-child emotion talk, and both mothers and their children demonstrated the capacity to influence each other's vocal qualities. However, its prevalence was dyad dependent.

As hypothesised, Study 2 found that callous-unemotional traits were associated with disruption to synchrony on a number of emotion relevant pitch and energy parameters, and these relationships were moderated by maternal characteristics. In contrast, child empathy demonstrated positive relationships with synchrony across a range of emotion relevant parameters. Oppositional Defiant Disorder (ODD), a diagnosis

primarily characterised by emotional and behavioural dysregulation, was not a predictor of disruption to synchrony.

Study 3 investigated vocal parameters associated with characteristics of the child and found that callous-unemotional children, but not their mothers, displayed substantial differences on two key parameters of vocal expression: a narrower pitch range and reduced listening time compared to their high empathy peers, findings that appear consistent with the restricted affect and impaired empathy in the CU construct. For mothers and their children with a diagnosis of ODD, the interactional system was characterised by high levels of mutual vocal arousal; together with the cointegration findings this suggests the presence of a feedback mechanism between the child's and the mother's vocal features.

Study 4 investigated vocal features associated with caregiving qualities of the mother. Lower pitch and intensity values by both the mother and child characterised observer-rated attuned conversations, with linguistic content and acoustic-prosodic parameters working together to optimise conveyance of this important caregiving quality. Attunement was beneficial in improving the proportion of talk time for all children, but was particularly notable in increasing the comparatively poor speaking time of high empathy children. There was no association between the mother's warmth or attunement and child CU traits, and these qualities did not moderate the shallower pitch range of high CU children. However the mother's dismissiveness was found to be particularly deleterious to the already compromised pitch range of high CU children.

This research is the first to demonstrate synchrony as a dynamic, bidirectional phenomenon prevalent across a large number of acoustic-prosodic parameters between mothers and their children, and to demonstrate the application of cointegration as a methodology to the study of acoustic-prosodic expression. It is the first study to show disruption to synchronous vocal processes — as well as other differences in vocal expression — for children with CU traits. The findings have implications for establishing the vocal channel as a bidirectional source of emotion contagion between mothers and their children, and for biobehavioural synchrony as a promising field of study for children with CU traits.

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This thesis is for Ella and Zachary.

And for Elisa Antonietta, whose voice is still my most memorable embodiment of warmth.

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CHAPTER 1: INTRODUCTION

1.1 Acoustic-prosodic synchrony in mother-child interactions

The voice has long been thought of as a cornerstone of emotional expression. It is a primal form of communication, observed ethologically since the nineteenth century as capable of rapidly conveying affective information between individuals within a species (Darwin, 1873). In human speech prosody is the element that carries this information reflexively, drawing on acoustic properties produced in the human vocal tract to communicate the speaker's emotional state through patterns of vocal stress and intonation (Juslin & Scherer, 2005). These patterns are suprasegmental in that they sit above language as a feature of the utterance other than consonantal and vocalic components (Stevenson, 2010), and together are referred to as *affective prosody*.

Pitch (fundamental frequency) and loudness (intensity or energy) are considered to be principal markers of affective prosody, however the contribution of other features that also arise from processes of articulation and phonation have gained increasing interest from researchers (e.g., Eyben et al, 2016; Patel, Scherer, Björkner & Sundberg, 2011). This wider group of features is broadly referred to as acoustic parameters, and includes measures such as the spectral distribution of energy in different frequency bands. Following the terminology of Levitan and Hirschberg (2011) and Lubold and Pon-Barry (2014), this thesis uses the integrated term *acoustic-prosodic* to refer to this larger group of vocal features.

Interpersonally, mothers and their infants, as well as adult dyads, display a phenomenon in their acoustic-prosodic expression known as synchrony. In child development, synchrony refers to a dyadic process involving "the matching of behaviour, affective states and biological rhythms between caregiver and child that together form a single relational unit" (Feldman, 2007a, p. 329). A related concept is mimicry, the phenomenon of unconscious or automatic imitation of nonverbal behaviours that has been observed across species (Ross, Menzler & Zimmermann, 2008; Yoon & Tennie, 2010). However where mimicry requires an immediate matching of behaviour within the same modality (van Baaren, Janssen, Chartrand & Dijksterhuis, 2009; Chartrand & Lakin, 2013), synchronous child-caregiver exchanges are typically observed across longer timeframes and can also occur between communication channels. Underpinned by the exchange of sensory, neural and hormonal signals during close contact (Feldman, 2017), synchrony is spontaneous and largely beyond conscious awareness (Hirsch, Zhang, Noah & Ono, 2017), and has been identified as a key mechanism in theories of emotion contagion (Chartrand & Lakin, 2013; Hatfield, Cacioppo, & Rapson, 1994; Parkinson, 2011; Prochazkova & Kret, 2017).

Despite the established role of biobehavioural synchrony in human communication, almost nothing is known about acoustic-prosodic synchrony between mothers and their children beyond the infant period, nor about the expression of vocal affect in those interactions more generally. Developmentally, these are key questions. Studies on biobehavioural synchrony with typically developing children and psychologically well mothers are consistently linked to positive outcomes, including child self-regulation (Davis, Bilms & Suveg, 2017) and empathy development (Feldman, 2007a; 2007b), and these prosocial associations are also apparent in adult relationships (Mogan, Fischer & Bulbulia, 2017; Rennung & Göritz, 2016).

Meanwhile, acoustic-prosodic features in adult speech have been increasingly identified as providing key markers of clinical conditions such as depression (Cummins et al, 2015a) and social anxiety (Laukka, Ahs, Furmark & Fredrikson, 2011). Clearly, understanding any mechanisms for the transmission of negative emotion or under or over-arousal between caregivers and children has important implications for child development

(Rutherford, Wallace, Laurent & Mayes, 2015). The construct of biobehavioural synchrony presents as a strong contender for such transmission.

Importantly, the presence of maternal psychopathology — particularly depression — is routinely associated with disruption to synchronous mother-child processes (e.g., Amole, Cyranowski, Wright & Swartz, 2017; Feldman, 2015a; Woody, Feurer, Sosoo, Hastings & Gibb, 2016), however it is notable that in a paradigm that increasingly views developmental processes as bidirectional (e.g., Combs-Ronto, Olson, Lunkenheimer & Sameroff, 2009; Feldman, 2015b; Fogel, 2011), few studies have examined what, if any, characteristics of the child may contribute to such disruption. This thesis proposes callous-unemotional (CU) traits as one such characteristic.

1.2 Acoustic-prosodic synchrony and child callous-unemotional traits

Callous-unemotional traits refer to a particular group of attributes, or a phenotype, in individuals who are under-emotional and show deficits in the affective component of empathy. They tend to exhibit intentional as well as reactive aggression, displaying cruel or uncaring behaviour toward others and limited feelings of guilt or concern for such conduct. While callous-unemotional traits are measured on a continuum and are present in individuals who do not clearly manifest disordered behaviour, in clinical settings they are typically observed in individuals with disruptive behaviour problems.

Most individuals with disruptive behaviour problems — of which the most prevalent diagnoses are Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD) — show difficulty in the regulation and expression of negative affect, particularly anger and irritable mood (American Psychiatric Association, 2013). They tend to be impulsive and largely reactive in their aggression but display levels of affective empathy similar to other adults

(Blair, 2013), although the findings are mixed in children (Lovett & Sheffield, 2007). In contrast, individuals in the smaller subgroup of these conditions with callous-unemotional traits are differentiated by problems in emotional under-arousal (Cheng, Hung & Decety, 2012) and in recognising distress cues from others (Dawel et al, 2012). Such responses have been associated with key differences in brain function, particularly a reduced reaction by the amygdala to distress cues, a finding referred to as the amygdala dysfunction hypothesis (Blair, 2013).

Notably, this high callous-unemotional group as a phenotype of conduct disordered behaviour is of particular clinical concern as it is associated with a range of poorer treatment outcomes, including a reduced treatment response (Frick, Ray, Thornton & Kahn, 2014) and more violence in a treatment context (White, Frick, Lawing & Bauer, 2013). Perhaps most conspicuously, callous-unemotional traits are also considered to be a defining characteristic of adult psychopathy, a condition with disproportionate social and interpersonal consequences linked to high levels of reactive and instrumental aggression (Blais, Solodukhin, & Forth, 2014; Fanti, Frick, & Georgiou, 2009).

Intriguingly, the shallowness of affective response and impaired empathy is in contrast to what is widely considered to be an intact capacity for individuals with such traits to cognitively appraise and respond to the emotions of others with learned social behaviours. This difference between the intellectual and the emotional experience of relationships was referred to in early literature on psychopathy as "the mask of sanity" (Cleckley, 1941/ 1988). This is a paradox that has been captured in more recent years in a metaphor by Blair et al (2006), following Johns & Quay (1962):

> Individuals with psychopathy do represent the lexical meaning of emotions, but they do not experience their affective value; they ''know the words but not the music'' (p. 114)

This thesis argues that biobehavioural synchrony offers a potential mechanistic pathway that might help to explain this apparent paradox. In particular, it is proposed that it is due to these key emotional and empathic deficits that children with callous-unemotional traits may be at particular risk for disruption to synchrony-related phenomena.

Beyond the key deficits in affective arousal and empathy that characterise the high callous-unemotional population, there is good reason to expect that disruption to acoustic-prosodic synchrony may be a sensitive marker for such traits. In addition to the established prosocial effects of synchrony in mother-child interactions, the ability to recognise emotion in prosodic expression has been positively associated with measures of empathy in non-clinical samples (Aziz-Zadeh, Sheng & Gheytanchi, 2010) as well as in clinical groups (Leigh et al, 2013).

Moreover, non-verbal synchronous processes are typically spontaneous and beyond conscious awareness, and therefore any disruption to such processes may be more difficult to mask. Further, accumulating evidence indicates that individuals with high CU traits show differences in their social-emotional features from an early age (e.g., Waller & Hyde, 2018; Viding, Frick & Plomin, 2007) and therefore disruption to synchronous processes may be more discernible during childhood when cognitive and self-regulation skills that might compensate for such deficits are still developing.

Notably, while affective impairments have been investigated in high callous-unemotional populations across a number of non-verbal modalities, such as facial expressions (Dawel, O'Kearney, McKone & Palermo, 2012) and eye contact (Dadds et al, 2014; Han Alders, Greening, Neufeld & Mitchell, 2012), surprisingly few studies have examined vocal affect in this cohort (Blair, Budhani, Colledge & Scott, 2005; Blair et al, 2002; Dawel et al, 2012; Mackenzie & Logan, 2014). Even fewer studies have examined its expression rather than recognition (Louth, Williamson, Alpert, Pouget & Hare, 1998), and none have examined synchronous processes of affective prosody.

1.3 Dynamic analytical approaches

In part, these gaps reflect the challenges faced by clinicians studying dynamic features in the human speech signal. Segmenting interactive speech with a high degree of accuracy across a large number of conversations is particularly labour intensive, while quantifying temporal shifts in affective prosody between speakers is challenging due to the multi-dimensional layers in the signal and its continuous nature. The limited number of studies in this field also tend to use statistical methodologies based on static rather than dynamic models, and have focused on a small number of dyads and a small number of prosodic features, primarily pitch and intensity (e.g., Ko, Seidl, Cristia, Reimchen & Soderstrom, 2016; Lubold & Pon-Barry, 2014). Such constraints have limited insights into the dynamic and reciprocal nature of this phenomenon, as well as understanding its prevalence across vocal parameters and across different child and maternal characteristics.

However, recent advances in methods and greater computing power now enable the extraction of a large range of acoustic-prosodic parameters from interactive speech. Meanwhile, shifts in conceptualising the dyad — rather than the individual — as a unit of analysis in psychological research (Butler, 2011; Cook & Kenny, 2005; Kashy & Kenny, 2000), and the rapid growth of statistical methods that can account for high dimensionality in the data (Adolphs, Nummenmaa, Todorov & Haxby, 2016; Kettenring, 2011), provide opportunities for the application of increasingly sophisticated approaches to studying prosodic expression as a dynamic interactive process (e.g., Barabási, 2012; Gates & Liu, 2016). In line with such methodological and theoretical developments, this thesis operationalises synchrony using the dynamic time series method of cointegration (Engle & Granger, 1987; Stroe-Kunold, Gruber, Stadnytska, Werner & Brosig, 2012). It will be argued that cointegration is an approach that is particularly well suited to capturing the reciprocal and adaptive relationship between each speaker's acoustic-prosodic values, qualities have been identified as inherent to the synchrony construct (Leclère et al, 2014).

Further, there are many unexamined questions about affective expression in the vocal channel for children with problems in their social and emotional functioning. Where reduced emotional arousal has been implicated in high callous-unemotional traits (Blair, 2013; Wright, Hill, Pickles & Sharp, 2019), the verbal interactions of children with Oppositional Defiant Disorder (ODD) are frequently marked as heightened and negativistic. It is possible that synchronous vocal affect in dyads with children with oppositional and defiant behaviours may operate as a mutual and maintaining factor for cycles of negative affectivity, and thus serve as a barrier to more effective parent management of these interactions.

At the same time, there is also increasing consensus that caregiving qualities can function to moderate the severity of both conduct problems and callous-unemotional traits in children (Waller et al, 2015; Pasalich, Dadds, Hawes & Brennan, 2011). In particular, parental warmth has been identified as an interactional quality that has been shown to be particularly important in attenuating problematic behaviours in children with these characteristics. Yet objective markers for the expression of caregiver warmth in this primal communicative channel have not been studied.

To examine these important questions, this thesis uses an integrated approach of psychological assessment, speech signal feature extraction, and cointegration analysis to investigate the vocal qualities of children aged 4 to 8 years and their mothers in an emotion reminiscing task. This thesis proposes that the synchrony construct, and this novel integrative paradigm, have the potential to provide new insights into the nature of affective communication for children at risk of serious impairments in the development of their social and emotional functioning.

1.4 Research questions

Based on the literature relating to the separate research streams of mother-child synchrony, callous-unemotional traits, and affective prosody, this thesis investigates four main questions: 1) is there evidence for cointegration of acoustic-prosodic features between mothers and their children aged 4 to 8 years; 2) are callous-unemotional traits associated with disruption to cointegration on emotion relevant vocal features during a mother-child emotion reminiscing task; 3) do children with callous-unemotional traits display other differences in their vocal expression; and 4) which acoustic-prosodic features are associated with the mother's caregiving qualities and with the mother's mental health.

1.5 Thesis structure

This thesis has 8 chapters. Chapter 2 (Literature Review) establishes the theoretical and empirical background for the research questions and is divided into four main sections: a theoretical overview of biobehavioural synchrony in mother-child interactions; an overview of the literature relating to callous-unemotional traits and deficits in affect and empathy; an outline of the literature relating to affective prosody in caregiving relationships and also to prosodic synchrony; and a summary and rationale regarding the analytical approach of cointegration.

Chapter 3 (Method) details the empirical approach and the methods used in the research. It outlines the nature of the participants under study, the psychological measures used, the empirical methods employed to conduct acoustic-prosodic feature extraction, and steps in the analytical approach used to examine the research questions.

Chapter 4 (Study 1) reports the results relating to cointegration of acoustic-prosodic features between mothers and their children engaged in a conversation about the child's emotional experiences. Chapter 5 (Study 2) reports the findings relating to cointegration and child callous-unemotional traits, and comparative results for children high in empathy and for children with a diagnosis of Oppositional Defiant Disorder (ODD).

Chapter 6 (Study 3) investigates acoustic-prosodic features associated with characteristics of the child. Specifically, this study compares the emotion talk of four groups of children: children with high callous-unemotional traits, children with high prosocial traits, children with ODD, and children with a high level of emotion regulation. Separate study was made of both the child's and the mother's acoustic-prosodic features due to the relevance of each speaker's features to the synchrony construct.

Chapter 7 (Study 4) investigates acoustic-prosodic features associated with characteristics of the mother. Specifically, this study examines vocal features associated with warmth in the mother's voice and with the relational qualities of the interaction (warmth, attunement, and dismissiveness). Study 4 further examines the effect of these relational qualities on key vocal parameters that were identified in Study 3 in the speech of children with high callous-unemotional traits, and in the speech of children with a diagnosis of ODD. Finally, Study 4 also reports on acoustic-prosodic features associated with mental health characteristics of the mother due to their demonstrated relationship with vocal affect expression.

Chapter 8 summarises and integrates the findings of the empirical chapters. It outlines the significance of the work and the theoretical and clinical implications. The chapter discusses the implications for the vocal channel as a source of emotion contagion between mothers and their children, particularly for those groups of children with high callous-unemotional traits or for groups with a diagnosis of ODD. Chapter 8 also discusses the limitations of the research and the remaining questions, and provides the conclusion for the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Chapter outline

This chapter establishes the theoretical background and context for the research questions. It is divided into four main sections: a theoretical overview of biobehavioural synchrony in mother-child interactions; a summary of affective deficits and parental warmth in callous-unemotional (CU) traits; a review of the literature relating to affective prosody and acoustic-prosodic synchrony; and an outline of the literature relating to cointegration as an empirical approach.

2.2 Bio-behavioural synchrony in mother-child interactions

From birth, nonverbal communication is critical to the development of the social brain, and the nature of that communication matters. In early childhood sensitive and attuned caregiver responses are conveyed through modalities such as touch, eye contact, facial expression and the caregiver's tone of voice, and these nonverbal responses have been shown to regulate the child's micro-processes of affect in ways that have positive and cascading effects on emotional and behavioural regulation over the lifespan (Bowlby, 1958; Ostlund, Measelle, Laurent, Conradt & Ablow, 2017; Schore, 2005; Schore & Schore, 2008). These responses are typically viewed as contingent on anticipating and responding to the child's emotional needs within a sufficient temporal envelope in ways that are active and largely intentional by the caregiver (Meins, 2013; Slade, 2005).

Yet mothers and their children have also been demonstrated to reciprocally influence each other's non-verbal behavioural displays (e.g., gaze, gestures, vocalisations) and dynamic physiological reactivity (e.g., heart rate, neural patterns, hormone expression) in processes that are automatic and beyond conscious awareness (Davis, West, Bilms, Morelen & Suveg, 2018; Feldman, 2007c; Feldman, 2015b; Levy, Goldstein & Feldman, 2017; Waters, West & Mendes, 2014). A rapidly expanding psychological and neuroscientific literature indicates that a proximal mechanism through which these spontaneous effects occur is biobehavioural synchrony (Atzil, Hendler & Feldman, 2014; Feldman, 2007a; Feldman, 2017; Kühn et al, 2011; Leclère et al, 2014).

2.2.1 Definitions

In close human relationships synchrony refers to "the coordination of biological and behavioural processes between attachment partners during social contact" (Feldman, 2017, p. 81). Central to this description, a number of key biological mechanisms are considered to underpin synchronous behavioural processes. This includes the neuroendocrine system, which demonstrates synchronous expression of the bonding hormone oxytocin during periods of mother-child affection (Feldman, 2015a; Feldman, 2012) as well as cortisol synchrony between mothers and their children during periods of stress and anxiety (Pratt et al, 2017; Williams et al, 2013). It also includes evidence in brain regions showing neural synchrony between caregivers and their young children, such as that seen in the dorsolateral prefrontal and frontopolar cortex during co-operative tasks (Reindl, Gerloff, Scharke & Konrad, 2018). A further example includes the synchronous pattern of mother-infant cardiac rhythms observed during episodes of vocal and affect synchrony (Feldman, Magori-Cohen, Galili, Singer & Louzoun, 2011).

It is also important to note that while synchronous behavioural exchanges can be multi-modal, for example occurring in a dynamic interplay between gesture and vocalisation (Harrist & Waugh, 2002), it has been observed that symmetry tends to predominate within the same expressive channel as the child achieves greater equality in communicative skill (Leclère et al, 2014). The defining characteristic of synchrony is considered to be the timing, specifically a temporal pairing of interacting variables within a system (Feldman, 2007a; Feldman, 2017), and it is for this key reason that synchronous biobehavioural processes have been described as analogous to a "dance" (Feldman, 2007a).

Critically, a recent systematic review by Leclère et al (2014) of 63 studies relevant to mother-child synchrony further elucidated the temporal nature of synchronous interactions. Observing adaptive and bidirectional elements in their findings, the authors expand on earlier definitions, which tended to use temporal terms such as "matching" (e.g., Feldman, 2007a, p. 329), by defining synchrony as "a dynamic and reciprocal adaptation of the temporal structure of behaviours and shared affect between interactive partners" (Leclère et al, 2014, p. 1). Thus, methodologies assessing synchrony should optimally account for these interactive and adaptive qualities.

2.2.2 Importance of mother-child synchrony in caregiving relationships

The importance of close and repeated patterns of interaction over time with caregiving figures seems to be a defining feature of synchrony in infancy (Harrist & Waugh, 2002). Early work by Bernieri, Reznick and Rosenthal (1988) identified high levels of genuine behavioural synchrony occurring between mothers and their 14-month-old children however this finding did not hold true when mothers interacted with unfamiliar children. In fact, those interactions showed significantly lower levels of synchrony compared to the levels expected due to randomness, a finding the researchers termed dis-synchrony. Supporting such differentiation, brain imaging has found differences in neural synchrony between children and strangers compared to parent-child dyads (e.g., Reindl, Gerloff, Scharke & Konrad, 2018), while Feldman, Bamberger and Kanat-Maymon (2013) found that biobehavioural synchrony with children differs between mothers and fathers, and thus appears to be dyad dependent.

2.2.3 *Early childhood and mother-child synchrony*

Early childhood is defined by the World Health Organization as the developmental window that occurs from ages 0-8 years (World Health Organization, 2018). Indeed, while the majority of studies on caregiver-child synchrony have been observed to relate to mother-infant relationships (Harrist & Waugh, 2002; Leclère et al , 2014), the significance of the synchrony phenomenon does not appear to decline as the child ages. In their early review Harrist and Waugh (2002) identified a trend toward increasing balance in the initiation and maintenance of synchrony as the child develops into childhood. More recently, Davis et al (2017) found in their meta-analysis inclusive of children up to 10 years old that age was an important mediator in the positive relationship between parent-child synchrony and child behavioural and emotion regulation. The relationship between these qualities was observed to be strongest when parent-child synchrony was measured at 24-48 months and self-regulation was measured at 48-67 months (Davis et al, 2017). Therefore the developmental period following infancy presents as a significant and under-studied window for synchrony-related phenomena.

2.2.4 *Prosocial benefits of mother-child synchrony*

Synchronous exchanges in the interactions of typically developing children and psychologically well mothers have been consistently associated with positive child outcomes. Mother-child synchrony in early childhood has been linked to lower levels of child aggression (e.g., Ambrose & Menna, 2013), fewer externalising problems (Woltering, Lishak, Elliott, Ferraro & Granic, 2015), higher levels of child communicative competence and self-controlled behaviour (Lindsey, Cremeens, Colwell & Caldera, 2009), and greater peer-rated social competence (e.g., Harrist, Pettit, Dodge & Bates, 1994). Higher mother-child synchrony has also been associated with improved functioning in 3-4 year old children with hyperactive and inattention problems (Healey, Gopin, Grossman, Campbell & Halperin, 2010), and has been positively associated with higher levels of child language skills and maternal caring of boys aged 17 to 27 months who were at risk of conduct problems (Skuban, Shaw, Gardner, Supplee & Nichols, 2006).

In a longitudinal study mother-infant synchrony was shown to predict higher empathy levels from infancy through to early adolescence (Feldman, 2007a). Such findings are also consistent with a recent meta-analysis of non-clinical samples aged from early adolescence through adulthood which found widespread evidence for positive relationships between behavioural synchrony and prosocial behaviour and bonding (Mogan et al, 2017). In sum, synchrony in development has been associated with close caregiver relationships and with prosocial behaviour in the child, and these findings suggest a positive role for synchrony in the development of child empathy and self-regulatory functions, maintaining equilibrium within the child as well as within the dyad.

2.2.5 Disruptions to mother-child synchrony

Not all mother-child dyads synchronise on the same communicative features or to the same degree. A recurring observation in the biobehavioural literature is that the capacity for synchrony within the dyad is influenced by the psychological health of the mother. In particular, the presence of a high level of maternal psychological distress or depression have been repeatedly associated with disruptions to mother-child biobehavioural synchrony (Amole et al, 2017; Feldman, 2007a; Feldman et al, 2009; Woody et al, 2016). For example, depressed mothers and their infants experience fewer and shorter periods of gaze synchrony (Feldman, 2007c; Granat, Gadassi, Gilboa-Schechtman, & Feldman, 2017), which may be mediated by the mother's capacity for emotion regulation (Lotzin et al, 2015).

It is possible that disruptions to synchronous processes in the presence of such maternal risk factors may in fact be adaptive (Suveg, Shaffer & Davis, 2016). For example, a cycle of reciprocal regulatory problems has been observed between some highly depressed mothers and their children (Gross, Shaw, Moilanen, Dishion & Wilson, 2008; Weinberg, Olson, Beeghly & Tronick, 2006), and the presence of physiological synchrony in contexts with high family stress has been found to confer risk for poor self-regulation in the developing child (Suveg et al, 2016).

It is the temporal relationships observed in the physiology, emotions and behaviour of mothers and their children — and between individuals in even short term exchanges (Chartrand & Lakin, 2013; Hatfield et al, 1994; Hatfield, Rapson & Le, 2009; Parkinson, 2011; Prochazkova & Kret, 2017) — that has seen the synchrony construct placed as a central candidate in theories of emotion contagion. For example, Hatfield et al (2009) propose that emotional experience is triggered by synchrony of automatic non-verbal cues such as vocal or facial expression maintained through feedback processes between individuals. In this way, disruptions to mother-child synchrony may theoretically provide protection against the transfer of emotion dysregulation from parent to child.

This does however leave significant questions in relation to the effect of such disruptions on child prosocial behaviour and empathy development. Further, in a bidirectional model such disruptions are likely driven not only by maternal but also child factors, however only a few studies have examined which, if any, psychological characteristics of the developing child might be implicated. In one such study, parent rated physical aggression in 3-6 year old children was positively associated with disruption to mother-child interactional synchrony in a free play task (Ambrose & Menna, 2013), while Healey et al (2010) found that in children with hyperactive and inattentive problems, poorer global child functioning was associated with lower levels of mother-child synchrony above and beyond severity of their hyperactive and inattentive symptoms. Child gender was not related to the level of mother-child synchrony in either of these studies, suggesting that child sex differences are not significant in the relationship between conduct problems and mother-child synchrony in this age cohort.

In terms of social functioning, autism has been observed as another child characteristic associated with disruption to parent-child synchrony from early-middle childhood (Trevarthen & Daniel, 2005). Baker et al (2015) found that the level of autism symptoms in children aged 4-10 years moderated the relationship between parent-child electrodermal synchrony in a free play task, while Fenning et al (2017) found that this was not influenced by intellectual functioning, leading the authors to propose that the tendency toward sympathetic arousal may therefore be an important factor in parent-child synchrony. While the scattered findings suggest that many questions remain about features of the child that might impact on parent-child synchrony during development, the prosocial outcomes that have been associated with this phenomenon render callous-unemotional traits a prime characteristic of interest.

2.3 Callous-unemotional (CU) trait and deficits in affect and empathy

2.3.1 Disruptive behaviour disorders and callous-unemotional (CU) traits

Disruptive behaviour disorders are defined by behaviours that violate the rights of others and/ or bring individuals into significant conflict with authority figures or with social norms (American Psychiatric Association, 2013). Although disruptive behaviour is common in childhood, it is the intensity of the behaviour that distinguishes disordered groups from typically developing children (Hong, Tillman & Luby,Chacko, 2015). Childhood disruptive behaviour disorders are of clinical importance as they show significant reciprocal relationships to distress in caregivers (e.g., Gross et al, 2008) and a prime reason for child referral to youth mental health services (Chacko et al, 2015; Wu et al, 1999). They are also an important target for intervention in childhood as the presence of a disruptive disorder is a risk marker for the development of later psychopathology, including depression (Wolff & Ollendick, 2006) and substance abuse (Neumann & Hare, 2008).

Moreover, a particular subgroup of children with disruptive behaviour problems, those with callous-unemotional (CU) traits, have been identified as being at greater of risk of developing serious forms of antisocial conduct compared to their low callous-unemotional disruptive peers (Frick & White, 2008) and are also considered to be the most difficult to treat (Hawes & Dadds, 2005; 2007). The Diagnostic and Statistical Manual (DSM-V; American Psychiatric Association, 2013) differentiates the high CU group using the specifier "with limited prosocial emotions" as it applies to Conduct Disorder. The four DSM-V criteria for this specifier are a lack of remorse or guilt, callousness or lack of empathy, a lack of concern about performance, and shallow or deficient affect. These criteria broadly align with the affective and empathic qualities of adult psychopathy (Hare & Neumann, 2008), and thus callous-unemotional traits are considered to be a defining characteristic of the psychopathic condition.

2.3.2 Deficits in affective arousal and affective empathy

Specific components of affect and empathy appear to be affected in individuals displaying callous-unemotional traits. Studies increasingly identify attenuated emotional arousal in individuals with high psychopathic traits in response to pain and fear in others (see

Blair, 2013 for a review; Brislin et al, 2018; Dawel, Wright, Dumbleton & McKone, 2019; Decety, Chen, Harenski & Kiehl, 2013) as well as deficits in recognising non-verbal emotional communication, including facial expressions and vocal qualities (Dawel et al, 2012). A number of studies suggest that these key deficits extend down to at least the teenage years, and possibly much earlier (White et al, 2016). For example, studies by Cheng, Hung & Decety (2012), Sebastian et al (2012), and Yoder, Lahey & Decety (2016) found that high CU conduct disordered teenagers displayed atypical neurological responses and connections when viewing others in pain compared to typically developing and low CU conduct disordered teens, including in the early stage of affective arousal.

A growing body of evidence indicates that these affective and empathic deficits are underpinned by biological and neurocognitive vulnerabilities that are present from birth (Mills-Koonce et al, 2015; Viding & McCrory, 2012). In particular, a number of studies using large twin cohorts signal the presence of genetic influences (e.g., Fontaine, Rijsdijk, McCrory & Viding, 2010; Viding, Frick & Plomin, 2007) while a recent adoptive study (Hyde et al, 2016) found that children born to high callous-unemotional mothers but adopted by other mothers at birth still showed callous-unemotional traits at 27 months of age. Together such findings strengthen the view that callous-unemotional traits have a high component of heritability.

In parallel with these developments in understanding vulnerabilities in the callous-unemotional population, brain imaging studies across the last decade have led to a more fine-tuned understanding of the empathy construct. Based on such research, Decety (2010) and Decety and Svetlova (2012) have proposed an integrative evolutionary model in which affective arousal is one of a “patchwork” of key empathic components, which also includes cognitive empathy and emotion regulation. As one of these key components of empathy, affective arousal is considered to develop from an imitative or synchronous exchange between oneself and others, located in mechanisms of mimicry and motor reasoning that are shared with other mammalian species (Decety & Svetlova, 2012).

Consistent with this component model, the premotor cortex involved in the mirror neuron system has been found to be more engaged in the presence of affective empathy than cognitive empathy (Nummenmaa, Hirvonen, Parkkola & Hietanen, 2008), and direct exposure to another's affective state, such as an emotional facial expression or an emotional tone of voice, has been shown to be sufficient to elicit spontaneous, bottom up autonomic affect sharing in a kind of "contagious" effect (de Waal & Preston, 2017; Nummenmaa et al, 2008; Preston & de Waal, 2002). It is this affect sharing component that is thought to provide at least some of the motivation to respond to the distress of others (Decety, 2010; Decety & Meyer, 2008).

However it is likely that this capacity for affect sharing does not always involve positive outcomes. For example, it has been argued that emotional over-arousal has the clear potential to result in an empathic individual becoming overwhelmed or avoidant of another's distress (Singer & Lamm, 2009). Given the multi-dimensional nature of the empathy construct, it is considered that the phylogenetically earlier capacity for shared emotional arousal should reciprocally interact with higher-level cognitive abilities and effective self-regulation in order to respond to the needs of others in prosocial ways (Decety & Svetlova, 2012; for an overview see also Zaki & Ochsner, 2012). For an optimal empathic response, this patchwork of empathic processes ideally becomes integrated throughout development (Decety & Meyer, 2008).

Intriguingly, while individuals with high callous-unemotional traits are more likely to have a diagnosis of conduct disorder and more severe conduct problems, researchers have found that many individuals with callous-unemotional traits do not display clear evidence of such problems, with high callous-unemotional traits present in community samples (Ray &

Frick, 2018; Gao & Zhang, 2016; Wall, Frick, Fanti, Kimonis & Lordos, 2016). Further, it appears that callous-unemotional traits, and the severity of any associated anti-social behaviour, are responsive to environmental influences during key developmental periods (Hawes & Dadds, 2007; Waller, Baskin-Sommers & Hyde, 2018). In explaining this apparent multi-finality, parenting behaviour presents as a promising, potentially modifiable factor. Parental warmth has emerged as one such factor.

2.3.3 Callous-unemotional traits and parental warmth

In child psychopathology, evidence increasingly stresses the importance of warmth in the parent-child relationship for lessening externalising problems (Deater-Deckard et al, 2006; von Suchodoletz et al, 2011) and for the development of child regulatory abilities (Pasalich et al, 2011) and empathy (Zhou et al, 2002). In particular, children with callous-unemotional traits appear to be particularly vulnerable to experiencing declining levels of warmth in early childhood. A review by Waller, Gardner and Hyde (2013) examined 30 longitudinal and intervention studies that investigated relationships between callous-unemotional traits, parenting, and anti-social behaviour, and identified a strong prospective association between increases in callous-unemotional traits and a lack of markers associated with warm parenting. Importantly, that review also identified evidence for a bidirectional effect, with a parenting style that is supportive and responsive thought to be protective against problematic behaviour in the high CU cohort.

For example, Pardini, Lochman and Powell (2007) found that high parental warmth as reported by the child was associated with a reduction in callous-unemotional traits within one year, while Waller et al (2014) found that a parent's level of warmth and child callous-unemotional behaviours were reciprocally related. In that study, high callous-unemotional behaviour at age two was associated with a decrease in parental warmth at age three, and low parental warmth at age two associated with an increase in callous-unemotional behaviour at age three. More recently, Hyde et al (2016) found that positive reinforcement by mothers who adopted high CU children attenuated the expression of the child's high callous-unemotional traits; this relationship was dose-dependent, with high warmth parenting completely ameliorating callous-unemotional behaviours in that sample. Indeed, Waller and Hyde (2017) has argued for the term callous-unemotional *behaviours* rather than callous-unemotional *traits* for the cohort in very early childhood, in recognition of the malleability and variable course of this clinical feature in very young children.

2.3.4 Warmth as a relational construct

Warmth is a relational quality of communication that has been broadly defined as "verbal and non-verbal signals of interest, caring, and kindness that are soothing" (Gilbert, 2010, p. 54). While there is no clearly agreed definition in the developmental literature, warmth as a construct has been associated with ideas of soothing and tenderness in parent-child relationships for over half a century (Baumrind, 1965; Becker, 1964). As a quality of caregiving it appears to be particularly important across human development (Guy et al, 2016), and is frequently used alongside attachment related concepts such as sensitivity and attunement (e.g., Legerstee et al, 2007).

However, these are in fact differentiated concepts. Mary Ainsworth began to tease apart these ideas when she observed the presence of sensitivity but not warmth in Ugandan maternal care of infants (Ainsworth, 1967; Ainsworth et al, 1974). Since then, MacDonald (1992) and MacDonald et al (2016) have observed from an evolutionary perspective that maintaining contact and protection from caregivers in moments of fear or anxiety is seen in almost all mammals in naturalistic settings but that tender and warm interactions are not. They suggested that warmth is distinct from the attachment construct and reflect two separate biological systems, being the reward system and threat system respectively. In such a context, it may be that warmth is an aspect of caregiving that contributes over the longer term to *optimal* — but not essential — functioning in social groups, such as through the maintenance of pleasurable or harmonious relationships.

A large population based Australian study (Guy et al, 2016) indicates that children across all ages are at risk of low parental warmth, but that a developmental trajectory appears present. One in ten infants experience low warmth parenting, rising to one in three by the time a child is 12-13 years old. This trajectory aligns with increasing autonomy by the child and suggests the prospect of reciprocal influences that may be associated not only with parental expectations given the child's age but also with the child's emerging personality characteristics.

The period of early childhood appears to be a particularly important time for intervening with children at risk of conduct problems. Conduct problems have been found to show substantial stability from middle childhood (e.g., Denham et al, 2000), and onset of symptoms that meet full criteria for conduct disorder usually occurs before puberty (American Psychiatric Association, 2013). Childhood onset of conduct disorder is also more likely to have persistent symptoms into adulthood compared to those with adolescent onset (American Psychiatric Association, 2013), and interventions prior to adolescence appear to be more effective than when older (Webster-Stratton et al, 2008). Better elucidating the markers of caregiver qualities that may have the potential to influence the trajectory of conduct problems in early childhood therefore presents as an important concern.

2.3.5 Vocal warmth

In parent-child communication, warmth has been predominantly measured by content markers, such as statements containing affection for the child (e.g., Polcari et al, 2014).

However warmth as a relational quality is also conveyed in nonverbal cues, such as smiling (Oveis et al, 2009) and voice tone (Oleszkiewicz et al, 2017). A small number of perceptual rating systems seek to capture the listener's impression of warmth subjectively through rating vocal qualities. A prominent example includes the Preschool Five Minute Speech Sample (PFMSS) (Daley et al, 2003), which requires listeners to rate the content of the caregiver's monologue about the child, including the tone of voice used when describing the child. In adult samples, an established measure of conversational involvement rates warmth in the vocal qualities of adults engaged in an interaction (Coker, 1987). Despite such measures, no known empirical work has attempted to validate the rating scales using objective measurements in parent-child samples. The most objective measurement is contained in the speech signal itself, specifically, in parameters of affective prosody.

2.4 Affective prosody

In the vocal channel, the patterns of stress and intonation in speech are defined as prosody (Stevenson, 2010). Prosody draws on acoustic properties produced in the human vocal tract, such as fundamental frequency (pitch) and intensity (loudness), to convey linguistic functions, such as whether the speaker is asking a question or making a statement (Raithel & Hielscher-Fastabend, 2004). Prosody is also the component of speech that spontaneously communicates the affective state of the speaker and the emotional tone of that communication (Grandjean et al, 2006), and it is this component that is referred to as *affective (or emotional) prosody*.

2.4.1 Vocal affect

Affective prosody is an evolutionarily old form of communication in which both affective state and emotions are rapidly conveyed in speech with a reasonably high degree of accuracy, irrespective of the content of that speech (Scherer et al, 2015). This efficiency is underpinned by the biological mechanisms shared between affective arousal and speech production. Such mechanisms include processes of respiration (Scherer et al, 2003), salivation (Pollermann & Archinard, 2002), and the vagus nerve (Porges, 2007), known as the primary nerve in the parasympathetic nervous system that has branches innervating the heart, lungs, stomach, and larynx.

This tight coupling is thought to be phylogenetically driven by the need to instinctively transfer salient information about the emotional state or intent of the speaker. For example, vocal affect that conveys fear signals the presence of a threat, anger as a warning, and tenderness as being safe to come close (Calvo et al, 2015). In this way, vocalisations are therefore considered as a fast acting social signal linked to survival. Such speed is likely critical in situations in which eye contact or facial expressions are reduced; in an evolutionary context, such situations might include in the dark or across distances. Even without visual constraints, vocal affect has been shown to contribute in essential ways to the accuracy of multi-modal information processing, particularly facial expressions (Baart & Vroomen, 2018; Hyde et al, 2011; Rigoulot & Pell, 2014), and is therefore a principal component of emotion processing.

The capacity to recognise and respond to vocal affect arrives early. Hearing and prosodic related neural systems develop prenatally (Abboub et al, 2016), with the pattern of newborn crying thought to be shaped by the child's native language (Mampe et al, 2009). Such early auditory functioning appears well suited to the priming of salient survival information. Newborn infants recognise their mother's voice compared to a stranger's voice (Beauchemin et al, 2011), and Grossmann et al (2010) observed that voice-sensitive regions in the right temporal cortex show increased activity as infants listened to speech with angry or happy intonation.

The researchers argued that this modulation of brain activity by prosodic signals is a critical mechanism to prioritise the processing of significant emotional stimuli in the environment. This hypothesis is supported by a novel brain imaging analysis of 6 to 12 month old sleeping infants, which demonstrated a relationship between an emotional tone of voice (i.e., anger) and reactivity of stress related brain areas in infants from high conflict homes (Graham et al, 2013). Older children (mean age 10.2 years) also display neural excitement associated with their mother's voice, and not with the voices of other women, in the areas of the brain essential for the processing of affect (Abrams et al, 2016).

2.4.2 Acoustic-prosodic parameters

Importantly, the relative location of acoustic-prosodic values in the vocal channel are consistently associated with certain emotions (Banse & Scherer, 1996; Juslin & Scherer, 2005). For example, low mean pitch levels are associated with the vocal emotions of sadness and tenderness, while high mean pitch is frequently aligned with the vocal emotions of anger and fear (Juslin & Scherer, 2005). However, analyses relating to a single vocal parameter are insufficient to categorise vocal emotion. Rather, they are represented by the patterns of relationships between multiple parameters. For example, the emotions of anger and fear are both also characterised by a high mean pitch and high voice intensity, but anger has a high degree of pitch variability whereas fear has a low degree of pitch variability (Juslin & Laukka, 2003).

An important meta-analysis by Juslin and Laukka (2003) identified 5 basic emotion categories identifiable by such patterns in both speech and music: anger, fear, sadness, happiness and tenderness. Prosodic features associated with the tenderness profile include low voice intensity (loudness) and a small amount of loudness variability, a low pitch level and a small amount of pitch variability, little high frequency energy, slow speech rate, and micro-structural regularity (Juslin & Laukka, 2003; Juslin & Scherer, 2005). In contrast, the anger profile is characterised by a profile of high mean intensity, a high amount of intensity variability, a high amount of high-frequency energy, fast speech rate, high mean pitch and a high amount of pitch variability, a rising pitch contour, and microstructural irregularity (Juslin & Laukka, 2003). In a more general sense, emotionally stressed speech is characterised by increases in both pitch and intensity (loudness) (Giddens et al, 2013), but with the range of those cues being typically narrower (Paulmann et al, 2016).

Interest in the study of such parameters and their relevance to clinical conditions has grown rapidly in recent years These studies suggest that deficits in aspects of affective prosody are important behavioural markers in clinical presentations such as depression and suicidality (Cummins et al, 2015), social phobia and trait anxiety (Pell et al, 2015), schizophrenia (Compton et al, 2018; Martínez-Sánchez et al, 2015), and autism (Charpentier et al, 2018; Lindström et al, 2018). Therefore it also seems that the affective markers of speech serve as a secondary signal of other primary processes, for example, the effects of psychomotor retardation in depression (Cummins et al, 2015). Commensurate with advances in speech signal methods, researchers are turning greater attention to examining markers of vocal affect expression for psychological conditions, and the field remains open for a better understanding its potential relevance to a wider range of clinical concerns.

2.4.3 Vocal affect and callous-unemotional traits

There have been no studies on the expression of vocal affect in children with callous-unemotional traits. However a small number of studies examining psychopathy in adulthood have found differences related to either prosodic expression or perception. Louth et al (1998) measured variations in amplitude and prosody in male psychopaths and found that psychopathic offenders spoke more quietly than non-psychopathic offenders and that their expressive prosody did not vary between neutral and affective words. Blair et al (2002) conducted a study with an incarcerated sample who listened to spoken words with neutral semantic content and varying affective prosody representing five emotions (happy, sad, angry, fear, and disgust), and were required to accurately categorise the emotion represented in the prosody of each word. Psychopaths demonstrated a higher error rate for categorisation of fearful prosody than non-psychopaths, but no group differences were observed for the other emotion categories.

Similarly, a meta-analysis by Dawel et al (2012) found that individuals with clinically significant psychopathy displayed poorer ability to identify emotion in the voice of others compared to non-psychopathic individuals. Overall the 6 vocal affect studies in the meta-analysis found support for the amygdala dysfunction hypothesis. Following that meta-analysis, Mackenzie and Logan (2014) also found that high scoring psychopathic individuals showed poorer ability to accurately identify affective prosody consistently across all emotion categories, and that adults with more psychopathic characteristics were less accurate at identifying emotion in word-length stimuli compared to those with fewer psychopathic characteristics.

Other studies have measured the response of psychopathic participants to auditory emotional stimuli and have also found evidence for these more generalised deficits in the processing of emotional speech. Bagley et al (2009) studied 107 incarcerated inmates and found that, under conditions requiring use of both semantic and prosodic cues, incarcerated male psychopaths displayed impairments in vocal affect recognition. In a study by Vassileva et al (2005) groups scoring highly on measures of psychopathy displayed deficits in the semantic condition compared to non-psychopathic participants across emotions such as sadness, happiness, surprise, and fear.

Primary psychopaths, identified as those with higher psychopathy scores but lower anxiety and substance use problems, exhibited impairment in recognising prosodic affect compared to those with fewer psychopathic features but higher anxiety and substance dependence, as well as compared to the non-psychopathic criminals. Interestingly, primary psychopaths also displayed impairment in correctly classifying neutral speech based on prosodic cues alone. The researchers concluded that the deficits in vocal affect recognition in their study are consistent with the theory that psychopaths are characterised by an overall deficiency in processing affective cues. Again, adults with only some psychopathic features did not demonstrate notable impairments in the recognition of vocal affect, which led the authors to suggest that the prosodic impairments displayed in these groups may be linked to particular features of the psychopathic phenotype, particularly those related to primary psychopathy (Bagley et al, 2009).

2.4.4 Affective prosody and empathy

Prosodic ability has also been correlated with deficits in affective empathy in other clinical and community samples. Leigh et al (2013) found in their study of acute brain lesions that patients with impaired affective empathy displayed significant deficits in the comprehension of affective prosody, compared to lesion patients with normal affective empathy. The researchers suggested that the capacity to recognise affective prosody may be a prerequisite for developing affective empathy, but was not necessarily required to make cognitive inferences about others' emotions.

Gazzola, Aziz-Zadeh and Keysers (2006) investigated the relationship between empathy and elements of the prosodic mirror neuron system using fMRI techniques and found evidence for an auditory mirror neuron system that was associated with higher scores on an empathy scale. This study was followed by Aziz-Zadeh, Sheng, and Gheytanchi (2010) who identified that these higher scores on empathy were associated with greater premotor activity in areas related to the perception and production of prosody during affective prosody perception, such as the premotor cortex. These areas were less active however during neutral prosody. They concluded that highly empathetic individuals may mentally simulate how to produce the perceived intonation themselves, leading to greater feelings of empathy for the other.

Consistent with this, Gheytanchi (2008) found a positive predictive relationship between self-reported empathy to high levels of distress in others and accuracy in a task of affective prosody perception in a sample of students. In terms of emotion recognition, Goerlich-Dobre et al (2014) examined the association between poor awareness and recognition of emotions (alexithymia) and prosody perception using functional magnetic resonance imaging (fMRI) and found a relationship between high alexithymia scores and reduced brain activity in the regions of interest for both affective prosody (i.e., angry and surprised) and neutral prosody. Taken together, these findings imply that the relationships between empathy, emotion recognition and processes of affective prosody warrant further study.

2.4.5 Acoustic-prosodic expression in a caregiving context

The expression and recognition of affective prosody plays a vital role in human development. Cross-culturally, parents display a characteristic form of prosody when interacting with their infants in a field of study known as "parentese" or "infant-directed speech" (IDS) (e.g., Saint-Georges et al, 2013). Infant directed speech is characterised by exaggerated prosodic features that are thought to function to regulate infant arousal and attention, enhance the expression of positive affect, and assist the development of language skills (Spinelli et al, 2017). Typically, this infant directed speech includes a profile of higher pitch, slower tempo, greater rhythm, elongated vowels (Miall & Dissanayake, 2003), and exaggerated contours (up/down patterns of pitch change) (Trainor & Desjardins, 2002), but the pattern of relationships varies depending on context. For example, mothers tend to use a lower average pitch and fewer rising pitch contours (compared to those used in yes/no questions) when trying to comfort a crying infant (e.g., Papoušek, 1991).

These prosodic features in infant-directed speech are thought to relay emotional information from the caregiver to the infant (Trainor et al, 2000) but there is also evidence for a bidirectional relationship. Specifically, it has been observed that infant-directed speech is followed by significantly more infant vocalisations than when engaged in other types of speech (Fernald, 1985). However there is also asymmetry in this dynamic. Van Puyvelde et al (2010) found that mothers matched their infant's pitch only half as much as the child matched the mother's pitch; these tones were displayed dyads in almost 75% of cases, leading the authors to suggest that the child's pitch imitations may be serving as a basis for the child's psychophysiological attunement.

Conspicuously however, few studies have examined interactive processes of acoustic-prosodic expression as they evolve in the caregiving relationship in the period beyond infancy, and those that have focus on a small number of prosodic parameters in a small number of dyads (e.g., six vocal parameters in 13 mother-child dyads in Ko et al (2016). Yet parent-child conversations are a ubiquitous feature of childhood. Moreover, specific types of conversations, particularly those that centre on reminiscing about the child's emotions, have been found to contribute in important ways to the child's social and emotional development (Fivush, Haden & Reese, 2006; Salmon & Reese, 2016), and yet almost nothing is known about the nature of acoustic-prosodic expression in those conversations. In general, it can be said that the interactive nature of affective prosody in parent-child conversations, particularly the dynamic coordination of their acoustic-prosodic features, remains a largely unexamined area in the literature.

2.4.6 Acoustic-prosodic synchrony and the role of oscillators in speech

The study of biobehavioural synchrony spans disciplines, including mammalian biology, developmental and social psychology, and speech and language learning. In the speech literature, the concept most related to synchrony is entrainment, a term which broadly describes the phenomenon of conversational partners becoming more similar to each other in what they say and how they say it (Levitan et al, 2012). This dyadic matching of vocal communication is evidenced in many aspects of spoken language, such as linguistic style (Niederhoffer & Pennebaker, 2002) and lexical choice (Brennan & Clark, 1996). Synchrony has also been observed in a conversational context in the acoustic-prosodic qualities of adult dyads, on features such as pitch and intensity (Levitan & Hirschberg, 2011; Levitan et al, 2012), speaking rate (Borrie & Liss, 2014) and latency and utterance durations (Levitan et al, 2015). While such studies typically observe adult dyads who are strangers to each other, Harma (2014) found evidence for acoustic-prosodic synchrony between partners in intimate relationships.

Synchrony is a phenomenon observed in many systems linked by physical oscillations, or periodic cycles of energy that occur around a set point or equilibrium. In speech, the oscillatory signal is the speech wave, the acoustic cycle that reflects syllable production (Moore, 2012). However the brain is also characterised by neural patterns of oscillation. Indeed, studies suggest that neural oscillations in the auditory cortex are modulated in phase to match rhythmic properties of incoming speech (Peelle et al, 2013;

Lakatos et al, 2005), and brain to brain coupling of neural response patterns has also been identified as occurring in the frontal lobes between speakers and listeners (Stephens et al, 2010). In that study, only a mild form of neural alignment was associated with nonsense jumbled speech compared to true speech, leading the authors to suggest that brain to brain neural coupling plays an important role in both speech production and comprehension.

Intriguingly, a specific type of synchronisation seems to occur during personal recall narratives. Hasson et al (2012) and Silbert et al (2014) identified the presence of brain to brain coupling based on a narrative account provided by the speaker who was reminiscing about a past personal event. Zadbood et al (2017) subsequently demonstrated that mutual alignment of neuronal patterns during a speaker-listener recall task was later associated with higher quality of the recall of episodic memories shared between individuals. Together, these studies suggest that the act of mother-child emotion reminiscing presents a suitable context for the assessment of mother-child synchrony.

2.4.7 Emotion talk and parent-child interactions

Parent-child conversations which include elaboration about emotional events are a growing area of clinical interest as they are associated with important aspects of the child's socio-emotional development, particularly their ability to understand and regulate their emotions (Fivush, Haden & Reese, 2006; Salmon et al, 2016). While most studies on elaborative parent-child reminiscing focus on the content markers of such talk, for example, elaborative questions and validating statements (e.g., O'Kearney, Salmon, Liwag, Fortune & Dawel, 2017), the non-verbal content of such interactions is also significant in conveying the affective tone of these conversations, and acoustic-prosodic features provide objective markers of such tones (Juslin & Scherer, 2005).

In particular, in discussing largely negative emotions that the child has experienced, such as sadness or fear, the task provides an opportunity for the parent to display empathic resonance and non-verbal cues of warmth and tenderness for the child's experiences. In this way, cues of warmth in the voice of the mother may support the child in managing stress or distress activated by the recall of such events. Such a proposition is supported by novel studies of associations between hormones and vocal cues in parent-child interactions (Seltzer et al, 2012; Seltzer et al, 2010).

In those studies, daughters in middle to late childhood who were subject to an induced social stressor received comfort from a combination of physical, vocal and other non-verbal contact from their mothers. Children receiving comfort from only from their mother's voice displayed a profile of oxytocin expression similar to that of daughters receiving comfort from a combination of other sources. Those profiles displayed high amounts of oxytocin and a faster return to cortisol baseline compared to the study controls, leading the authors to propose that prosodic cues may have evolved as an alternative to touch for oxytocin expression in caregiving relationships.

However, progress in examining the caregiving aspects of acoustic-prosodic expression has been almost non-existent, attributable in part to the multidimensional nature and speed of the speech signal. Capturing temporal relationships between speakers in a reliable way, such as that seen in the careful observation and micro-coding of facial expressions (Ebisch et al, 2012; Riehle et al, 2017) and gaze (Dadds et al, 2012; Harel et al, 2011) is particularly challenging. Moreover, the statistical methods used in studies on mother-child synchrony do not typically capture the feedback that tends to occur between interacting variables in a dynamic system. Given this, the field appears ready to benefit from new methods to improve understanding of the factors contributing to child and maternal emotional and behavioural dynamics.

2.5 Synchrony as a dynamic interpersonal system

2.5.1 Dynamic systems theory

Dynamic systems theory (DST) originally emerged from general information theory to represent the *feedback* observed in many natural systems, whereby successive states of interacting components are influenced by their own previous states and also by the previous states of other components in the system (Steenbeek & van Geert, 2007). In this way, interpersonal processes are conceptualised as complex dynamic systems (Butler, 2011; Fogel, 2011; Butler, 2011; Gelfand & Engelhart, 2012; Gottman, 2005). At a macroscopic level, dynamic systems are characterised by a relationship of both randomness and orderliness across time, based on principles of self-organisation, homeostasis and equilibrium (van Geert, 2011). This homeostasis is typically achieved using self-correcting mechanisms between variables that contribute to greater stability and predictability of the system.

In human development, such a system is variously referred to as co-regulated (Feldman, 2003), mutually influenced (Feldman, 2015b), or synchronous (Feldman, 2007a). This temporal element is a defining characteristic of a dynamic system (van Geert, 2011), with data collected across multiple points in time and subsequently represented as time series variables. Therefore, applying a dynamic systems approach to the study of interpersonal interactions requires the use of statistical methods infrequently, albeit increasingly, adopted in psychology (Gates & Liu, 2016). Such advanced methods are well suited to investigating subtle dynamics of interpersonal interactions and the influence of each party within them.

2.5.2 Vector auto-regressive (VAR) modelling

Methodology using a dynamic systems approach diverges from many traditional static methods in psychology which isolate dependent and independent variables based on ordinary least square (OLS) regression (Gelfand & Engelhart, 2012). Standard OLS regression reflects associative relationships in observational data through correlation. Cross-correlation is a straightforward extension to time series data. Based on the correlated lead-lag relationship of one series relative to another series, the cross-correlation method has commonly been used to examine the relationship between two time series variables.

However the use of correlation for identifying relationships between time series variables is problematic as individual time series are frequently auto-correlated (Dean & Dunsmuir, 2016). Auto-correlation refers to the fact that, in time series, the current value of *X* typically depends on preceding values of *X* and can be partially predicted by knowledge of those values; as the observations are not truly independent, the assumption of independence is violated, thus leading to spurious correlations (Dean & Dunsmuir, 2016).

A method that has been used to address this important problem in time series data is auto-regressive integrated moving average (ARIMA) modelling. An ARIMA model regresses the dependent value of *Y* on lagged values of error terms (moving average terms), as well as the lagged values of *Y* (autoregressive terms). An ARIMA model examines unidirectional relationship between *X* and *Y* by treating certain variables as endogenous and others as exogenous in the model. This approach has been used previously in the study of mother-child synchrony (Feldman, 2007), in the study of prosodic synchrony in adult dyads (Harma, 2014), and in the study of interpersonal processes (e.g. Gottman, 2005).

Vector-autoregressive (VAR) modelling is a multivariate extension of this univariate model that uses vectors of variables, and matrices as coefficients, to examine in a single model how variables concurrently impact each other. It does not assume prior knowledge about the direction of influence; rather, each variable is treated as endogenous and modelled concurrently as both dependent and independent variables (Gelfand & Engelhart, 2012). To achieve this, VAR models use many autoregressive equations, with each equation allowing one variable to take the position of the dependent variable while remaining endogenous in the model.

In this way, VAR modelling enables the investigation of bidirectional relationships, indicating the extent to which one individual's variables predict both their own and their partner's values at a later time. It is therefore particularly suited to studies of dynamic systems where the influence of each variable is unknown. A further strength of VAR modelling is in providing a stricter statistical criterion for identifying causation compared to the methods based on computing cross-correlation (Dean & Dunsmuir, 2016).

2.5.3 Stationarity

With advances in computing power, VAR modelling has become one of the most successful and popular models for the analysis of multivariate time series data. However statistical methods used in VAR modelling, such as OLS regression, rely on the assumption that variances and means in a series do not change as a function of time. A time series with such properties is referred to as stationary (Shumway & Stoffer, 2006). Stationarity is a prerequisite for many time series techniques, including ARIMA modelling. Diagnostic tests, such as a unit root test, are therefore used to first test for the presence of non-stationarity in a series. Methods such as differencing are then used to transform non-stationary series into (weakly) stationary ones, before building a model where inferences may then be meaningful. A differenced series reveals the change that occurs between each observation in the original series, calculated by the successive subtraction of the value xt from $xt+1$ at each observation point which then produces a series that represents the changes in time. When stationarity is achieved through such a method, a time series is referred to as "integrated to an order of k", or I(k). Time series variables are frequently integrated of order 1, or I(1).

2.5.4 Stochastic trends between time series variables

In practice, very few natural processes are stationary. Rather, a stochastic trend occurs. A stochastic trend reflects the movement of a variable over time, in a path that cannot be precisely predicted but can be analysed statistically (Cryer & Chan, 2008). Rendering an individual time series (weakly) stationary through a statistical process such as differencing is a common approach to time series data, in order to control for such trends, to enable the application of standard predictive statistics. However it also results in a loss of important information regarding the stochastic trends that may be shared between the variables within that system. These trends frequently contain important information about the dynamic relationships between the variables as a function of time.

Fortunately, a number of important papers by Granger (1983; Granger & Weiss (1983) and Engle & Granger (1987) profoundly changed the study of time series for dynamic systems. Their investigations resulted in a Nobel Prize in 2003, for revealing that when two or more non-stationary or unstable time series in a VAR model share a common stochastic trend, they can have a linear combination which is stationary. For example, series that are individually integrated I(1) may be jointly integrated to I(0). Engel and Granger (1987) defined this linear combination of trends shared by time series variables as cointegration.

2.5.5 Cointegration

As a statistical method, cointegration enables the study of systems in which individual variables may be individually unstable but in fact maintain a predictable influence on each other over time. That is, there is a dynamic "long run equilibrium" relationship that is tying the behaviour of the variables together (Stroe-Kunold et al, 2012). Conceptually, cointegration is represented by the Granger representation theorem (Engle & Granger, 1987).

The Granger representation theorem states that when two or more nonstationary variables are shown to be cointegrated an error correction mechanism (ECM) exists. An error correction mechanism refers to the fact that any short-term derivations from equilibrium within the system are automatically corrected using a self-regulating mechanism. In practice, this means that when cointegration exists individual time series do not require transformation to achieve stationarity. Rather, the cointegrated variables can be analysed as a stationary unit, and their lagged disequilibrium terms included as explanatory variables in the model (Engle & Granger, 1987).

The example of a drunk and his dog is commonly used to illustrate the concept of cointegration. A drunk and his dog are walking home. Depending on, for example, how drunk the man is and the temperament of the dog, their patterns may be individually unpredictable and potentially unrelated; their individual paths might deviate for unlimited time or distance. Their paths are not stationary; they contain a unit root. However, if the dog is tied with a lead, neither the dog nor the owner wander far or long from each other; they maintain a predictable relationship in their pattern of movements. The lead is considered to represent an auto-correcting mechanism in their relationship.

2.5.6 Granger causality

Cointegration describes "long-run" synchronous relationships over time (e.g., Stroe-Kunold et al, 2012). However it does not identify the direction of influence within a system. For that, a causality test is required. Mathematically, a causality test is a statistical hypothesis test used to determine the degree to which one variable is useful in predicting another. It is based on mutual information theory, and in dyads, examines how an individuals' values on a group of variables predict their partner's and also their own subsequent values.

Mutual information theory is based on the principle of transfer entropy, which measures the degree of uncertainty that is reduced in the subsequent values of variable Y, by using the preceding values of X while considering past values of Y. Using t-tests and F-tests on the lagged values of both X and Y, X is said to Granger-cause Y if it can be shown those values provide statistically significant information in relation to the future values of Y (Dean & Dunsmuir, 2016). In this way, Granger causality seeks to identify relationships which reflect temporal dynamics rather than just associations.

In a bivariate system, a Granger causality test is run on simultaneous autoregressive vector models of X and Y. Essentially, a VAR model is built for the time series of both X and Y, which produces estimation errors for a "full" model. Another VAR model is estimated which omits one variable, resulting in a "reduced" model with a second set of prediction errors. The two models are compared to identify if the errors for the full model, which includes both X and Y, are significantly smaller than the errors for the model which excludes one variable. In this way, fitting a VAR model in Granger causality seeks to minimise estimation error (Granger & Weiss, 1983).

2.5.7 Toda-Yamamoto (TY) procedure

Importantly, Engel and Granger (1987) established that risks of spurious regression and specification bias occur in cointegrated systems using the standard Granger-causal inference. This is because if some of the data are non-stationary, which is typical in a cointegrated system, then what is referred to as the asymptotic chi-square distribution under the null for the Wald test statistic does not follow its expected distribution and has parameters that can't be observed (Toda & Yamamoto, 1995).

To address the serious problems arising from this, Toda and Yamamoto (1995) introduced a modified Wald test statistic (MWALD) for tests of Granger- causality, which has an asymptotic chi-square distribution in estimating the VAR. To establish the maximum order of integration *(k+dmax)* for the dyad an ADF test is used to identify the order of integration for each series. A VAR model is then set up in the levels of the data. Then, the maximum lag order is identified using information criterion, such as the Akaike Information Criteria (AIC) to identify the optimal lag length and make the VAR well specified. Then, based on the maximum order of integration, the additional lags are added into the equation to correct the asymptotics.

A further strength of the Toda-Yamamoto (TY) procedure is that it avoids any bias or distortions arising from the interpretation of initial diagnostic tests for stationarity and cointegration, and can be applied regardless of the order of integration in the series. This is because the TY approach intentionally overfits the model using the maximum order of integration of the individual series, although there is some loss of power. Hence sample size (i.e., the length of the series) can result in a failure to reject the null, even when Granger-causality is present.

2.5.8 High dimensional data and the multiple comparisons problem

In the vocal domain, early speech analysis tools extracted a small range of prosodic measures from the human speech signal, such as fundamental frequency and intensity data. However methods to extract and calculate additional acoustic-prosodic parameters have rapidly advanced in recent years, and such tools are now capable of generating tens or even hundreds of prosodic calculations for each segmented unit of speech. In the nascent field of child affective prosody, in which there is little research regarding which of the available parameters is of relatively greater importance, there is a convincing case for multiple testing.

Multiple testing describes any instance that involves the simultaneous testing of several null hypotheses (Castro-Conde & de Uña-Álvarez, 2015). For example, in fields using high dimensional biological data such as genomics, where there are many variables of potential significance, it has become routine using modern computing power to run thousands or even millions of tests simultaneously.

Traditionally, the family wise error rate is used to protect against making any Type 1 error in a family of tests. However it is a particularly conservative test for high dimensional data as it leads to a correspondingly large increase in Type 2 errors. It has been argued that multiple testing does not need to be corrected in exploratory studies (Bender & Lange, 2001), particularly those observing natural processes (Rothman, 1990), with validation studies being the task of further work using new subjects (Li et al, 2017). On the other hand, legitimate concerns for making a Type 1 error in high dimensional data has driven rapid expansion of multiple testing correction methods for large datasets.

One early and well known alternative to the family wise error rate is the false discovery rate (FDR) (Benjamini & Hochberg, 1995). However it is increasingly understood that the FDR and similar approaches to multiple test adjustments, such as the Benjamini-Yekutieli (BY) procedure (Benjamini & Yekutieli, 2001), quickly lose statistical power as the number of tests increase, reducing the probability of detecting even one true result. In exploratory studies, the significant cost of this reduction in power is a high risk of false negatives, i.e., a true effect is present but is not detected, thus providing little guidance in identifying a set of variables for further study. To address this significant problem, the sequential goodness of fit meta-test (SGoF) has been developed (Carvajal-Rodríguez, 2018; Carvajal-Rodríguez et al, 2009; Castro-Conde & de Uña-Álvarez, 2015).

2.5.9 Sequential Goodness of Fit (SGoF) adjustment for multiple comparisons

In contrast to the FDR and BY approaches, the sequential goodness of fit (SGoF) adjustment for multiple comparisons (Carvajal-Rodríguez, 2018) has been found to increase statistical power with the number of tests, displaying power that is magnitudes higher than the FDR and other multi-test methods without a significant increase in the false discovery rate (Carvajal-Rodríguez et al, 2009). The SGof method has been developed for bioinformatics (Castro-Conde & de Uña-Álvarez, 2015) and has been successfully applied to neuroimaging (Thompson et al, 2013; Thompson et al, 2014). It has been found to perform particularly well in small sample sizes when there are a large number of tests, if there is a small to moderate proportion of significant weak effects, and if any significant effects are widespread through the family of tests (Carvajal-Rodríguez et al, 2009; Carvajal-Rodriguez & de Uña-Alvarez, 2011), all factors considered relevant to the current study.

2.6 Conclusion

Drawing on the distinct research streams of mother-child synchrony, callous-unemotional traits, and affective prosody, this thesis proposes that children with callous-unemotional traits are at particular risk for the disruption of acoustic-prosodic synchrony due to problems in affective empathy, particularly impairments in emotional arousal and in recognising distress in others. Using a novel empirical paradigm, this thesis integrates methods of psychological assessment, speech signal feature extraction, and dynamic time series analysis to test the theory that focusing on the neglected area of acoustic-prosodic synchrony in parent-child interactions may provide new insights into the nature of affective communication for children at risk of disruptions to their social functioning.

CHAPTER 3: METHOD

3.1 Chapter outline

This chapter details the empirical approach and the methods used in this research. It outlines the participants, the procedure and the measures used, the computational methods used to conduct acoustic-prosodic feature extraction, and the statistical approaches used in the studies.

3.2 Participants and procedure

3.2.1 Participants

Participants were 79 children aged four to eight years (M = 6.04 years, SD = 1.44 years; Range 4.00 to 8.90 years) and their mothers recruited to be part of a larger study aimed at understanding the effects of emotion talk between mothers and their children in the development of emotion competencies. All children were biological offspring and sixty-six percent of children were male (n = 52). Referrals were obtained through community health services and through schools as part of an intervention study for parents to learn strategies for enhancing their early school aged child's ability to manage emotions. The nature of the referral sources and the intervention-oriented recruitment resulted in a predominantly treatment seeking population. Approval was obtained from the appropriate human ethics committees in line with standards equivalent to the 1964 Helsinki declaration and later amendments. Written informed consent for participation was obtained from the parents and verbal consent from children.

3.2.2 Screening

Families were screened via telephone for the inclusion criteria, recruiting children aged 4-8 years with English as a first language and excluding the presence of childhood autism spectrum disorder and other neurodevelopmental disabilities. Children and parents who met criteria were invited to attend a face to face assessment session and were posted information regarding the study. Parents were also asked to complete a baseline battery of clinical questionnaires, a demographic questionnaire and a consent form, ahead of attendance at the assessment session.

3.2.3 Assessment Session

The mother and their child were interviewed separately. The assessment interview with the parent involved a clinical history taking of developmental milestones and current behaviours including any history of pregnancy and birth complications, attachment concerns, child language or social problems, child temperament observations, child ill health, and history of mental health conditions within the family. While the mother completed the clinical interview the child undertook a play based task followed by a test of verbal ability in a separate room. After completion of the separate assessment sessions the mother and child reunited and the parent-child emotion reminiscing task commenced.

3.3 Emotion talk (Emotion Reminiscing Task)

This task provided the mother-child conversations from which the data was extracted for the subsequent analyses. The task consisted of a semi-structured reminiscing task between parents and their children where mothers were instructed to speak with their child "in their usual way" about experiences that had produced three different types of emotions for the child (happy, sad or angry and afraid or scared). The following instructions were provided:

"In this part of the project we are interested in how you and your child talk about feelings. We would like you to think of three occasions when [child's name] felt three types of emotions; firstly happy, secondly sad or angry, and thirdly afraid or scared. We would like you to ask your child about each of these events beginning with the happy one. Just discuss the events in your usual way. The conversations will be recorded. Do you have any questions?"

After responding to questions the experimenter left the room and the parent and child commenced the task. Parents provided written informed consent for the conversation to be audio recorded using an Audio and Visual Recording Consent Form.

3.4 Clinical measures

3.4.1 Child measures

3.4.1.1 Callous–unemotional traits

The Inventory of Callous Unemotional traits (ICU) (Frick, 2004) was used to evaluate the level of child CU traits. Ratings are made by parents on 24 items against a 4-point scale ranging from "Not at all true" to "Definitely True". There are an equal number of positively and negatively worded items and positively worded items are reverse scored. Example items include *"Shows no remorse when he/she has done something wrong"*, *"Does not show emotions"*, and *"Easily admits to being wrong"* (reverse score). Higher total ICU scores indicate a higher trait level and studies on the internal structure typically identify three factors: callousness, unemotional, and uncaring (Essau, Sasagawa, & Frick, 2006; Kimonis et al, 2008). The measure has been shown to have good construct validity (Ray & Frick, 2018; Kimonis et al, 2016). The ICU has acceptable reliability across different age ranges and genders (Kimonis et al, 2014) and was found to have good internal consistency in the present sample (Cronbach's alpha = .76).

3.4.1.2 Child empathy

The Griffith Empathy Measure (GEM) (Dadds et al, 2008) is a 23 item parent rated measure of the child's empathic behaviour, in particular, their understanding of, and emotional resonance with, other's people's emotions. It can be scored for total child empathy (Cronbach's alpha = .81) or separated into largely orthogonal cognitive (Cronbach's alpha = .62) and affective (Cronbach's alpha = .83) components and has displayed good reliability and validity across age and gender (Dadds et al, 2008). Items on the affective scale include *"My child becomes sad when other children around him/her are sad"* and *"Sad movies or TV shows make my child sad"*. Items on the cognitive scale include *"My child rarely understands why other people cry"* (reverse scored) and *"My child would eat the last cookie in the cookie jar, even when he/she knows that someone else wants it"*.

3.4.1.3 Diagnostic status

The Diagnostic Interview Schedule for Children, Adolescents and Parents (DISCAP) (Holland & Dadds, 1995; Johnson & Shortt, 1999) is a clinician-administered semi-structured clinical interview and was used to conduct a comprehensive assessment of child psychopathology with the parent. From these findings, diagnoses of Oppositional Defiant

Disorder (ODD) were established if indicated. The DISCAP has displayed adequate concurrent validity against an established measure of child internalising and externalising problems, the Youth Self Report (Achenbach, 1991; Johnson & Shortt, 1999). Moreover, the DISCAP has displayed strong inter-rater reliability ($\varkappa$ = .93 - 1) for diagnoses of childhood psychiatric disorders (Johnson & Shortt, 1999). In this sample fifty-three children had a diagnosis of ODD and reliability of the DISCAP-IV diagnosis was strong (Kappa = .96).

3.4.1.4 Child emotion regulation

The Emotion Regulation Checklist (ERC) (Shields, 1997) was utilised as a parent-report instrument to assess the child's level of emotion regulation for the comparison groups and given its demonstrated relevance to the synchrony construct. This measure is a 24-item parent-report questionnaire requiring responses on a Likert Scale from 1 (never) to 4 (always) with some items reverse scored. The measure consists of two subscales: Emotion Regulation and Emotion Lability/Negativity. The 15-item Emotion Lability/Negativity sub-scale was used in this research as a dimensional measure of the construct of emotional lability and negativity typically associated with ODD. Items relating to emotion lability include *"Has wild mood swings (changes unexpectedly from a good to a bad mood)"* and *"Is likely to have an angry outburst or easily throws tantrums"*.

In contrast, the 9-item Emotion Regulation subscale measures the appropriateness of the child's displays of emotions to the situation, their self-awareness of their emotions, and their empathy, where higher scores indicate greater emotion regulation. This subscale was used as a measure of prosocial characteristics and to account for any moderating influence of child emotion regulation on vocal synchrony (Davis et al, 2017). Items include *"Is able to say when he/she is feeling sad, angry or mad, fearful or afraid"* and *"When another child acts aggressively toward child, he/she reacts appropriately (e.g., expresses anger, fear,* *frustration, distress, but does not return aggression)"*. The instrument has displayed adequate internal consistency (Lability/Negativity Cronbach's alpha = .96, Emotion Regulation Cronbach's alpha = .83) and multitrait-multimethod analyses have displayed significant convergence between the two sub-scales and the Emotion Regulation Q-Scale, another established psychometric measures of child emotion regulation (Shields & Cicchetti, 1997; Lability/Negativity r = –.79, $p < .001$ and Emotion Regulation $r = .68$, $p < .001$).

3.4.1.5 Child behavioural and emotional problems

The Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997) is a 25 item parent rated screening questionnaire to assess child psychopathology in 3-16 year olds. The SDQ provides scores on three clinical subscales and two interpersonal subscales as well as a total difficulties score. The conduct problems subscale was used as a comparison measure for the clinical hypotheses in this research, and includes items such as *"Often fights with other children or bullies them"*, *"Often lies or cheats"*, and *"Steals from home, school or elsewhere"*. The prosocial behaviour subscale includes items such as *"Kind to younger children"*, *"Helpful if someone is hurt, upset or feeling ill"*, and *"Considerate of other people's feelings"*.

The emotional symptoms subscale was used as a measure of internalising problems and includes items such as *"Many worries or often seems worried"*, *"Often unhappy, depressed or tearful"*, and *"Many fears, easily scared"*. Cronbach's alpha shows some variability for the SDQ (from .46 to .82) however McDonald's omega is good (Stone et al, 2015) as an alternative indicator of the reliability of the scale. The questionnaire is well established and the individual clinical subscales (conduct problems, emotional symptoms, and hyperactivity) display reasonable predictive validity of the risk and severity of related mental disorders based on a structured interview (Hawes & Dadds, 2004).

3.4.2 Mother measures

3.4.2.1 Mother's mental health

Mothers completed the 42 item-version of the Depression, Anxiety and Stress Scale or DASS (Lovibond, 1995) to test the hypotheses relating to maternal factors and mother-child synchrony. Respondents use a 4-point severity/frequency scale to rate the extent to which they have experienced symptoms associated with each state over the past week. Items include *"I couldn't seem to experience any positive feeling at all"*, *"I felt I was close to panic"*, and "*I tended to over-react to situations"*, The DASS is well established as a screening measure and has shown good reliability in both clinical and community samples (alpha = .97, .92, and .95 for depression, anxiety and stress respectively) (Antony et al, 1998; Page et al, 2007).

3.4.3 Clinical groups

Table 3.1 provides the clinical characteristics of the sample based on cutoffs for the low/high groups established from existing literature (Kimonis et al, 2014; Goodman et al, 2000; Goodman, 1997; Dadds et al, 2008; Lovibond & Lovibond, 1995). The correlation between child measures is reported in Appendix C.

Table 3.1

Clinical characteristics of the sample

	Mean (*N = 79*)	*SD* (*N = 79*)	*SE* (*N = 79*)	*Low group* (*%*)	*High group* (*%*)
Child psychopathology					
ICU Total	25.7	10.7	1.23	39.2 (*n* = 31)	60.8 (*n* = 48)
ERC Lability/Negativity	15.0	8.58	0.98	43.0 (*n* = 34)	57.0 (*n* = 45)
ERC Emotion regulation	14.5	4.04	0.46	39.2 (*n* = 31)	60.8 (*n* = 48)
SDQ Prosocial	6.05	2.31	0.26	55.7 (*n* = 44)	44.3 (*n* = 35)
SDQ Conduct	3.87	2.39	0.27	34.2 (*n* = 27)	65.8 (*n* = 52)
GEM Total	15.6	28.9	3.43	58.2 (*n* = 46)	41.8 (*n* = 33)
GEM Cognitive	5.58	7.23	0.87	43.0 (*n* = 34)	57.0 (*n* = 45)
GEM Affective	2.74	12.55	1.51	36.0 (*n* = 45.6)	43.0 (*n* = 54.4)
ODD diagnosis (%)	67.08 (*n* = 53)				
Mother psychopathology					
DASS Depression	4.35	6.80	0.77	62.0 (*n* = 49)	38.0 (*n* = 30)
DASS Anxiety	2.86	4.79	0.55	70.9 (*n* = 56)	29.1 (*n* = 23)
DASS Stress	11.1	7.05	0.81	35.4 (*n* = 28)	64.6 (*n* = 51)
Maternal mental health history	26.6 (*n* = 21)				

Note.
ICU Inventory of Callous–Unemotional Traits, ERC Emotion Regulation Checklist, SDQ Strengths and Difficulties Questionnaire, GEM Griffith Empathy Measure, DASS Depression Anxiety Stress Scales

3.5 Relational qualities of the emotion talk

The recorded voice files for the mother-child reminiscing conversations were used to extract data on the relational qualities of the emotion talk as communicated through the voice. Ratings of warmth in the mother's voice were made using two rating scales. Another measure rated the degree of warmth, attunement and dismissiveness in the emotion talk as dyadic qualities relevant to child development. Ratings were made by two post-graduate clinical psychology trainees blind to psychological characteristics of the mother and the child in each dyad. The judges ratings of these qualities were then examined for significant acoustic-prosodic parameters associated with the relational qualities, and the findings compared to the acoustic-prosodic profile for the vocal emotion of tenderness.

3.5.1 Characteristics of the mother's speech

3.5.1.1 Vocal warmth

Recordings were rated for the degree of warmth in the mother's voice in two ways. Firstly, using a measure on which the lexical content had been masked in order to mitigate the effects of semantics on the warmth rating. This was achieved by using an anonymise script in Praat (Hirst, 2010; Hirst, 2013). The anonymise script used the TextGrid annotations to identify all sequential segments of the *.wav* file assigned to the mother and then replaced each speech segment with a hum sound with the same acoustic-prosodic envelope as the original segment based on pitch and intensity values.

The mother's anonymised speech was rated on a coding system adapted from the Preschool Five Minute Speech Sample (PFMSS) (Daley et al, 2003). While the original

PFMSS rating system rates both linguistic and paralinguistic features of warmth in the speech of the parent about their child, the manual identifies tone of voice, particularly pitch and intensity modulation, as the most important element of the rating (Manual; Daley, 2001; Daley et al, 2003). Ratings of warmth in the mother's voice were made on a scale representing high, moderate or low, with high and moderate ratings differentiated by consistency and intensity of the tone of voice in displaying warmth.

3.5.1.2 Vocal warmth/ expressiveness

The second measure of warmth in the mother's speech was also a judges' rating however the lexical content was not masked to account for the lexical content in the mother's speech, particularly the mother's degree of engagement in the conversation. The rating used a measure of conversational involvement from the speech communication literature (Coker & Burgoon, 1987). Conversational involvement reflects the measurement of nonverbal, relational messages in dyadic interactions, and refers to the extent to which participants in a conversation display observable behaviours that indicate engagement in both the topic and the relationship. The current study adopted the Vocal Warmth / Interest subscale (6 items) from the altercentrism dimension of Coker and Burgoon's (1987) study.

Items in this subscale assess vocal warmth (warm-cold), vocal interest (interested-bored), vocal involvement (involved-apathetic), vocal pleasantness (pleasant-unpleasant), vocal friendliness (friendly-unfriendly), and vocal appeal (appealing-unappealing). Items were rated on a 7 point Likert scale ranging from strongly agree (7) to strongly disagree (1), with higher scores proportional to a greater degree of those attributes. Inter-rater reliability coefficients for these subscale items in the original study ranged from .72 to .81 (Coker & Burgoon, 1987).

Ratings of the emotion talk were also made on two other subscales that were found to be related to, but distinct from, ratings of Vocal Warmth / Interest in the original Coker and Burgoon (1987) study. These were Vocal Expressiveness and the Amount of Relaxed Laughter. Using the ratings on all three subscales, a Principal Components Analysis (PCA) was conducted using a Varimax rotation with Kaiser Normalization. The PCA extracted 4 principal components and identified a Parent Vocal Warmth/ Expressiveness factor as dominant (Eigenvalue 6.59), accounting for 73% of the variance. The total score from this principal component variable was used in subsequent regression analyses.

3.5.2 Characteristics of the emotion talk

3.5.2.1 Warmth, attunement, and dismissiveness

Ratings were made of the qualities of the emotion talk using the Connectedness Scale, a measure developed for the *Enhancing emotion knowledge in pre-schoolers with disruptive behaviour: the role of mother-child emotion talk* project. The judges' rated the emotion talk for the degree of warmth *("the overall emotional ambience is warm and positive")*, the degree of attunement *("parent and child are in tune with one another")*, and the degree of dismissiveness in the emotion talk *("parent disagrees with or is dismissive of the child's emotions")*.

Ratings were made on a 5 point Likert scale ranging from 0 (not at all like this conversation) to 5 (very like this conversation). These dyadic items were based on the construct of Mutually Responsive Orientation (MRO) (Kochanska, 2002) and its measurement using the MRO Scale (Aksan et al, 2006). The MRO construct has been associated with child conscience development (Kochanska et al, 2005), disruptive behaviour (Kochanska et al, 2008), and more recently, the expression of child callous-unemotional traits

(Kochanska et al, 2013). High MRO dyads show proficiency in reading each other's social signals in a reciprocal and co-ordinated pattern of communication, which is thought to reflect implicit shared procedural expectations (Aksan et al, 2006). The judges were trained using a manual protocol for the Connectedness Scale, which demonstrated high internal consistency (alpha = .733).

3.6 Acoustic-prosodic feature extraction

3.6.1 Praat

The initial dataset comprised 79 audio recordings of the mother-child emotion topic laboratory task. Sessions were recorded using an Olympus Digital Voice Recorder (DS-660) on a table between the speakers in the centre of the room. Data was stored as *.wma* files and converted to *.wav* files to enable the acoustic-prosodic parameter extraction. This research used the software Praat version 6.0.14 (Boersma, 2017) for speaker annotation and for the feature extraction. Praat is a software program developed for the analysis of acoustic signals. It was developed primarily for the phonetic analysis of language and has become widely used by researchers for diverse applications involving speech analysis (Boersma, 2018). Praat has broad appeal for academic and clinical researchers, as it has a large number of scripts able to be modified for various analytical purposes, is deployed on all major computer platforms, and has a wide user base of support in the academic community.

3.6.2 Annotation

Seventy-nine mother-child conversations were manually annotated into interpausal units in Praat Textgrids based on "who was speaking when" (Tranter & Reynolds, 2006; Moattar &

Homayounpour, 2012). In line with previous research on acoustic-prosodic entrainment (Levitan & Hirschberg, 2011; Lubold & Pon-Barry, 2014), an interpausal unit refers to a pause-free unit of speech separated by another by at least 50ms, which was the average length of stop gaps found in other conversational research (Levitan, 2014). The audible threshold for manual annotation of a pause in the current research was approximately 200 milliseconds, a timeframe similar to other studies in this area (Heldner & Edlund, 2010). The mean length of conversations was 6.08 minutes (48 turns). Extraneous audible sounds within the recording, such as a chair scraping on the floor, were annotated and removed from the analyses. Figure 3.1 shows an example of a spectrogram, a visual representation of sound, used during the annotation process to aid annotation accuracy.

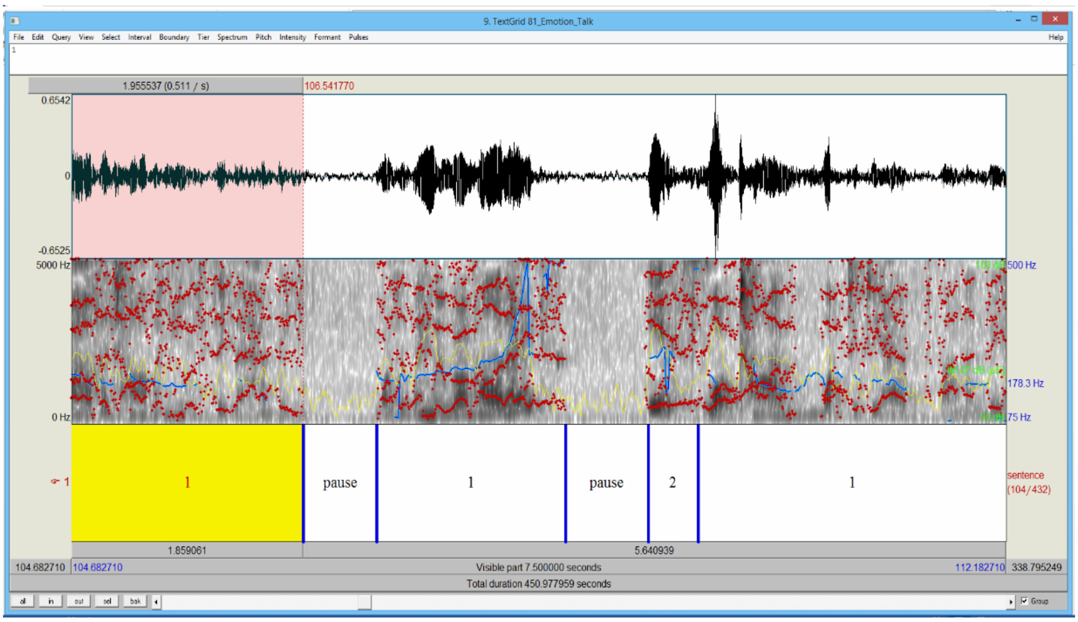

Figure 3.1 Example of a Praat spectrogram and annotations in a Textgrid

Note. “1” represents speech by the mother and “2” represents speech by the child

Red dots = formants; Blue lines = pitch; Yellow lines = intensity

Overlaps were also annotated to identify who was speaking and who spoke over. For example, the annotation “21” indicates that speaker 2 (the child) was speaking at the time when speaker 1 (the mother) initiated and maintained the overlap for the duration of that annotated period (Figure 3.2). The Textgrid annotation "21" therefore contains contiguous speech from both the child and the mother for the length of the overlap period. Such annotation allows for the removal of overlaps, but also the quantification and comparison of temporal and acoustic-prosodic data in relation to overlaps, such as which speaker initiated the overlaps, how often, how long those overlaps were maintained by each speaker, and the acoustic-prosodic content of those overlaps.

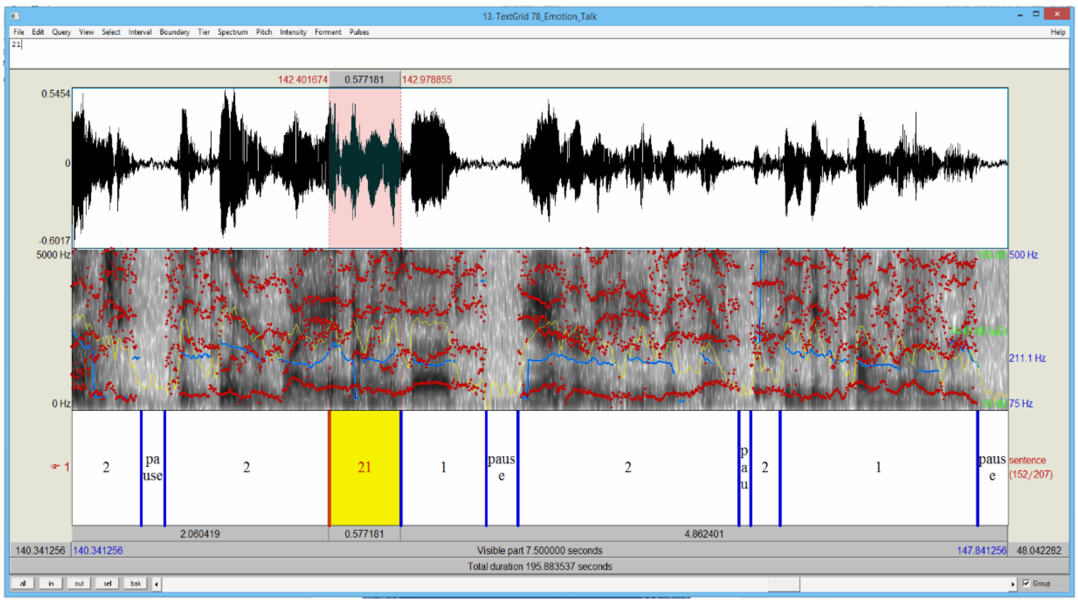

Figure 3.2 Example of overlap annotations in a Textgrid

Note. "21" represents mother-initiated overlap for the duration of the segment

Red dots = formants; Blue lines = pitch; Yellow lines = intensity

3.6.3 Scripts

Three separate Praat scripts were used for the extraction of the vocal parameters. These scripts were ProsodyPro, Mietta Lennes, and Prosogram (outlined below). The scripts produced output as *.txt* files exported as *.csv* files and stored in Excel 2013 for data management. Acoustic-prosodic data was produced for each interpausal unit in the Textgrid to generate two feature datasets: a time series dataset and a session level dataset. The time series dataset was based on the speaker values extracted for each speech turn in the conversation. Conversational turns were defined as consecutive interpausal units of speech by the same speaker until the speaker changed, or when an overlap occurred. This is broadly in line with Levitan et al (2015), who define a turn as a continuous speech utterance by a single speaker, including filled pauses as well as laughter. Table 3.2 provides an outline of commonly used terms used in this thesis and in studies of vocal emotion. Descriptions of the parameters drawn from the Praat scripts for this research can be found in Appendix A.

Table 3.2

Commonly used acoustic-prosodic terms in this thesis[1]

Term	Descriptor
Interpausal unit (positive integer)	An interpausal unit (or "unit") is a temporal measure of speech identifying who was speaking when. Units were annotated interactively in Praat using the *.wav* file and stored in a .textgrid file. Units were separated by at least 200 milliseconds (ms) using manual segmentation.
Turn (positive integer)	A turn is a temporal measure of speech comprised of consecutive units of speech by the same speaker.
Fundamental frequency (F0) / (Hz)	Fundamental frequency (F0) is a physical property of sound; pitch is its perceptual quality. The higher the fundamental frequency the higher the perceived pitch. F0 is measured in Hertz (Hz). Physically, frequency is the rate at which the pressure wave, which is a periodic signal, travels through air in a number of periods per second; F0 reflects the lowest periodic cycle. When vocal organs are the source of sound, F0 reflects the rate at which the vocal folds open and close across the glottis (i.e., the number of glottal pulses per second). Perceptually, the human ear has a non-linear response to the frequency of sound. The peak human response occurs around 2,500 to 3,000 Hz and has less sensitivity to sounds in the lower or higher ends of the spectrum (below 1000Hz and above 3000Hz). Sex differences in F0 are not apparent until at least age 11 (Lee, Potamianos, & Narayanan, 1999).
Semitones (ST)	Semitones are part of a logarithmic, or non-linear pitch measurement system; frequency in Hertz (Hz) is a linear pitch measurement system. Doubling the frequency (Hz) raises the pitch by one octave (12 semitones) which also reflects the interval between standard musical notes. As pitch increases, each semitone consists of a larger change in the frequency compared to the semitone before it. The logarithmic scale is widely accepted to better approximate the human perception of pitch.
Intensity (dB)	Intensity is a physical property of sound; loudness is its perceptual quality. Intensity reflects the amount of energy in the speech signal; specifically, the amplitude or size of pressure variation in air when a sound is produced, e.g., large pressure variations result in loud sounds. Intensity is measured in decibels (dB) which is a logarithmic scale. The logarithmic scale is widely accepted to better approximate the human perception of relative loudness.
Formant (F)	Formants reflect a concentration of energy at a certain pitch and occur approximately every 1000Hz. Formants represent resonances (vibrations) made in a particular part of the vocal tract. The first formant (F1) is associated with the air behind the tongue whilst the second formant value (F2) is associated with the air above and in front of the tongue. Sex differences in formant frequencies are not apparent until at least age 11 (Lee, Potamianos, & Narayanan, 1999).

[1] Further information and illustrated guides to the physical properties of speech can be found at www.animations.physics.unsw.edu.au/waves-sound/human-sound/

3.6.3.1 Script 1: ProsodyPro version 5.7.3

http://www.homepages.ucl.ac.uk/~uclyyix/ProsodyPro/

ProsodyPro (Xu, 2013) is a script that uses a method for the extraction of large scale acoustic-prosodic data for the analysis of continuous prosody in Praat. As per its user guide, the script "combines automatic vocal pulse marking, a trimming algorithm that removes spikes and random variations that were unintended by the speaker as well as a triangular smoothing function" (Xu, 2017). Among other features it quantifies the measurement of continuous pitch velocity, and conducts what is referred to as a time-normalisation function. Time-normalisation allows averaging across repetitions by the speaker, a process that smooths out random variations unintended by the speaker, leaving only consistent variations due to tonal differences.

In line with the user guide recommendation, this study used the syllable as the unit of analysis for the time normalisation feature (Xu, 2017). In addition to standard measurements, ProsodyPro produces a set of emotion-relevant measurements referred to as Bio-informational Dimensions (BID) (Xu et al, 2013). Bio-informational dimensions include pitch level (Hz), pitch range (Hz), intensity (dB) and mean syllable duration (ms). Measures of pitch are also calculated in semitones (ST), an exponential measurement system, including mean pitch and excursion size. The standard ProsodyPro output and the associated bio-informational measurements provided acoustic-prosodic data for analysis of both the session level averages and of the turn-by-turn speaker values.

Acoustic-prosodic measurements were automatically generated by ProsodyPro for each annotated unit in the TextGrid and saved in a file paired to the name of the *.wav* sound file being analysed. These *.txt* files are opened by a spreadsheet or statistical program for analysis. The program ran from a single Praat script whose parameters had been modified to account for the higher female and child vocal ranges, with extraction ranges up to 1000Hz for fundamental frequency and 7500 for formants.

3.6.3.2 Script 2: Mietta Lennes collect_formant_data_from_files.praat

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https://lennes.github.io/spect/

This Praat script extracts the value of the fundamental frequency (f0), the first formant (F1), the second formant (F2), and the intensity value at the midpoint of each labelled speech unit in the Text Grid. It is distributed under the GNU General Public License and was originally written by Mietta Lennes and modified by Dan McCloy (drmccloy@uw.edu) in December 2011 and extended by Esther Le Grézause (elg1@uw.edu) in May 2016 to add intensity and further labels. This script provided the acoustic-prosodic data for analysis of both the session level averages and of the turn-by-turn speaker values.

3.6.3.3 Script 3: Prosogram version 2.14

https://sites.google.com/site/prosogram/home

ProsodyPro and the Mietta Lennes scripts are methods used to extract the physical properties in the speech signal. In contrast, Prosogram (Mertens, 2004) is a Praat script that has been developed to more closely match the perceptual experience of speech at a psychoacoustic level, referred to as a tonal perception model. Psychoacoustic approaches transform the physical properties into curves that simulate how they are perceived by human listeners (e.g., Coutinho, 2013; Globerson et al, 2013; Globerson et al, 2015; Mertens, 2014). To achieve this, Prosogram uses a process referred to as stylization (Mertens, 2004).

Stylization provides acoustic-prosodic information by simulating the auditory perception of pitch movements, representing only those features of speech that are perceived by the human ear. For example, by deleting pitch values outside the human auditory range (Mertens, 2017). As per the user guide, Prosogram uses a representation of tonal perception based on vowel sounds, and focuses on the pitch contour, particularly features of intonation (pitch movements), such as pitch range and trajectory. The syllable nucleus, a foundational element of prosody, is used to compute and transcribe statistical data about the pitch properties of speech. Syllable nuclei in Prosogram are the central (or stressed) section of the voiced section of a syllable, and appear on the pitch curve as an intensity peak.

Prosogram also extracts time-normalised values which are computed by dividing the measured value by the assigned time interval (Mertens, 2017). For example, the pitch trajectory indicates the sum of absolute pitch intervals, while the time-normalised pitch trajectory computes the total trajectory divided by time (Mertens, 2017). Values are given in Hertz as well as in semitones. The script provided data for the analyses of the session level averages only due to the nature of the software at the time of study. Prosogram is provided under a Creative Commons attribution for non-commercial use license. A sample profile of the data extracted by Prosogram is below (Figure 3.3).

```
Prosodic profile for input file: C:\Users\Jodie\Documents\Prosogram\Prosogram\01_Emotion_Talk.wav

Date: Thu May 11 13:27:13 2017
Segmentation type: asyll
Time: (assumes there's only 1 speaker)
    total speech time        =758.61 s (= internucleus time + intranucleus time + pause time)
    estimated phonation time =117.74 (15.52% of speech time) (= internucleus time + intranucleus time)
    estimated pause time     =640.87 (84.48% of speech time) (= when internucleus time >= 0.3)
    estimated speech rate    =7.48 (nrof_nuclei/phonation_time)
Nucleus: 881 nuclei in signal
Duration:
    Nucleus duration:
       mean=0.056(s) stdev=0.032 summed nucleus duration=49.73(s)
    nPVI (nucleus duration)=54 (assumes there's only 1 speaker)
    nPVI (vowel duration)=54 (assumes there's only 1 speaker)

Pitch range of speaker(s): (based on 2 stylization values per nucleus)
    Speaker label: Range, Bottom, Mean, Median, Top, MeanOfST, StdevOfST
    3            : 16.0ST, 138Hz (85.2ST), 191Hz (90.9ST), 179Hz (89.8ST), 347Hz (101.3ST), 90.5ST, 3.6ST
    31           : 15.9ST, 124Hz (83.5ST), 209Hz (92.5ST), 196Hz (91.4ST), 311Hz (99.4ST), 92.0ST, 3.9ST
    13           : 14.6ST, 170Hz (88.9ST), 240Hz (94.9ST), 213Hz (92.8ST), 394Hz (103.5ST), 94.1ST, 5.1ST
    1            : 21.5ST, 125Hz (83.6ST), 223Hz (93.6ST), 212Hz (92.7ST), 433Hz (105.1ST), 93.0ST, 4.3ST
    12           : 11.6ST, 163Hz (88.2ST), 228Hz (94.0ST), 199Hz (91.6ST), 319Hz (99.8ST), 93.4ST, 4.8ST
    2            : 22.9ST, 129Hz (84.1ST), 304Hz (99.0ST), 269Hz (96.9ST), 483Hz (107.0ST), 98.1ST, 5.6ST
    pause        : 16.1ST, 105Hz (80.6ST), 183Hz (90.2ST), 145Hz (86.2ST), 266Hz (96.7ST), 89.4ST, 5.3ST
    21           : 3.9ST, 212Hz (92.7ST), 246Hz (95.3ST), 254Hz (95.8ST), 265Hz (96.6ST), 95.3ST, 1.6ST

Pitch range of speaker(s): (based on 2 raw F0 values per nucleus)
    Speaker label: P02, Mean, Median, P98
    3            : 135Hz, 192Hz, 179Hz, 349Hz
    31           : 125Hz, 210Hz, 195Hz, 339Hz
    13           : 160Hz, 241Hz, 213Hz, 404Hz
    1            : 124Hz, 223Hz, 213Hz, 438Hz
    12           : 157Hz, 226Hz, 199Hz, 331Hz
    2            : 127Hz, 304Hz, 274Hz, 481Hz
    pause        : 103Hz, 182Hz, 152Hz, 266Hz
    21           : 205Hz, 247Hz, 254Hz, 268Hz

Pitch and duration profile of speaker(s):
    Speaker label: NuclDur, InterNuclDur, TrajIntra, TrajInter, TrajPhon, TrajIntraZ, TrajInterZ, TrajPhonZ, Gliss, Rises, Falls, SpeechRate
    3            : 12.80 s, 19.51 s, 22.2 ST/s, 17.8 ST/s, 19.5 ST/s, 6.2 sd/s, 5.0 sd/s, 5.5 sd/s, 1.8%, 1.4%, 0.5%, 6.81 syll/s
    31           : 3.40 s, 5.85 s, 35.4 ST/s, 15.4 ST/s, 22.7 ST/s, 9.1 sd/s, 3.9 sd/s, 5.8 sd/s, 12.1%, 6.9%, 5.2%, 6.27 syll/s
    13           : 0.99 s, 1.24 s, 19.6 ST/s, 15.0 ST/s, 17.0 ST/s, 3.9 sd/s, 3.0 sd/s, 3.4 sd/s, 8.3%, 0%, 8.3%, 5.38 syll/s
    1            : 29.55 s, 37.89 s, 18.7 ST/s, 22.5 ST/s, 20.8 ST/s, 4.4 sd/s, 5.2 sd/s, 4.9 sd/s, 2.1%, 0.7%, 1.3%, 7.93 syll/s
    12           : 0.52 s, 0.66 s, 11.8 ST/s, 2.6 ST/s, 6.7 ST/s, 2.5 sd/s, 0.5 sd/s, 1.4 sd/s, 0%, 0%, 0%, 5.93 syll/s
    2            : 1.59 s, 1.79 s, 18.3 ST/s, 38.5 ST/s, 29.0 ST/s, 3.3 sd/s, 6.9 sd/s, 5.2 sd/s, 3.7%, 3.7%, 0%, 7.98 syll/s
    pause        : 0.63 s, 0.82 s, 43.0 ST/s, 2.8 ST/s, 20.4 ST/s, 8.2 sd/s, 0.5 sd/s, 3.9 sd/s, 5.6%, 0%, 5.6%, 12.37 syll/s
    21           : 0.24 s, 0.24 s, 11.3 ST/s, 17.7 ST/s, 14.5 ST/s, 7.1 sd/s, 11.1 sd/s, 9.1 sd/s, 0%, 0%, 0%, 8.33 syll/s

SpeechTime = total speech time (in s) = internucleus time + intranucleus time + pause time
PhonTime   = phonation time (in s) = without pauses = internucleus time + intranucleus time
PropPhon   = proportion (%) of estimated phonation time (= internucleus time + intranucleus time) to speech time
PropPause  = proportion (%) of estimated pause time (= when internucleus time >= 0.3) to speech time
SpeechRate = estimated speech rate (in syll/s) = nrof_nuclei/phonation_time
MeanOfST   = mean of pitch values, where values are min and max pitch in ST for each syllable
StdevOfST  = stdev of pitch values, where values are min and max pitch in ST for each syllable
PitchRange = estimated pitch range (in ST) (2%-98% percentiles of data in nuclei without discontinuities)
Gliss      = proportion (%) of syllables with large pitch movement (abs(distance) >= 4ST)
Rises      = proportion (%) of syllables with pitch rise (>= 4ST)
Falls      = proportion (%) of syllables with pitch fall (<=-4ST)
NuclDur    = sum of durations for nuclei for this speaker
InterNuclDur = sum of durations between successive nuclei for this speaker
TrajIntra  = pitch trajectory (sum of absolute intervals) within syllabic nuclei, divided by duration (in ST/s)
TrajInter  = pitch trajectory (sum of absolute intervals) between syllabic nuclei (except pauses or speaker turns), divided by duration (in ST/s)
TrajPhon   = sum of TrajIntra and TrajInter, divided by phonation time (in ST/s)
TrajIntraZ = as TrajIntra, but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)
TrajInterZ = as TrajInter, but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)
TrajPhonZ  = as TrajPhon,  but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)
```

Figure 3.3 Example of a data table extracted using Prosogram

3.7 Prosody datasets

3.7.1 Session level dataset (speaker average values for the interaction)

This dataset contains the mother and child averages for every vocal parameter calculated for the conversation. Acoustic-prosodic measurements for the shared conversational units in the interaction — specifically overlaps and pauses — also form part of this dataset due to their demonstrated role in human communication, such as turn-taking and speaker competitiveness (e.g., Heldner & Edlund, 2010; Hilton, 2016). These session level averages served as the dependent variables for the correlation and linear regression analyses, and the mother and child factors served as the independent variables. A full list of the session level parameters can be found in Appendix B.

3.7.2 Time series dataset (speaker turn-by-turn values for the interaction)

The second dataset was comprised of the 44 mother-child vocal parameters generated at the turn-by-turn level for each dyad for the study of synchrony. Pauses and overlapping speech were removed from the time series variables and consecutive interpausal units by the same speaker were treated as one turn and the acoustic-prosodic values averaged across those consecutive units. Missing data due to errors in the acoustic-prosodic feature extraction were not imputed, as such strategies were considered to potentially distort the investigation of synchrony. Instead, any unpaired (consecutive) acoustic-prosodic data due to missingness was removed. A full list of the parameters extracted for the time series analyses and tested in the cointegration and logistic regression analyses can be found in Appendix D.

3.8 Analytical strategy

The analytical strategy was informed by four main research questions:

1) is there evidence for cointegration of acoustic-prosodic features in the emotion talk of mothers and their children in early childhood (aged 4-8 years);
2) are callous-unemotional traits associated with disruption to cointegration on acoustic-prosodic features during mother-child emotion talk;
3) do children with callous-unemotional traits display other differences in their acoustic-prosodic parameters during mother-child emotion talk; and
4) do mothers of callous-unemotional children display less warmth in their emotion talk, and which acoustic-prosodic parameters are associated with the tenderness profile and with the mother's mental health.

3.8.1 Cointegration and Granger causality

To address the first research question, statistical analyses were conducted using the statistical platform *R* (R Core Team, 2017). This platform was selected for its ability to build vector-autoregressive (VAR) models for the tests of cointegration and Granger causality, and for its flexibility in handling the high dimensional datasets for the regression analyses. To investigate the presence of cointegration between each speaker's acoustic-prosodic parameters, statistical tests for stationarity were conducted in *R* version 3.4.3 using the Augmented Dickey-Fuller (ADF) test in the *tseries* package version 0.10-44 (Trapletti, 2018). The ADF test was iterated until the time series vector for each individual parameter was found to be stationary, and the order of integration recorded. VAR models for each dyad were then built using the *vars* package (Pfaff, 2008), with the mother assigned as *x1* and the child assigned as *y1*.

Where the mother and child in each VAR had the same order of integration, the VAR was tested for cointegration. The *urca* package in *R* version 3.4.3 (Pfaff, 2008) was used to conduct the Johansen cointegration test using the "long run" specifier, rejecting the null hypothesis of no cointegration at 10%, 5% and 1% significance levels. All figures relating were produced using the default *plot* function in *R* version 3.5.1. For those acoustic-prosodic parameters displaying mother-child cointegration, the direction of information flow was investigated using the *forecast* package version 8.4 (Hyndman & Khandakar, 2008; Hyndman R, 2018) in *R* version 3.5.1.

Granger causality tests were performed, rejecting the null hypothesis of *no Granger causality* at 5% and 10% significance levels. While more generous than typically used in psychological research, the 10% percent significance level for Granger causality test was included due to the sample size (i.e., length of some series resulting in a loss of power) (Toda & Phillips, 1994) and because the Toda-Yamamoto approach intentionally overfits the model and can result in a failure to reject the null hypothesis, even when Granger causality is present (Toda & Yamamoto, 1995).

3.8.2 Logistic regression and interactions

To address the second research question relating to child CU traits and acoustic-prosodic synchrony, binomial logistic regression was fitted in *R* 3.5.1 using the default *glm* function. While ordinary least squares regression can be used to fit a linear probability model on a binary variable, the OLS model violates assumptions of homoskedasticity and the normality of errors, and can result in the possibility of predicting probability values beyond 0 to 1. In comparison, logistic regression provides a classification algorithm that predicts the probability of obtaining an outcome based on a given set of predictor variables. It uses maximum likelihood estimation as an optimisation procedure to iteratively test for the set of regression coefficients that best fit the observed data, i.e., the optimal intercept and slope.

Estimation is based on the logarithm of the odds of success (pi/(1 − pi)) of the reference variable modelled as a linear combination of the predictor variables.

It is a computationally intensive approach when applied to a high number of dependent variables however is readily executed in *R*. The coefficient returned in *R* is a logit, or the log of the odds, using the default "logit" link in the *glm* "binomial" family. Compared to simple linear regression the use of the logarithm further avoids the problem of outliers. The binary output for the cointegration and Granger causality tests were used as the dependent variables, with the maternal factors, child factors, and the dyadic interaction factors used as predictor variables.

As missingness in the dependent variables occurred randomly due to errors in the process of parameter extraction, and without dependence on any other variable, the cause of missing data for the dependent variables was treated as missing completely at random (MCAR). As noted by Von Hippel (2007) and Little (1992), in such cases maximum-likelihood estimates can be obtained by deleting only those cases with missing values on the dependent variable as imputation simply adds noise to the estimates. Listwise deletion was applied in *R* using the default na.omit function.

Simple and two factor multiple regression equations were tested iteratively for the effects of CU traits and the secondary child and maternal factors on the binary outcomes of cointegration and Granger causality on all 44 acoustic-prosodic time series variables. To examine the interactions, descriptive statistics were obtained for every predictor variable and dichotomised into high/low categories. Cut-offs were established based on either existing literature, or on a hypothesis regarding categorical membership. For example, for child age, a cut-off of 5 years was established to mark the transition to full-time schooling and reflecting wider social influences on the child. To determine the cut-offs for the properties of the mother's speech (warmth and dismissiveness) and for dyadic qualities of the interaction (warmth and attunement), the means and quartiles from the dataset were used to determine representative categories. Table 3.3 provides the clinical cutoffs used to determine group membership for the child and maternal factors of primary interest. Appendix E shows the cutoffs used for the child and maternal factors of secondary interest.

Table 3.3

Cutoffs for dichotomised predictor variables

Measure	Median	Mean	Max	Min	Cutoff value	Reference
ICU Total	25	25.61	59	0	>= 24	ICU Total is all ages & sex cutoff (Kimonis et al., 2014)
GEM Cogn. Empathy	6	5.52	21	-83	>= 7	GEM Cutoffs (mean from Dadds et al, 2008)
GEM Affect. Empathy	4	2.79	32	-13	>= 5	GEM Cutoffs (mean from Dadds et al, 2008)
ERC Lability	15	14.83	37	2	>= 15	ERC mean
ERC EmotReg	15	14.58	21	-1	>= 15	ERC mean
DASS Depression	2	4.3	37	40	>= 5	DASS Cutoffs (Lovibond and Lovibond, 1995)
DASS Anxiety	1	2.86	29	0	>= 4	DASS Cutoffs (Lovibond and Lovibond, 1995)
DASS Stress	11	11.07	33	0	>= 8	DASS Cutoffs (Lovibond and Lovibond, 1995)
PFMSS Warmth	2	2.35	3	1	>= 3	High rating (low, mod, high)
Parent Vocal Warmth Expressiveness	5	5.09	7	1	>= 5	Variable mean
CS Intune	4	3.43	5	1	>= 3	Variable mean
CS Warmth	4	3.89	5	1	>= 4	Variable mean
CS Dismissive	1	1.95	5	1	>= 2	Variable mean

Note. ICU refers to the Inventory of Callous-Unemotional Traits; GEM refers to the Griffith Empathy Scale; DASS refers to the Depression, Anxiety and Stress Scale; PFMSS refers to Preschool Five Minute Speech Sample; CS refers to the Connectedness Scale

Dummy coded variables were created based on iterated pairings of every dichotomised predictor variable: a low/ low combination, a low/high combination, a high/low combination, and a high/high combination. Dummy coded variables with less than 5 observations were removed from the analysis. Each dummy coded predictor variable was then tested in a regression equation with every acoustic-prosodic parameter to identify significant equations. As outlined in Chapter 2 the sequential goodness of fit (SGoF) test was conducted using the SGoF package version 2.3 (Castro-Conde, 2016) to correct for Type 1 error in multiple comparisons, with a p-adjusted value set at .05 significance.

To assess the performance of each model, logistic regression used deviance calculations instead of the sums of squares as for OLS. Null deviance reflects the prediction of the model using the intercept alone, while model deviance incorporates the independent variables to predict the response of the model. In logistic regression the difference between the null deviance and the model deviance is distributed like a Chi-squared; if the model deviance is less than the value for the null deviance at significance the addition of the independent variables are considered to improve model fit.

In addition, pseudo R-squared was produced in *R* using the Log-Likelihood model, and together with the Akaike Information Criterion (AIC) was used to evaluate various models predicting the same outcome. Higher pseudo R-squared and lower AIC indicated the model that better predicted the outcome of cointegration or Granger causality. The models with the best fit identified using this approach, and significant dependent variables of consequence to the research questions, are discussed in further detail in the following chapters.

3.8.3 Feature reduction

To address the third research question relating to differences in the acoustic-prosodic expressions of children with callous-unemotional traits, Pearson's zero order and first order correlations were computed to identify significant relationships between the ICU measure and the session level acoustic-prosodic means. Comparative studies of these relationships were also made on the GEM child empathy measure, the ERC measure, and selected subscales on the SDQ. Discriminant analysis (DDA) was used for feature reduction by conducting a multivariate analysis of variance test of the hypothesis that children with callous-unemotional traits differ significantly from children with low callous-unemotional traits on a linear combination of the child's acoustic-prosodic features at the session level. The DDA approach is closely aligned to the study of effects in multivariate analysis of variance (MANOVA) to identify one or more latent variables that discriminate between groups (Huberty, 1994). For comparative purposes, discriminant analysis was also conducted for the diagnostic group of ODD children and also for the group of children scoring high on prosocial traits. All discriminant function analyses were conducted in SPSS version 22.

3.8.4 Associations, linear regressions and interactions

To address the fourth research question, Pearson's correlations were run between child characteristics and ratings of the relational qualities (vocal warmth, dismissiveness, interactional warmth, attunement) to identify significant relationships between these variables. In addition, Pearson's correlations were run between the ratings of the relational qualities and the session level acoustic-prosodic means and the findings compared to the profile for the vocal emotion of tenderness. Linear regression was conducted using the high dimensional approach outlined in Chapter 2 to examine relationships between CU traits and child and maternal factors as the predictor variables, and acoustic-prosodic parameters as the response variables. Finally, acoustic-prosodic parameters associated with the mother's mental health status were examined for their relevance to the parameters identified as significant in Study 2 and Study 3.

CHAPTER 4: ACOUSTIC-PROSODIC SYNCHRONY IN MOTHER-CHILD EMOTION TALK

4.1 Chapter outline

Chapter 4 investigates evidence for acoustic-prosodic synchrony in 79 mother-child dyads engaged in a conversational task about the child's emotions. Using computational vocal feature extraction and the dynamic time series method of cointegration, results for 44 vocal parameters are reported across four domains that are relevant to vocal affect. In addition, Granger causality results, which seek to capture the direction of acoustic-prosodic information flow, are reported for all parameters. The findings are discussed in relation to the existing body of literature on synchronous mother-child relationships and acoustic-prosodic synchrony in human communication.

4.2 Introduction

Examining mechanisms for the transmission of emotion between caregivers and children is an important concern for children at risk of emotional and behavioural problems (e.g., Psychogiou et al, 2017; Tully & Donohue, 2017). One established mechanism for such transmission is mother-child synchrony, a biobehavioural phenomenon considered normative in early development (Feldman, 2007a; Feldman, 2007c; Harrist & Waugh, 2002). In the vocal channel, synchrony has been shown on a small number of prosodic parameters in a small number of mother-child dyads in the period beyond infancy (Ko et al, 2016). Synchrony has also been identified across a small number of acoustic-prosodic parameters in close adult relationships (Harma, 2014) and between adult strangers (e.g., Levitan et al, 2012). However across all studies and age groups, no studies of acoustic-prosodic synchrony have used dynamic modelling to test for adaptive relationships between vocal parameters.

To address these important gaps, this chapter reports results relating to acoustic-prosodic cointegration across a large number of parameters in a large group of mothers and their children in early childhood. As outlined in Chapter 3, Study 1 operationalised mother-child synchrony using the statistical method of cointegration to test for a dynamic relationship between the vocal parameters of mothers and their children during the course of a conversational task about the child's emotions. Based on the separate research streams relating to biobehavioural synchrony in child development, and acoustic-prosodic entrainment in adults, it was hypothesised that acoustic-prosodic synchrony would be a prevalent phenomenon in the interactions of mothers and their children aged 4-8 years.

4.3 Do children ages 4 to 8 years display acoustic-prosodic cointegration with their mothers?

Acoustic-prosodic parameters were extracted in 79 dyads using the ProsodyPro and Lennes Praat scripts. Psychoacoustic data from Prosogram was not produced for the turn-by-turn analyses due to limitations in the software at the time of feature extraction. Forty-four matching time series variables were created for each child and mother in the dyad and vector autoregressive models (VAR) built in *R*. Johansen's test of cointegration and Granger causality were conducted on each of the matched acoustic-prosodic parameters and the results produced as binary output at both $p < .01$ and $p < .05$ significance levels, where 0 = no cointegration and 1 = cointegration.

Tables 4.1 to 4.4 present the summary cointegration results divided into four domains relevant to vocal affect. Following Goudbeek and Scherer (2010), these are the frequency (pitch) domain, voice quality (spectral balance) domain, voice quality (variability) domain, and the vocal energy (amplitude) domain. Results are presented in descending order, from the parameter displaying the highest rate of cointegration in the sample (i.e., the parameter on which the greatest number of dyads were cointegrated at $p < .01$) through to the parameter displaying the lowest rate of cointegration (i.e., the parameter on which the least number of dyads were cointegrated at $p < .01$).

Table 4.1

Frequency and percentage of cointegration on parameters in the frequency (pitch) domain

Parameter	**VARs** *(N)*	**Coint.** $p < .01$ *(N)*	**Coint.** $p < .01$ (%)	**Coint.** $p < .05$ *(N)*	**Coint.** $p < .05$ (%)	**Parameter Descriptor**
F0maxlocms	63	53	84.13	56	88.89	Time of the F0 peak relative to the onset of the turn in milliseconds (ms)
F0max	63	50	79.37	56	88.89	The maximum F0 value in Hertz (Hz) within each turn
F0final	62	49	79.03	59	95.16	The F0 value near the turn offset, in Hertz (Hz)
F0min	63	49	77.78	57	90.48	The minimum F0 value in Hertz (Hz) within each turn
Fdisp1_5	68	53	77.94	61	89.71	Average distance between adjacent formants up to fifth formant (F5)
velocitymax	63	49	77.78	56	88.89	Maximum F0 velocity in semitones/s (ST) within each turn
velocityfinal	63	48	76.19	60	95.24	F0 velocity near the interval offset in semitones/s (ST) within each turn
excursion	63	48	76.19	55	87.3	The difference between maximum F0 and minimum F0 (ST)
F2midpt	76	57	75	66	86.84	The second formant value at the midpoint of each turn
Fdisp1_3	67	50	74.63	58	86.57	Average distance between adjacent formants up to the third formant (F3)
maxf0locratio	62	45	72.58	54	87.1	Relative location of the F0 peak as a proportion to the duration of the turn
F0mean	63	44	69.84	51	80.95	The mean F0 value in Hertz (Hz) within each turn
medpitch	68	43	63.24	58	85.29	Median pitch (Hertz) in each speech turn
F1midpt	66	32	48.48	46	69.7	The first formant value at the midpoint of each turn
F0midpt	38	18	47.37	27	71.05	The F0 value in Hertz (Hz) at the midpoint of each turn

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.2

Frequency and percentage of cointegration on parameters in the voice quality (spectral balance) domain

Parameter	VARs (*N*)	Coint. $p < .01$ (*N*)	Coint. $p < .01$ (%)	Coint. $p < .05$ (*N*)	Coint. $p < .05$ (%)	Parameter Descriptor
h1bh2b	69	54	78.26	60	86.96	Formant-adjusted h1-h2
energybel500	68	51	75	63	92.65	Energy of voiced segments below 500Hz (proportion between energy below 500 Hz and total energy (up to 4000 Hz)
H1A1	69	51	73.91	60	86.96	Amplitude difference between 1st harmonic and 1st formant
h1h2	69	50	72.46	60	86.96	Amplitude difference between 1st and 2nd harmonics
H1A3	69	48	69.57	60	86.96	Amplitude difference between 1st harmonic and 3rd formant
centerofgrav	69	48	69.57	56	81.16	Center of gravity (CG) measures the tilt of the spectrum, i.e., measure for the average height of frequencies in a spectrum
energybel1000	68	47	69.12	58	85.29	Energy of voiced segments below 1000Hz (proportion between energy below 1000 Hz and total energy (up to 4000 Hz)
Hammarberg	69	47	68.12	57	82.61	Difference in maximum energy between 0-2000 Hz and 2000-5000 Hz measured in decibels

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.3

Frequency and percentage of cointegration on parameters in the voice quality (variability) domain

Parameter	**VARs** *(N)*	**Coint.** $p < .01$ *(N)*	**Coint.** $p < .01$ (%)	**Coint.** $p < .05$ *(N)*	**Coint.** $p < .05$ (%)	**Parameter Descriptor**
cpp	68	52	76.47	56	82.35	Cepstral Peak Prominence (CPP): the degree of harmonic organisation, i.e., how far the cepstral peak radiates from the "background noise"
shimmer	66	47	71.21	57	86.36	Cycle-to-cycle micro-variations of amplitude (loudness)
jitter	66	45	68.18	57	86.36	The cycle-to-cycle rapid micro-variations of pitch
harmonicity	59	34	57.63	49	83.05	Harmonics-to-Noise Ratio (HNR): the proportion of harmonic sound to noise in the voice measured in decibels

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.4

Frequency and percentage of cointegration on parameters in the intensity (amplitude) domain

Parameter	**VARs** *(N)*	**Coint.** $p < .01$ *(N)*	**Coint.** $p < .01$ (%)	**Coint.** $p < .05$ *(N)*	**Coint.** $p < .05$ (%)	**Parameter Descriptor**
intensmidpt	76	57	75	66	86.84	Intensity value in decibels (dB) at the midpoint of turn
E500	68	50	73.53	60	88.24	Energy in the spectral band 0–500Hz
E2500	69	49	71.01	62	89.86	Energy in the spectral band 2000-2500Hz
E2000	69	48	69.57	59	85.51	Energy in the spectral band 1500-2000Hz
E1750	68	47	69.12	58	85.29	Energy in the spectral band 1250-1750Hz
E2250	69	47	68.12	58	84.06	Energy in the spectral band 1750-2250Hz
E3750	69	47	68.12	57	82.61	Energy in the spectral band 3250-3750Hz
E1500	68	45	66.18	58	85.29	Energy in the spectral band 1000-1500Hz

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.4 continued.

Parameter	**VARs** *(N)*	**Coint.** ***p* < .01** *(N)*	**Coint.** ***p* < .01** **(%)**	**Coint.** ***p* < .05** *(N)*	**Coint.** ***p* < .05** **(%)**	**Parameter Descriptor**
E750	69	45	65.22	56	81.16	Energy in the spectral band 250-750Hz
E1250	68	44	64.71	59	86.76	Energy in the spectral band 750-1250Hz
E1000	69	44	63.77	60	86.96	Energy in the spectral band 500-1000Hz
E2750	69	43	62.32	56	81.16	Energy in the spectral band 2250-2750Hz
E3250	69	43	62.32	53	76.81	Energy in the spectral band 2750-3250Hz
E3500	69	43	62.32	51	73.91	Energy in the spectral band 3000-3500Hz
intensmean	63	39	61.9	48	76.19	Mean intensity in decibels (dB) within each turn
energyprof250	68	42	61.76	59	86.76	Energy present in voiced segments 0-250Hz
E3000	69	41	59.42	58	84.06	Energy in the spectral band 2500-3000Hz

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

4.4 Which acoustic-prosodic parameters display cointegration?

As seen in Tables 4.1 to 4.4, all forty-four acoustic-prosodic parameters demonstrated the capacity for cointegration between mothers and their children. The three variables which showed the highest rates of cointegration were located in the frequency domain: the time of the pitch peak relative to the time of turn onset (F0maxlocms), the pitch maximum in speech turns (F0 max), and the pitch value near the turn offset (F0 final). These parameters displayed cointegration in 84.13% to 79.03% of dyads however were followed closely by variables in the spectral balance domain (formant-adjusted h1-h2), in the voice quality variability domain (Cepstral Peak Prominence; cpp), and in the energy domain (intensity value at the midpoint of turns).

The variable displaying the lowest rate of cointegration was the pitch value at the midpoint of speech turns, however an important confound was that only 38 VAR models were built for this parameter. The reason for this was due to inconsistent turn-by-turn output during acoustic-prosodic parameter extraction from the speech signal; that is, one or both speakers had missing values on this particular parameter and were not paired for the minimum number of observations required for the test. The first criterion to build the VAR model in such cases was therefore not met. This factor likely explains the comparatively low rate of cointegration identified on this parameter, given the high rates of cointegration observed on other pitch features. This missingness seems likely to have arisen from a malfunction in the script itself rather than in the audio recording, given that similar problems were not encountered during the extraction of any other parameter. For all other acoustic-prosodic parameters, a comparable number of VAR models were built across the dataset (minimum $N = 59$, maximum $N = 76$, mean $N = 67.17$, median $N = 68$).

Figures 4.1 to 4.10 provide are examples of cointegrated and non-cointegrated parameters in four acoustic-prosodic domains: frequency (pitch) domain, voice quality (spectral energy) domain, voice quality (variability) domain, and the vocal energy (amplitude) domain for particular dyads. The examples selected are parameters which demonstrated a significant relationship to child CU traits or maternal depression in the subsequent regression analyses. Two examples are provided in the pitch domain (pitch median and the second formant) due to the relevance of these parameters found across the studies in this research.

Cointegration is primarily a statistical test where the values of one variable are used to predict the values of another variable, however there are some observations that can be made regarding the figures. As can be seen in the cointegrated examples, the pattern between speakers approaches a “dance” like quality. For example, Figure 4.1 and Figure 4.3 display both predictability and proximity between each speaker’s values, while Figure 4.9 displays predictability only. In contrast, the non-cointegrated dyads displayed noticeably less predictability between each speaker’s acoustic-prosodic values (e.g., Figure 4.4 and Figure 4.6).

Frequency (pitch) domain: Median pitch

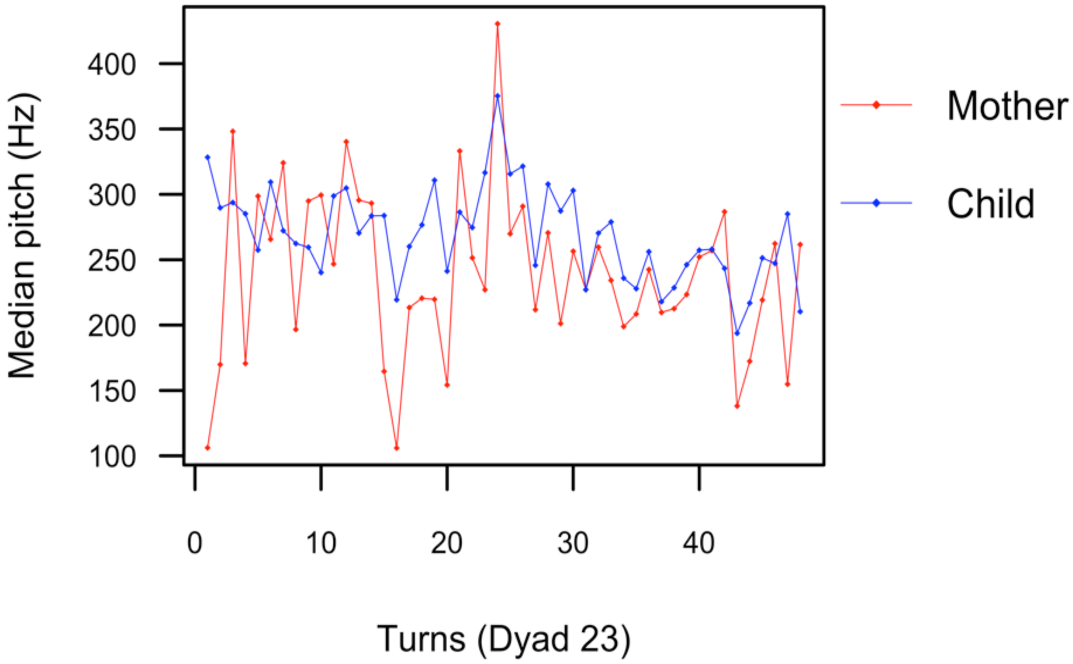

Figure 4.1 Dyad cointegrated on median pitch

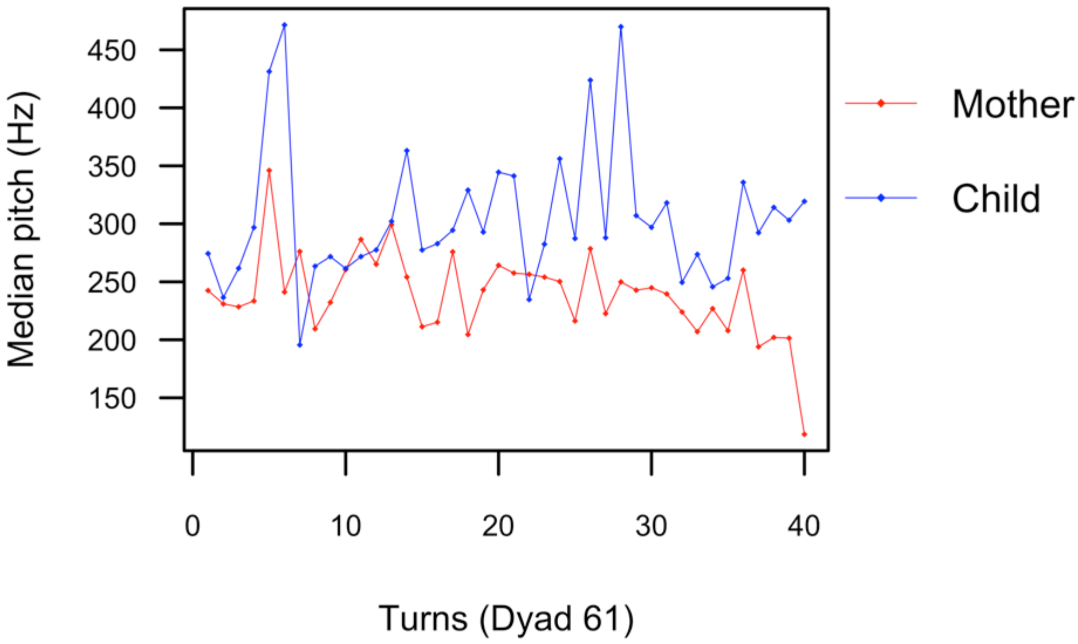

Figure 4.2 Dyad not-cointegrated on median pitch

Frequency (pitch) domain: Second formant

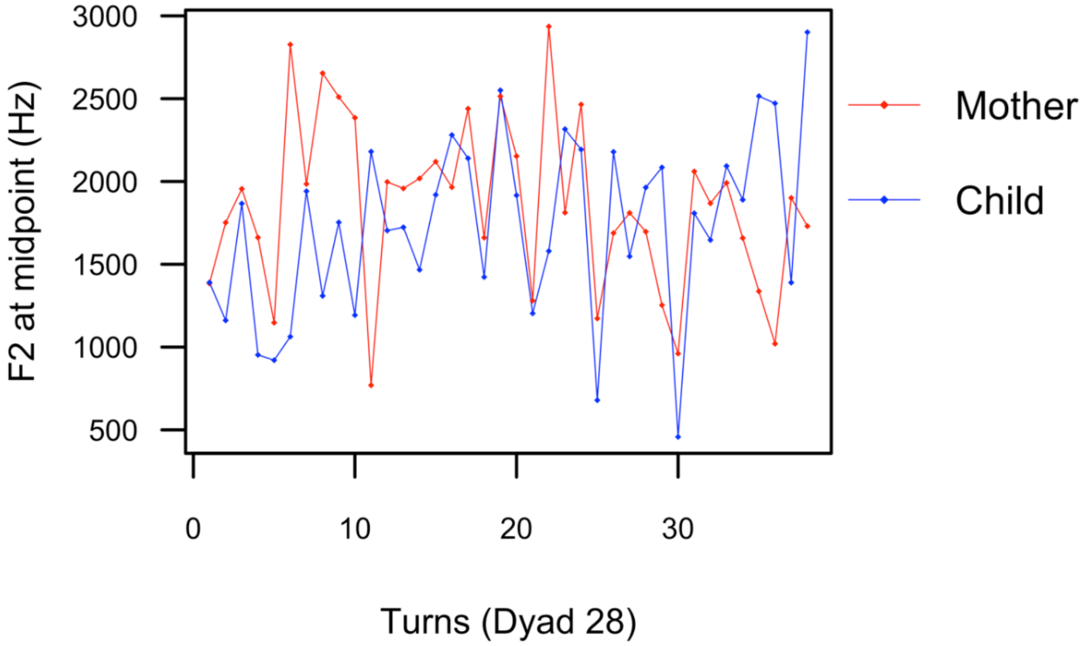

Figure 4.3 Dyad cointegrated on the second formant

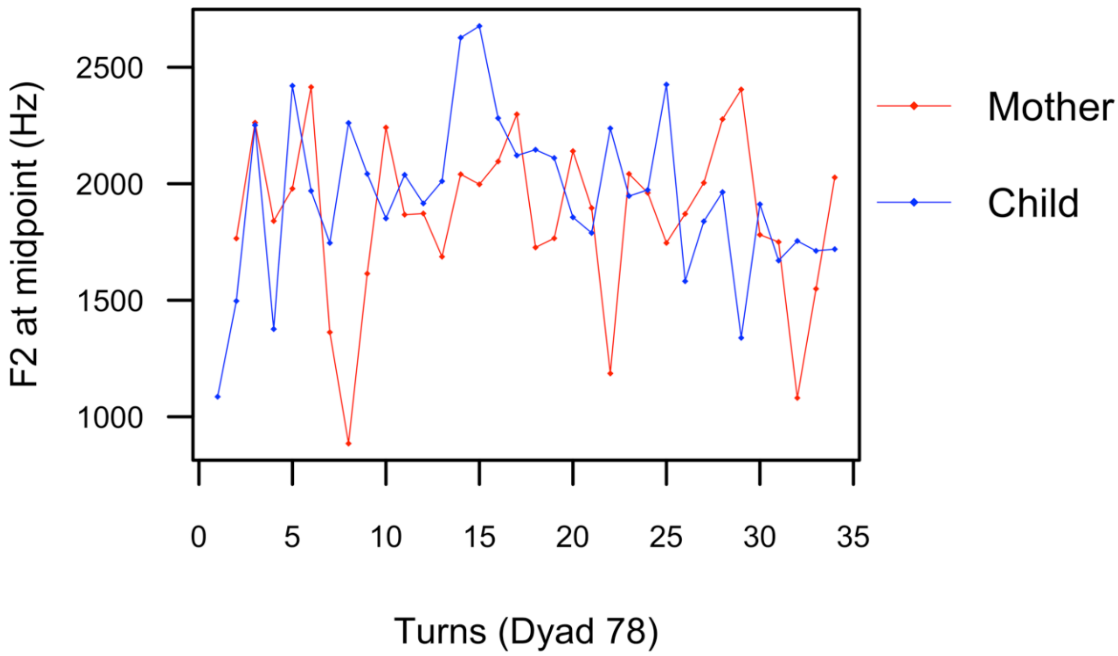

Figure 4.4 Dyad not-cointegrated on the second formant

Voice quality (variability) domain: Cepstral peak prominence (CPP)

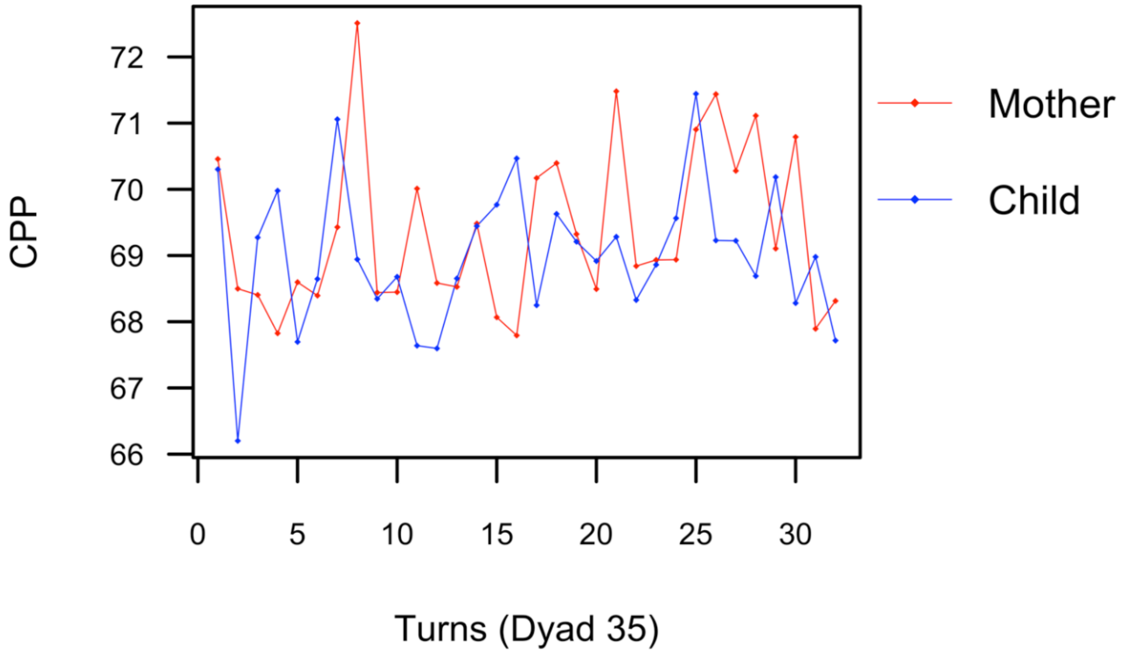

Figure 4.5 Dyad cointegrated on cepstral peak prominence

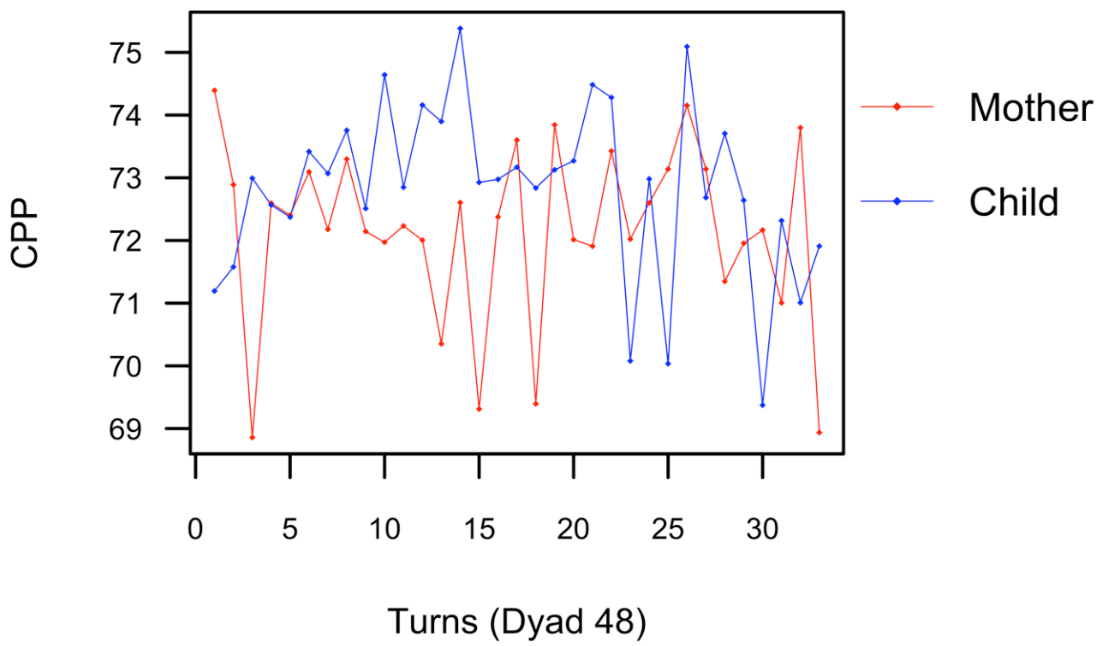

Figure 4.6 Dyad not-cointegrated on cepstral peak prominence

Voice quality (spectral balance) domain: Formant adjusted amplitude difference between the first and second harmonic (H1-H2)

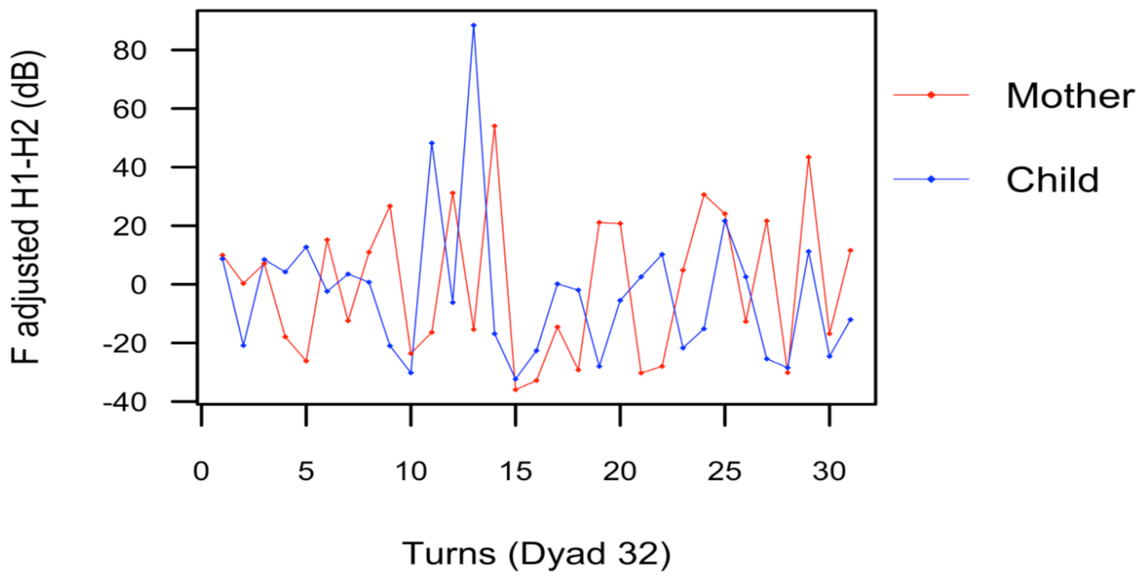

Figure 4.7 Dyad cointegrated on the formant adjusted H1-H2

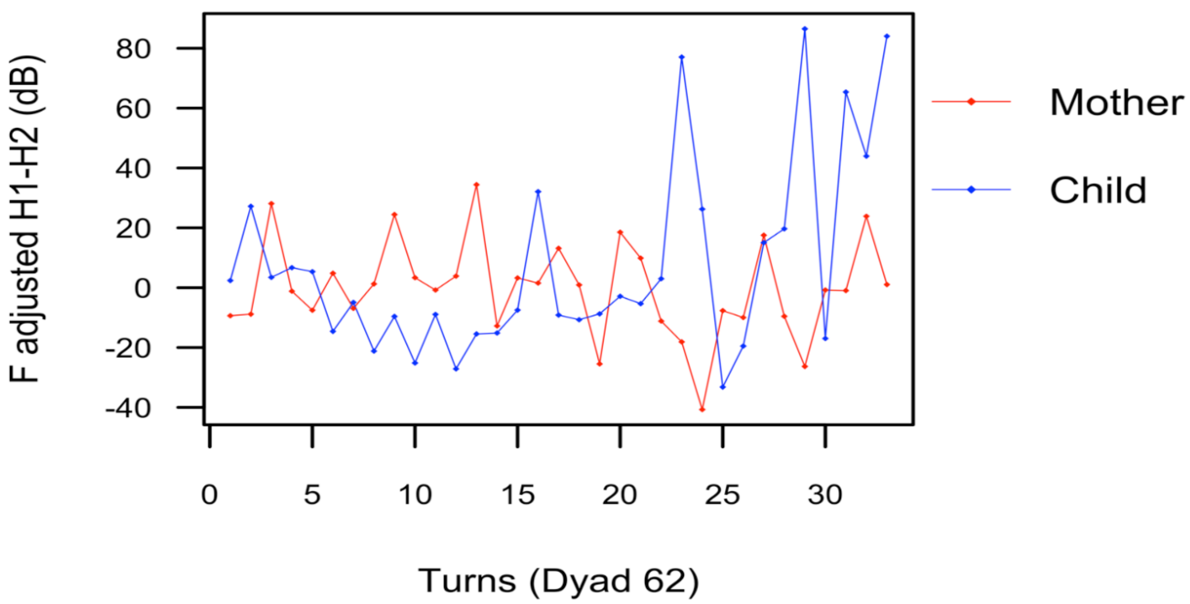

Figure 4.8 Dyad not-cointegrated on the formant adjusted H1-H2

Vocal energy (amplitude) domain: Energy profile in the spectral range 0Hz-250Hz

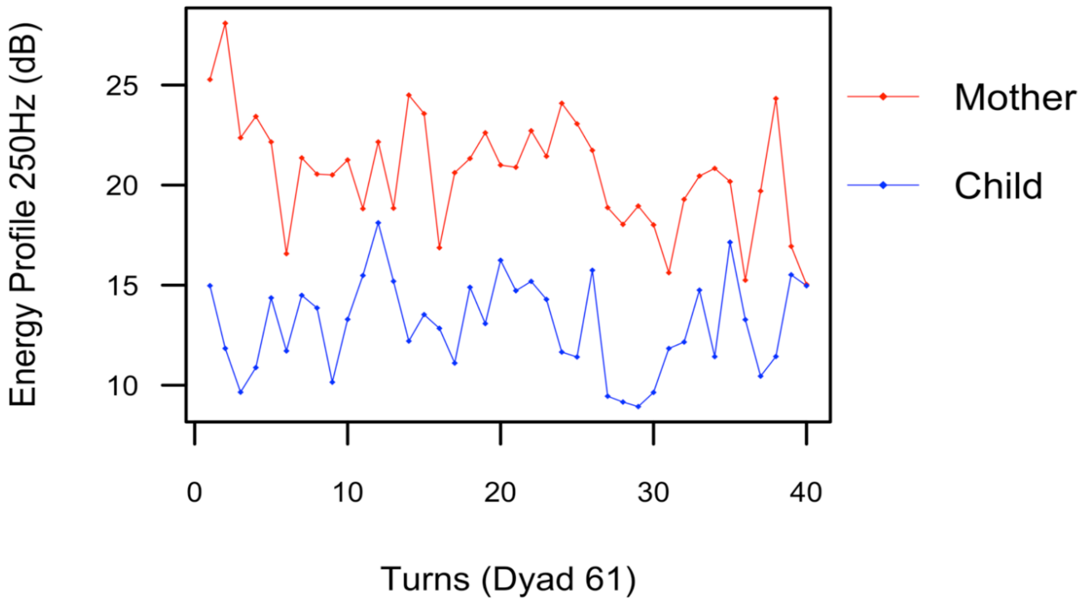

Figure 4.9 Dyad cointegrated on 250Hz energy profile

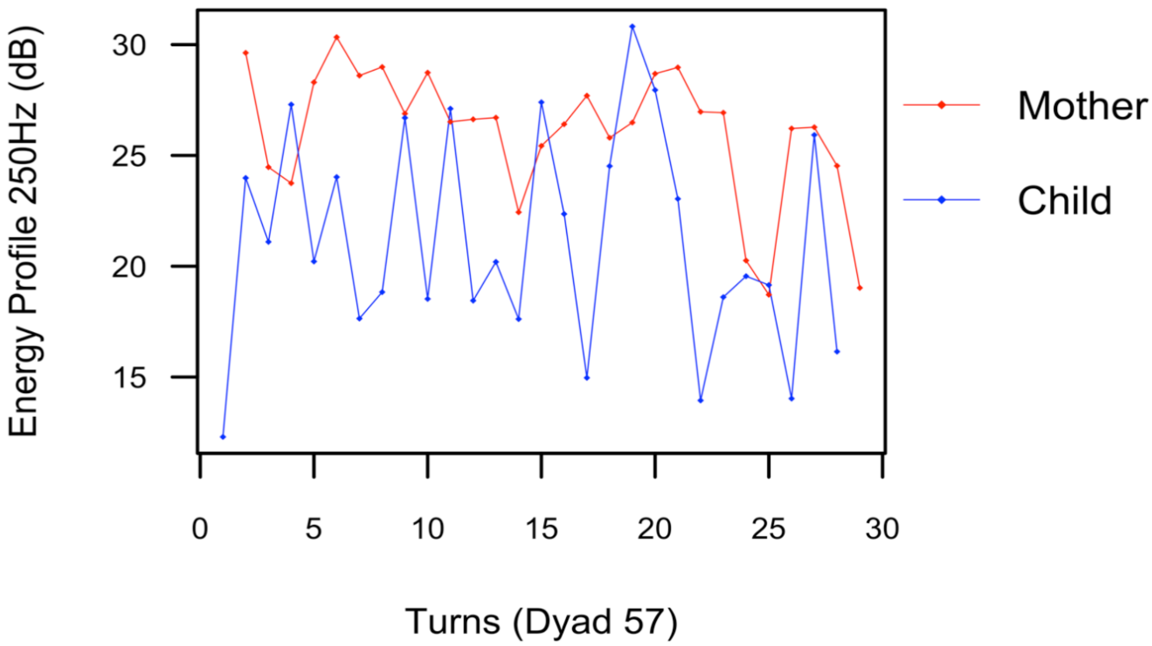

Figure 4.10 Dyad not-cointegrated on 250Hz energy profile

4.5 Which acoustic-prosodic parameters display Granger causality?

Tables 4.5 to 4.8 present the summary Granger causality results for each parameter, matched to the same order as those for the cointegration results reported in Tables 4.1 to 4.4. Granger causality was tested at both $p < .05$ and $p < .10$ significance levels with a view to identifying cases that both met and approached significance, and thus identifying parameters of potential further interest. As can be seen, the rates of Granger causality are substantially less than those seen for cointegration on the same parameter in Tables 4.1 to 4.4.

Table 4.5

Frequency and percentage of Granger causality on parameters in the frequency (pitch) domain

Parameter	**Mother to child $p < .05$ (%)**	**Child to mother $p < .05$ (%)**	**Bi-direction $p < .05$ (%)**	**Mother to child $p < .10$ (%)**	**Child to mother $p < .10$ (%)**	**Bi-direction $p < .10$ (%)**	**Parameter Descriptor**
F0maxlocms	4.76	3.17	0	7.94	6.35	0	Time of the F0 peak relative to the onset of the turn in milliseconds
F0max	9.52	6.35	1.59	22.22	9.52	1.59	The maximum F0 value in Hertz (Hz) within each turn
F0final	9.68	3.23	1.61	12.9	8.06	1.61	The F0 value near the turn offset in Hertz (Hz)
F0min	12.7	4.76	0	19.05	9.52	0	The minimum F0 value in Hertz (Hz) within each turn
Fdisp1_5	11.76	4.41	0	19.12	7.35	2.94	Average distance between adjacent formants up to fifth formant (F5)
velocitymax	9.52	4.76	0	15.87	17.46	0	Maximum F0 velocity in semitones/s (ST) within each turn
velocityfinal	7.94	7.94	0	11.11	12.7	0	F0 velocity near the interval offset in semitones/s (ST) within each turn

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.5 continued.

Parameter	Mother to child $p < .05$ (%)	Child to mother $p < .05$ (%)	Bi-direction $p < .05$ (%)	Mother to child $p < .10$ (%)	Child to mother $p < .10$ (%)	Bi-direction $p < .10$ (%)	Parameter Descriptor
excursion	17.46	3.17	0	22.22	6.35	1.59	The difference between maximum F0 and minimum F0 (ST)
F2midpt	9.21	6.58	1.32	14.47	11.84	1.32	The second formant value at the midpoint of each turn
Fdisp1_3	8.96	1.49	0	13.43	5.97	1.49	Average distance between adjacent formants up to the third formant (F3)
maxf0locratio	8.06	1.61	0	20.97	6.45	1.61	Relative location of the F0 peak as a proportion to the duration of turn
F0mean	6.35	4.76	0	15.87	7.94	1.59	The mean F0 value in Hertz (Hz) within each turn
medpitch	14.71	7.35	2.94	20.59	11.76	4.41	Median pitch (Hertz) in each speech turn
F1midpt	3.03	3.03	0	12.12	3.03	0	The first formant value at the midpoint of each turn
F0midpt	15.79	2.63	0	23.68	10.53	2.63	The F0 value in Hertz (Hz) at the midpoint of each turn

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.6

Frequency and percentage of Granger causality on parameters in the voice quality (spectral balance) domain

Parameter	Mother to child $p < .05$ (%)	Child to mother $p < .05$ (%)	Bi-direction $p < .05$ (%)	Mother to child $p < .10$ (%)	Child to mother $p < .10$ (%)	Bi-direction $p < .10$ (%)	Parameter Descriptor
h1bh2b	4.35	5.8	5.8	5.8	0	0	Formant-adjusted h1-h2
energybel500	8.82	14.71	4.41	10.29	0	1.47	Energy of voiced segments below 500Hz (proportion between energy below 500 Hz and total energy (up to
H1A1	4.35	8.7	1.45	7.25	0	1.45	Amplitude difference between 1st harmonic and 1st formant
h1h2	4.35	8.7	4.35	10.14	0	0	Amplitude difference between 1st and 2nd harmonics
H1A3	5.8	8.7	5.8	11.59	0	0	Amplitude difference between 1st harmonic and 3rd formant
centerofgrav	8.7	14.49	5.8	15.94	1.45	1.45	Center of gravity (CG) measures the tilt of the spectrum, i.e., measure for the average height of frequencies in a
energybel1000	10.29	16.18	8.82	13.24	0	1.47	Energy of voiced segments below 1000Hz (proportion between energy below 1000 Hz and total energy (up to
Hammarberg	5.8	10.14	7.25	17.39	0	4.35	Difference in maximum energy between 0-2000 Hz and 2000-5000 Hz measured in decibels

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.7

Frequency and percentage of Granger causality on parameters in the voice quality (variability) domain

Parameter	**Mother to child $p < .05$ (%)**	**Child to mother $p < .05$ (%)**	**Bi-direction $p < .05$ (%)**	**Mother to child $p < .10$ (%)**	**Child to mother $p < .10$ (%)**	**Bi-direction $p < .10$ (%)**	**Parameter Descriptor**
cpp	8.82	4.41	0	14.71	8.82	1.47	Cepstral Peak Prominence (CPP): the degree of harmonic organisation, i.e., how far the cepstral peak radiates from
shimmer	7.58	7.58	0	7.58	15.15	1.52	Cycle-to-cycle micro-variations of amplitude (loudness)
jitter	7.58	3.03	0	10.61	10.61	0	The cycle-to-cycle rapid micro-variations of pitch
harmonicity	8.47	10.17	0	13.56	15.25	0	Harmonics-to-Noise Ratio (HNR): proportion of harmonic sound to noise in the voice measured in decibels

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.8

Frequency and percentage of Granger causality on parameters in the intensity (amplitude) domain

Parameter	Mother to child $p < .05$ (%)	Child to mother $p < .05$ (%)	Bi-direction $p < .05$ (%)	Mother to child $p < .10$ (%)	Child to mother $p < .10$ (%)	Bi-direction $p < .10$ (%)	Parameter Descriptor
intensmidpt	11.84	7.89	0	17.11	11.84	0	Intensity value in decibels (dB) at the midpoint of turn
E500	10.29	5.88	0	16.18	14.71	4.41	Energy in the spectral band 0–500Hz
E2500	5.8	10.14	0	13.04	17.39	1.45	Energy in the spectral band 2000-2500Hz
E2000	5.8	5.8	0	15.94	15.94	4.35	Energy in the spectral band 1500-2000Hz
E1750	13.24	11.76	1.47	20.59	19.12	5.88	Energy in the spectral band 1250-1750Hz
E2250	8.7	5.8	1.45	14.49	15.94	4.35	Energy in the spectral band 1750-2250Hz
E3750	8.7	11.59	2.9	14.49	20.29	2.9	Energy in the spectral band 3250-3750Hz
E1500	19.12	17.65	2.94	25	27.94	8.82	Energy in the spectral band 1000-1500Hz

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

Table 4.8 continued.

Parameter	**Mother to child $p < .05$ (%)**	**Child to mother $p < .05$ (%)**	**Bi-direction $p < .05$ (%)**	**Mother to child $p < .10$ (%)**	**Child to mother $p < .10$ (%)**	**Bi-direction $p < .10$ (%)**	**Parameter Descriptor**
E750	11.59	11.59	1.45	24.64	18.84	4.35	Energy in the spectral band 250-750Hz
E1250	8.82	7.35	0	11.76	16.18	0	Energy in the spectral band 750-1250Hz
E1000	13.04	8.7	0	23.19	21.74	0	Energy in the spectral band 500-1000Hz
E2750	8.7	8.7	0	14.49	17.39	1.45	Energy in the spectral band 2250-2750Hz
E3250	10.14	7.25	0	18.84	13.04	1.45	Energy in the spectral band 2750-3250Hz
E3500	11.59	14.49	2.9	17.39	20.29	2.9	Energy in the spectral band 3000-3500Hz
intensmean	4.76	9.52	0	17.46	19.05	1.59	Mean intensity in decibels (dB) within each turn
energyprof250	8.82	7.35	1.47	14.71	17.65	4.41	Energy present in voiced segments 0-250Hz
E3000	11.59	5.8	0	14.49	13.04	0	Energy in the spectral band 2500-3000Hz

Note. Ranked in order of most frequently cointegrated to least frequently cointegrated based on percentage at $p < .01$

4.6 Between dyad differences and acoustic-prosodic cointegration ages 4 to 8 years

Table 4.9 reports the number of acoustic-prosodic parameters on which each dyad displayed cointegration ($p < .01$) and Granger causality ($p < .05$). Forty-five dyads (56.96%) displayed cointegration on more than half of the acoustic-prosodic parameters examined in their interaction, while a minority of dyads (12.65%) were cointegrated on all 44 acoustic-prosodic variables. Therefore, while cointegration on acoustic-prosodic features in mother-child emotion talk was a prevalent phenomenon, it was also dyad specific.

Table 4.9

Number of parameters per dyad displaying cointegration and Granger causality

Dyad ID (*N* = 79)	Child age (mths)	Child gender (0 = male)	Mother Talk Time* (%)	Child Talk Time* (%)	*N* Variables per dyad Cointegration ($p < .01$)	*N* Variables per dyad Granger mother to child ($p < .05$)	*N* Variables per dyad Granger child to mother ($p < .05$)	*N* Variables per dyad Granger bidirectional ($p < .05$)
1	69	0	40.49	8.48	11	0	0	0
2	55	0	29.43	32.44	32	3	3	1
3	103	0	50.44	20.07	44	6	12	1
4	97	0	44.32	27.48	40	3	5	1
5	95	0	21.23	9.30	6	2	0	0
7	100	1	33.61	34.50	18	1	7	0
8	90	0	40.60	18.38	44	3	0	0
10	67	0	42.74	13.84	17	4	3	0
11	107	1	25.21	33.26	37	2	3	1
12	66	0	34.99	21.10	3	4	0	0
13	68	1	41.56	17.58	37	4	0	0
14	101	0	38.61	24.49	2	0	2	0
15	58	1	35.90	21.59	31	8	1	0
16	75	1	40.88	27.84	18	1	4	0
17	99	1	46.18	16.71	22	2	0	0
18	62	0	40.44	22.30	39	3	0	0
20	58	0	31.15	15.83	36	1	6	0
21	75	0	30.57	41.59	3	0	0	0
22	56	0	31.55	27.12	41	13	14	5
23	80	0	28.80	27.94	39	2	1	0
24	49	0	38.24	35.74	37	2	0	0
25	68	0	42.22	23.41	14	4	4	0
26	49	0	28.81	26.12	14	4	1	0

Note. *Does not include overlaps and pauses; Green = Cointegration on 22 (50%) or more parameters per dyad; Yellow = Granger causality on five (11%) or more parameters per dyad; Red = Granger bidirectional causality on one or more parameters per dyad.

Table 4.9 continued.

Dyad ID (N = 79)	Child age (mths)	Child gender (0 = male)	Mother Talk Time* (%)	Child Talk Time* (%)	*N* Variables per dyad Cointegration ($p < .01$)	*N* Variables per dyad Granger mother to child ($p < .05$)	*N* Variables per dyad Granger child to mother ($p < .05$)	*N* Variables per dyad Granger bidirectional ($p < .05$)
27	65	0	34.65	38.71	19	4	5	0
28	63	0	36.90	32.14	37	3	3	0
29	72	0	43.54	23.91	35	6	2	0
30	58	1	44.82	26.60	4	1	0	0
31	54	0	46.29	15.75	10	2	2	1
32	99	0	43.65	17.44	22	4	6	0
33	77	0	34.85	30.79	41	2	3	0
34	70	0	30.35	31.31	12	3	4	0
35	86	1	42.90	22.51	18	1	3	0
37	61	0	45.06	25.58	43	2	1	1
39	56	0	9.50	47.39	29	4	4	0
40	55	1	41.60	21.28	34	2	2	0
41	80	1	42.52	22.97	20	6	1	0
42	92	0	27.24	33.88	8	4	2	0
43	54	1	43.01	27.46	12	8	1	0
44	54	1	38.54	18.52	0	0	0	0
45	63	0	50.68	24.31	44	3	4	0
46	51	0	30.79	28.12	1	3	1	0
48	67	0	23.93	31.67	24	4	2	0
49	90	1	26.37	23.23	3	0	0	0
50	58	0	35.81	16.73	44	5	2	2
51	54	1	45.07	21.84	2	0	0	0
52	50	0	47.91	26.44	44	1	3	0
53	54	1	31.35	22.55	1	1	1	0
54	90	0	38.89	28.06	39	12	1	0
55	50	0	38.17	30.08	17	6	1	0
56	48	0	40.91	38.64	10	4	3	0
57	74	1	53.77	13.47	33	1	9	0

Note. *Does not include overlaps and pauses; Green = Cointegration on 22 (50%) or more parameters per dyad; Yellow = Granger causality on five or more parameters per dyad; Red = Granger bidirectional causality on one or more parameters per dyad.

Table 4.9 continued.

Dyad ID (N = 79)	Child age (mths)	Child gender (0 = male)	Mother Talk Time* (%)	Child Talk Time* (%)	N Variables per dyad Cointegration ($p < .01$)	N Variables per dyad Granger mother to child ($p < .05$)	N Variables per dyad Granger child to mother ($p < .05$)	N Variables per dyad Granger bidirectional ($p < .05$)
58	51	0	43.64	28.71	44	1	0	0
59	102	1	41.53	23.47	41	5	0	0
60	99	0	41.23	9.33	20	4	2	0
61	94	0	46.44	15.34	40	2	3	0
62	79	0	31.99	16.69	19	4	2	0
63	99	1	42.91	23.74	35	2	4	0
64	104	0	41.49	19.85	42	6	1	0
65	86	0	45.89	17.12	32	14	4	3
66	62	0	34.69	8.23	12	3	1	0
67	71	0	47.92	12.87	23	5	2	0
68	82	1	44.73	26.16	43	2	1	0
69	69	0	34.32	26.89	44	3	3	0
70	56	1	44.22	7.25	0	0	0	0
71	96	1	42.15	26.90	18	1	1	0
72	57	1	44.74	25.70	37	6	3	0
73	71	0	25.29	22.60	16	4	2	0
74	102	1	36.54	22.99	44	9	3	0
75	53	0	6.53	17.20	0	0	0	0
76	97	0	30.78	30.54	8	4	4	0
77	51	0	31.44	27.71	25	0	1	0
78	92	0	38.30	34.88	21	4	0	0
79	49	1	37.78	20.80	33	4	1	0
80	92	1	48.84	21.38	44	4	2	0
81	66	0	45.35	18.49	42	6	4	0
82	58	1	40.87	22.76	44	3	10	0
83	67	0	36.62	18.33	38	1	0	0
84	53	0	31.11	19.27	41	6	1	0
85	80	1	30.73	27.19	39	2	9	0

Note. *Does not include overlaps and pauses; Green = Cointegration on 22 (50%) or more parameters per dyad; Yellow = Granger causality on five or more parameters per dyad; Red = Granger bidirectional causality on one or more parameters per dyad.

4.7 Discussion

A number of fundamental questions were addressed by this study. The first was whether acoustic-prosodic synchrony is a prevalent occurrence in the interactions of mothers and their children beyond the infant period. To address this question, this study examined a large number of parameters in a comparatively large sample of mother-child dyads. Synchrony was operationalised using the statistical approach of cointegration, a technique situated in the field of dynamic time series methods that sought to capture the adaptive, interactive nature of human communication.

As hypothesised, this study found widespread evidence for cointegration across acoustic-prosodic parameters, supporting the view that affective prosody is an element of mother-child communication that displays the capacity for synchrony in early childhood. While cointegration on every acoustic-prosodic parameter examined in the emotion talk seems a surprisingly pervasive phenomenon, this is consistent with both evolutionary theory (e.g., Feldman, 2015c; 2017) and empirical research regarding the normative function of mother-child synchrony (e.g., Davis et al, 2017; 2018).

It is also consistent with the sparse research to date on acoustic-prosodic synchrony in this age group, which has examined a small number of dyads and a small number of vocal parameters (Ko et al, 2016). In fact, across all age groups including adulthood, studies have been limited to examining a small group of acoustic-prosodic features (e.g., Borrie et al, 2015; Harma, 2014). Therefore, the current study significantly expands the number of parameters that have been shown to synchronise between two speakers.

Nevertheless, it should be noted that in contrast to the current work some studies on acoustic-prosodic synchrony in adult dyads have not found evidence for synchrony on every parameter (Lubold & Pon-Barry, 2014). Some key differences exist between previous studies and the current one. The first important difference is the nature of the relationships being examined. Mother-child interactions from early to middle childhood reflect communicative dynamics that have been established across proximal and repeated interactions during critical periods of human physiological and psychological development. In addition, as all mother-child dyads in the current study involved biological offspring, it is also conceivable that there are genetic influences that may be contributing to the results.

In contrast, studies on acoustic-prosodic synchrony in adulthood are typically conducted using stranger dyads engaged in a co-operative task, and thus dyad members do not have pre-existing relationships or shared environmental or genetic factors that may be contributing to long-run processes that are captured in an observational study. Studies on acoustic-prosodic entrainment in adults have also used statistical methods based on static models such as *t* tests (e.g., Levitan & Hirschberg, 2011). In comparison, it is argued that cointegration is a more sensitive statistical measure that is able to capture the feedback inherent in dynamic systems.

Where cointegration identifies the existence of a long-run relationship between variables, Granger causality tests attempt to elucidate the nature of the relationship over the short-run, that is, the direction of information flow. In the current study, the rates of Granger causality were substantially less than those seen for cointegration on the same parameter and within the same dyad. However the Granger representation theory (Engle & Granger, 1987) states that when cointegration occurs it is generated by an error correction mechanism and that Granger causality must be occurring in one or both directions.

As identified by Toda and Phillips (1994), a loss of power is unavoidable when conducting Granger causality testing in cointegrated systems because the sequential nature of the test places a high statistical demand on the sample size, in this case, the number of speech turns. This particular problem likely arose from the use of a convenience dataset in which there was no set minimum length required for the emotion talk task, resulting in those cases being underpowered for the test. In addition, causal relationships that are not apparent in bivariate testing can arise from the influence of a third or omitted variable, which in this case may be the movement of another vocal parameter. Therefore tests of multi-cointegration between different types of vocal parameters may prove a fruitful avenue of further work.

Noting the above limitations, there was evidence that the mother Granger-caused the child's acoustic-prosodic values more frequently than the child Granger-caused the mother's values (in 41 dyads or 52% of the total sample), while in 21 dyads (26%) there was evidence that the child more frequently Granger-caused the mother's acoustic-prosodic values. In 17 dyads (22%) there were equal rates of influence for both the mother and the child for Granger-causing each other's acoustic-prosodic values.

Some dyads showed higher rates of influence by either speaker compared to the rest of the sample, i.e., in 17 dyads (21.51%) there was evidence that the mother Granger-caused the child's values on 5 or more of the child's acoustic-prosodic features, while in 10 dyads the child Granger-caused their mother's values on 5 or more of the mother's acoustic-prosodic features (12.65%). However it can be said that, across all acoustic-prosodic parameters, both mothers and children display the capacity to influence the other's values. The findings have implications for the vocal channel as a source of emotional contagion, implications that are discussed in the subsequent chapters.

As previously discussed, the existence of cointegration implies that there must be Granger causality in one or both directions. It should also be noted that some dyads showed Granger causality on more parameters than they demonstrated cointegration. In such cases, i.e., where there is evidence of Granger causality but not cointegration on a particular variable, there are also likely to be omitted variables in the model (Stern & Enflo, 2013). In speech, it is probable that the omitted variables relate to acoustic-prosodic parameters

(Moore, 2012) missing from the bivariate VAR models. Therefore, Granger causality results occurring in the absence of cointegration must be interpreted with additional caution, as omitted variables can contribute to either over-estimation or under-estimation of the effects of one or more of the predictor variables. As above, future work may address this concern by testing for multi-cointegration concurrently on multiple parameters.

In sum, this is the first study to find evidence for cointegration on acoustic-prosodic parameters in speaker interactions, the first to identify its prevalence across a large number of parameters, and the first to detect the capacity for both mothers and their children to Granger-cause each other's acoustic-prosodic communication. However, while all forty-four acoustic-prosodic variables showed evidence of cointegration, there were significant between dyad differences in this prevalence. While forty-four dyads were cointegrated on fifty percent or more of the parameters in their speech, sixteen dyads were cointegrated on less than a quarter of parameters, and a minority showed very little or no evidence of cointegration. These findings raise questions about the factors that might be contributing to such differences, and attention will now be turned to investigating the potential correlates of those differences.

CHAPTER 5: ACOUSTIC-PROSODIC SYNCHRONY AND CHILD CALLOUS-UNEMOTIONAL TRAITS

5.1 Chapter outline

This chapter investigates cointegration on vocal features between mothers and their children and its relationship to callous-unemotional (CU) traits. The chapter reports results for all acoustic-prosodic parameters that demonstrated a significant main effect with the Inventory of Callous-unemotional Traits (ICU) Total Score as well as in interaction with other child and maternal characteristics. For comparative purposes, this chapter also reports significant results relating to children with a diagnosis of Oppositional Defiant Disorder (ODD) and children high in empathy. The findings are considered in the context of the literature on mother-child synchrony and CU traits, and the implications for the vocal channel as a source of emotion transference and empathy development are discussed.

5.2 Introduction

In the period beyond infancy, the literature to date on mother-child vocal synchrony has examined a small number of prosodic parameters in a small number of mother-child dyads (Ko et al, 2016). Chapter 4 expanded substantially on this literature by identifying the presence of synchrony as a dynamic phenomenon across a large number of acoustic-prosodic parameters in a large sample of mother-child dyads with school aged children. However, significant between-dyad differences were observed in the prevalence of this phenomenon across the dataset.

Due to the deficits in emotional arousal and emotion recognition that characterise the high CU population, it was hypothesised that child CU traits would be associated with disruption to synchrony on a number of emotion relevant vocal parameters, particularly in the principal domains of frequency (pitch) and intensity (amplitude), as well as on spectral balance parameters (e.g., Hammarberg Index, formants, and spectral slope and harmonic differences). The current study was inclusive of as many vocal parameters as possible due to the absence of prior studies in this area and the large number of acoustic-prosodic parameters associated with vocal emotion in previous studies (e.g., see Eyben et al, 2016 for 88 emotion relevant parameters). The purpose was to test a hypothesis of a pervasive pattern of disruption on emotion relevant cues and to identify parameters of potential relevance to future studies of callous-unemotional traits.

Given the limited literature on vocal synchrony and child and maternal characteristics, interactions between callous-unemotional traits (ICU) and other child and maternal factors were tested using the high dimensional methods outlined in Chapter 2. It was hypothesised that poor maternal mental health would be related to disruption on emotion relevant parameters due to the disruption to mother-child synchrony associated with maternal depression in previous studies (e.g., Feldman & Eidelman, 2007; Woody et al, 2016).

In addition, due to the centrality of the concept of emotion transference to the synchrony construct, it was hypothesised that high levels of child empathy (as measured by the Griffith Empathy Measure; GEM) would predict positive relationships with mother-child synchrony on emotion relevant parameters. Finally, it was hypothesised that children high in emotionality, specifically those with an ODD diagnosis or children otherwise scoring highly on emotional lability (as measured by the Emotion Regulation Checklist; ERC) and on internalising symptoms (as measured by the Strengths and Difficulties Questionnaire; SDQ), would not show disruption to synchrony on emotion relevant parameters.

5.3 Analytical approach

5.3.1 Probabilities of cointegration and Granger causality

As outlined in Chapter 3, logistic regression was used to test these hypotheses. The dependent variables were the binary cointegration (cointegrated/ not cointegrated) and Granger causality (Granger causality/ no Granger causality) results and the predictor variables were the child and maternal factors in the dataset. The probability that the dependent variable was cointegrated (1) versus not cointegrated (0) was modelled using the following equation:

$$P\{Y = 1\} = \frac{1}{1 + e^{-t}}$$

As outlined in Chapter 3, interactions were incorporated using binary interaction regressors for clinical utility. That is, dichotomised variables for each of the child and maternal predictors (low/ high groups) were established as membership above and below cutoffs based on previous clinical literature (Table 3.3). The numbers for each of these groups are reported in Table 3.1. The cutoff for children scoring at or above 24 on mother-ratings on the ICU was adopted based on work by Kimonis et al (2014) which used a large community-based sample of school-aged children (*N* = 1,370) and a mixed cross-sectional and longitudinal design to predict future instrumental aggression. Although this cutoff is lower than is typical in studies in this clinical group, it was selected to potentially identify those children trending toward anti-social features that might be signalled by disruption to synchrony with their mothers at an early or possibly prodromal stage.

These dichotomised factors were entered into the equations as dummy coded interaction regressors, with each dyad assigned to membership in one of four mutually exclusive groups using binary coding (0, 1). For example, dyads who were members of the Low child CU/ Low maternal depression group were coded as dummy variable D00 and assigned a value of 1 for that combined variable. Exponents for the interactions between each X1 and X2 (low/low; low/high; high/low; high/high) were calculated and iteratively tested with the quantitative predictors in the regression equations where the exponent of the Euler's number was regressed on the data:

$$P\{Y=1|X;\beta\} = \frac{1}{1+e^{-\{\beta_0+\beta_1 x_1+\beta_2 x_2+\beta_{00}\delta_{00}+\beta_{01}\delta_{01}+\beta_{10}\delta_{10}+\beta_{11}\delta_{11}+\varepsilon\}}}$$

These dummy coded interaction regressors are functions of the continuous X1 and X2 but are not linear functions; the models incorporate different slopes for the different groups and the coefficient for each dummy regressor provides constant separation between the regression surfaces (Fox, 1997), avoiding the problem of colinearity.

The SGoF multi-test identified the subset of acoustic-prosodic parameters that met $p < .05$ significance for each predictor in the model as well as for the whole model (the Chi square p). Models that met these criteria were then selected for analysis based on the principle of marginality (Fox, 1997); that is, significant models must include both the higher order term (the interaction term) and both lower order relatives of the term (each of the main effects) to optimise applicability of the results. Given the exploratory nature of the study, results are also reported for models in which the interactions met significance but included only CU as the lower order relative in the model. In a similar vein, results that met these criteria are reported for the GEM empathy measure and for ODD diagnosis. Results are presented in Tables 5.1 to 5.4 with additional statistical data for the models available in Appendix F.

Odds ratios are a commonly reported statistic in logistic regression and are computed by exponentiating the regression coefficient. Odds ratios reflect the likelihood of obtaining a value of 0 or 1 on a binary response variable; odds ratios range from - infinity to + infinity, and a large odds ratio indicates that the relationship between the reference group and the alternative group is large. Even if an odds ratio between the groups is large, the probability of that outcome can still be small, and the reverse is also true. Odds ratios are stated in the chapter for those models with main, or additive, effects.

However, it is particularly challenging to interpret the effects of *interactions* in regression models that incorporate dummy coded predictors against a binary response variable simply by examining the regression coefficients (Fox, 1997). To aid interpretation of the direction of effects for each of the interaction models, four additional exponents were estimated from the dataset. These four additional exponents represent the expected value of Y (i.e., the dyad being cointegrated, or evidence for Granger causality) for each possible combination of the minimum and maximum values of X1 and X2 *when accounting for the influence of the interaction coefficient*. Each exponent is then transformed into a probability. Said another way, the probabilities are mathematical extrapolations from the dataset and reflect the likelihood of obtaining a 1 on the response variable for cases at the observed extremities of X given the interaction effect.

Caution is required regarding the size of the probabilities as this type of modified extreme groups approach (EGA) typically results in estimates for the standardised effect size being upwardly biased (Preacher et al, 2005). However, as an interpretative guide in complex regression models it enables a straightforward comparison of both the direction and dominance of effects across the various predictors. This approach is particularly helpful as a guide in studies in which there is little or no prior research relating to the effects of the various predictors on the response variables, as power is known to increase at the edge of the independent variable in linear models (Preacher, 2015). These probabilities are reported in tables and graphed to visualise the trends in the data.

It is important to note that this extreme groups approach was used only in estimating the probabilities on binary response variables; the coefficients and odds ratios relating to X1 and X2 represent the continuous values in the dataset, and the coefficients for the dummy coded variables reflect dyad membership falling above and below the clinical cutoff on those continuous factors. The following examples illustrate the analytical approach.

Cointegration on median pitch (Hertz) in speech turns

Y	Cointegration on median pitch in speech turns
X_1	ICU Total
X_2	DASS Depression

Pseudo R^2	0.336 (Likelihood Ratio)
Chi_p_value	9.87E-05
SGoF p value	8.74E-08
Null_dev	54.783
Null_dev_df	61
Res_dev	36.337
Res_dev_df	59
AIC	42.337

$\beta_0 =$ 6.1614 (LL 3.278, UL 10.261) ($p = .0003$)
$\beta_1 = -0.1194$ (LL -0.226, UL -0.034) ($p = .012$)
$\beta_2 = -0.1350$ (LL -0.287, UL -0.021) ($p = .042$)

$$P\{Y = 1|X; \beta\} = \frac{1}{1 + e^{-\{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon\}}}$$

Predicted probabilities of *y* based on minimum and maximum values for *x*1 and *x*2 accounting for the interaction coefficient:

δ_{00}	Min ICU/ Min maternal depression ($x_1 = 0$ and $x_2 = 0$): 99.39% probability
δ_{01}	Min ICU/ Max maternal depression ($x_1 = 0$ and $x_2 = 37$): 52.27% probability
δ_{10}	Max ICU/ Min maternal depression ($x_1 = 59$ and $x_2 = 0$): 29.16% probability
δ_{11}	Max ICU/Max maternal depression ($x_1 = 59$ and $x_2 = 37$): 00.28% probability

Cointegration on formant adjusted amplitude difference between 1st and 2nd harmonics (H1b-H2b) values in speech turns

Y	Cointegration on formant adjusted amplitude difference between harmonics
X_1	ICU Total
X_2	DASS Depression
δ_{00}	Low ICU/ Low maternal depression ($x_1 \leq 24$ and $x_2 \leq 4$)
δ_{10}	High ICU/ Low maternal depression ($x_1 \geq 24$ and $x_2 \leq 4$)

Pseudo R^2	0.301 (Likelihood_Ratio_R2L)
Chi_p value	.0004
SGoF p value	.0162
Null_dev	66.742
Null_dev_df	62

Res_dev	46.623
Res_dev_df	58
AIC	56.623

$\beta_0 =$ 9.4634 (LL 6.535, UL 12.391) $(p = .001)$
$\beta_1 =$ -0.1266 (LL -0.183, UL -0.069) $(p = .025)$
$\beta_2 =$ -0.3850 (LL -0.529, UL -0.240) $(p = .007)$
$\beta_{00} =$ -5.6957 (LL -7.824, UL -3.566) $(p = .007)$
$\beta_{10} =$ -3.3264 (LL -4.950, UL -1.702) $(p = .040)$

$$P\{Y = 1|X; \beta\} = \frac{1}{1 + e^{-\{\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{00}\delta_{00} + \beta_{10}\delta_{10} + \varepsilon\}}}$$

Predicted probabilities of *y* based on minimum and maximum values for *x*1 and *x*2 accounting for the interaction coefficient:

δ_{00} Min ICU/ Min maternal depression ($x_1 = 0$ and $x_2 = 0$): 93.26% probability
δ_{01} Min ICU/ Max maternal depression ($x_1 = 0$ and $x_2 = 37$): 00.27% probability
δ_{10} Max ICU/ Min maternal depression ($x_1 = 59$ and $x_2 = 0$): 20.82% probability
δ_{11} Max ICU/ Max maternal depression ($x_1 = 59$ and $x_2 = 37$): 00.00% probability

5.4 Results

Table 5.1 and Table 5.2 identifies the subset of the acoustic-prosodic parameters that met $p < .05$ significance for every predictor in the model as well as for the total model (the Chi square p) for callous-unemotional traits. For comparative purposes, Table 5.3 and Table 5.4 report the findings using the same criteria for the child empathy measure (Griffith Empathy Measure; GEM). Where β X1 and β X2 only are produced these are main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term/s. The coefficients for X1 and X2 are the continuous factors while the coefficients for the dummy coded variables in the regression equations reflect groups falling above and below the cutoff for each independent variable.

Where reported, β D00 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 below the clinical cutoff; β D0 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 above the clinical cutoff; β D10 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 below the clinical cutoff; β D11 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 above the clinical cutoff.

As outlined in the previous section, four additional exponents were estimated for each model to illustrate the direction of effects. These exponents are represented as probabilities in the tables and figures. For example, in Table 5.1 the probability of cointegration on variable Y for a dyad composed of a mother with the minimum maternal depression score in the dataset and a child with the minimum ICU score in the dataset is denoted as “EGA 00 Prob”; the probability of cointegration for a dyad composed of a mother with the minimum maternal depression score in the dataset and a child with the maximum ICU score in the dataset is denoted as "EGA 01 Prob". These minimum and maximum values for the predictor variables are drawn from the dataset and located in Table 3.3 and Appendix E. For comparative purposes for each model, the mean probability of cointegration or Granger causality on variable Y based on all 79 dyads in the dataset is reported in the final column.

Table 5.1

ICU Total significant main and interaction effects for cointegration with both lower order relatives

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	coint medpitch	5.636	-0.128	ICUTotal							0.232	46.583	0.003	98.88%	98.88%	12.87%	12.87%	85.29%
2	coint medpitch	6.161	-0.119	ICUTotal	-0.135	DASSDep					0.337	42.338	0.000	99.39%	52.27%	29.16%	0.28%	85.29%
3	coint medpitch	6.205	-1.980	Maternal MH Hx	-0.127	ICUTotal					0.318	43.357	0.020	99.37%	21.77%	95.62%	3.70%	85.29%
4	coint 0.01 F0max	-0.406	0.078	Childage	-0.133	ICUTotal		3.128	-2.227		0.204	57.450	0.045	89.44%	19.94%	98.91%	51.99%	79.37%
5	coint 0.01 energyprof250	1.635	0.126	ERCLability	-0.132	ICUTotal		2.378			0.142	82.185	0.014	57.87%	1.93%	99.39%	17.76%	60.87%
6	coint 0.01 energyprof250	1.200	0.451	SDQConduct	-0.111	ICUTotal		3.400			0.166	80.982	0.006	54.96%	12.34%	98.61%	21.46%	60.87%
7	coint 0.01 Fdisp1 5	2.587	1.115	SDQEmotions	-0.204	ICUTotal		5.391	-4.248		0.323	53.429	0.001	67.85%	1.65%	99.95%	84.18%	79.10%
8	coint 0.01 h1bh2b	9.463	-0.127	ICUTotal	-0.385	DASSDep	-5.696		-3.326		0.301	56.623	0.016	93.26%	0.27%	20.82%	0.00%	78.26%
9	coint 0.01 maxf0locratio	2.873	-0.182	ICUTotal	0.908	CS13Dismissive			3.614		0.255	60.296	0.040	89.54%	99.69%	3.50%	3.56%	71.43%

Note. All predictors and Chi *p* significant < .05 with ICU Total and the second predictor as the lower order relatives in these models. Where β X1 and β X2 only are reported these represent main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term. LR^2 refers to Likelihood Ratio test. AIC refers to Akaike Information Criterion. SGoF refers to Sequential Goodness of Fit multi-test correction. EGA refers to extreme group analysis.

Table 5.2

ICU Total significant main and interaction effects for cointegration with CU only as the lower order relative

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	coint F2midpt	6.928	-0.142	ICUTotal		CS9Warmth		-2.988			0.164	54.494	0.013	99.65%	93.45%	18.57%	18.57%	86.84%
2	coint F2midpt	6.910	-0.142	ICUTotal		DASSDep	-3.073				0.175	53.894	0.008	92.83%	99.64%	18.83%	18.83%	86.84%
3	coint F2midpt	7.442	-0.156	ICUTotal		DASSStress	-4.142				0.262	48.827	0.013	86.98%	99.76%	14.99%	14.99%	86.84%
4	coint 0.01 energyprof25	1.961	-0.076	ICUTotal		CS13Dismissive			1.553		0.120	82.963	0.011	78.23%	78.23%	27.84%	7.55%	92.71%
5	coint energybel500	11.351	-0.211	ICUTotal		DASSDep	-5.578				0.309	26.693	0.033	97.97%	99.99%	25.54%	25.54%	81.02%
6	coint energybel500	11.599	-0.216	ICUTotal		DASSStress	-6.437				0.392	24.190	0.026	96.15%	99.99%	24.19%	24.19%	80.58%
7	coint Hammarberg	6.507	-0.139	ICUTotal		DASSDep	-3.206				0.185	56.683	0.010	88.58%	99.48%	15.38%	15.38%	82.61%
8	coint Hammarberg	2.761	-0.062	ICUTotal		CS13Dismissive			2.201		0.142	59.373	0.030	90.03%	90.03%	78.30%	28.54%	93.96%
9	coint Hammarberg	6.442	-0.138	ICUTotal		CS9Warmth		-2.959			0.159	58.292	0.016	99.45%	90.41%	15.69%	15.69%	87.14%
10	coint E1750	6.277	-0.126	ICUTotal		CS13Dismissive	-3.504				0.185	54.194	0.008	83.69%	99.42%	23.52%	23.52%	88.13%
11	coint E2500	-5.294	0.275	ICUTotal		CogEm100		3.791			0.194	38.089	0.035	5.66%	72.64%	100.0%	100.0%	91.18%
12	coint 0.01 cpp	2.841	-0.084	ICUTotal		CS13Dismissive			2.865		0.218	62.746	0.003	88.92%	88.92%	67.59%	10.62%	91.92%
13	coint 0.01 medpitch	2.694	-0.097	ICUTotal		PFMSSWarmth			1.377		0.128	78.868	0.012	86.11%	86.11%	16.40%	4.72%	90.79%
14	coint 0.01 intensmidpt	5.299		ERCEmotReg	-0.118	ICUTotal			-2.710		0.127	74.706	0.028	98.58%	15.99%	82.17%	15.99%	75.00%
15	coint 0.01 F0max	6.017		ERCEmotReg	-0.133	ICUTotal			-3.068		0.146	56.898	0.046	99.20%	13.85%	85.23%	13.85%	79.37%
16	coint F2midpt	7.394		ERCEmotReg	-0.155	ICUTotal			-3.430		0.187	53.151	0.006	99.75%	15.04%	92.90%	15.04%	86.84%
17	coint medpitch	4.050	-0.378	ICUCallous		ICUUnemotional			2.380		0.207	50.001	0.003	98.29%	98.29%	40.64%	5.96%	68.51%

Note. All predictors and Chi *p* significant < .05 but ICU Total is the only lower order relative in these interaction models. AIC refers to Akaike Information Criterion. SGoF refers to Sequential Goodness of Fit multi-test correction. LR^2 refers to Likelihood Ratio test. EGA refers to extreme group analysis.

Table 5.3

GEM empathy significant main effects for cointegration with both lower order relatives

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	coint medpitch	-22.163	0.235	CogEm100							0.299	39.321	0.030	15.42%	15.42%	99.82%	99.82%	85.29%
2	coint F0max	-16.133	0.176	CogEm100							0.177	38.286	0.010	30.44%	30.44%	99.43%	99.43%	88.89%
3	coint 0.01 energyprof250	-12.011	0.118	CogEm100							0.110	76.515	0.007	14.73%	14.73%	90.48%	90.48%	60.87%
4	coint F2midpt	-5.731	0.076	AffEm100							0.141	52.511	0.007	35.60%	35.60%	98.58%	98.58%	86.84%
5	coint F0max	-2.235	0.042	GEM100							0.243	35.953	0.040	17.85%	17.85%	99.34%	99.34%	88.89%
6	coint E2000	-1.204	0.032	GEM100							0.150	40.974	0.038	33.93%	33.93%	98.66%	98.66%	86.76%
7	coint F0mean	-1.691	0.029	GEM100							0.125	52.153	0.028	23.18%	23.18%	96.64%	96.64%	82.26%
8	coint F0max	-5.328	0.075	AffEm100							0.146	39.580	0.023	43.75%	43.75%	98.93%	98.93%	88.89%
9	coint F0max	-8.097	0.119	AffEm100	-0.192	DASSDep					0.466	25.879	0.003	50.29%	0.08%	99.95%	62.73%	88.89%
10	coint 0.01 medpitch	5.013	0.083	GEM100	-0.137	AffEm100					0.138	74.050	0.011	5.17%	0.00%	100.00%	78.83%	63.24%

Note. All predictors and Chi *p* significant < .05 with main, or partial separate, effects for GEM empathy. LR^2 refers to Likelihood Ratio test. AIC refers to Akaike Information Criterion. SGoF refers to Sequential Goodness of Fit multi-test correction. EGA refers to extreme group analysis.

Table 5.4

GEM empathy significant main and interaction effects for cointegration with GEM only as the lower order relative

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	coint F0max	-32.635		SDQConduct	0.348	CogEm100				-4.122	0.333	33.792	0.003	8.82%	99.99%	8.82%	99.54%	88.89%
2	coint F2midpt	-9.850	0.125	AffEm100		DASSStress			-2.882		0.257	47.966	0.012	20.38%	20.38%	97.69%	99.87%	86.84%
3	coint E2000	-2.696	0.054	GEM100		DASSAnx			-3.066		0.255	38.398	0.014	14.45%	14.45%	97.41%	99.88%	86.76%
4	coint E1750	-9.840	0.127	AffEm100		CS13Dismissive			-2.756		0.222	45.459	0.007	23.00%	23.00%	98.46%	99.90%	84.06%
5	coint E1750	-9.872	0.127	AffEm100		CS8Intune				-2.668	0.214	45.895	0.017	22.80%	22.80%	99.90%	98.60%	84.06%
6	coint E1750	-9.909	0.128	AffEm100		CS9Warmth				-2.624	0.209	46.132	0.017	22.62%	22.62%	99.90%	98.68%	84.06%
7	coint E1750	-9.956	0.128	AffEm100		DASSAnx			-2.674		0.212	45.951	0.005	22.47%	22.47%	98.65%	99.91%	84.06%
8	coint E1750	-10.506	0.135	AffEm100		DASSDep			-3.069		0.237	44.726	0.017	20.53%	20.53%	98.51%	99.93%	84.06%
9	coint E1750	-9.562	0.124	AffEm100		ParentWarmthExpress			-3.020		0.251	44.006	0.028	24.32%	24.32%	97.76%	99.89%	84.06%
10	coint E1750	-15.617	0.180	CogEm100		DASSDep			-3.388		0.165	48.353	0.041	50.46%	50.46%	93.94%	99.78%	84.06%

Note. All predictors and Chi *p* significant < .05 but GEM empathy is the only lower order relative in these interaction models. LR^2 refers to Likelihood Ratio test. AIC refers to Akaike Information Criterion. SGoF refers to Sequential Goodness of Fit multi-test correction. EGA refers to extreme group analysis.

5.5 CU traits and significant acoustic-prosodic parameters

As can be seen In Table 5.1, ICU Total exerted a main negative effect on the probability of cointegration on the parameter median pitch, and significant negative effects on parameters in the domains of pitch, intensity, and spectral balance when interacting with other child and maternal predictors. Energy in the range 2000Hz-2500Hz was the only parameter on which CU traits showed a positive relationship with cointegration. Consistent with the finding for CU traits, GEM empathy predicted positive relationships with cointegration on many of the same parameters that predicted negative relationships with CU traits (Tables 5.3 to 5.4).

As discussed in Chapter 4, the Granger-casualty results lack sufficient power to draw conclusions regarding between dyad differences. Results that met significance for the ICU on parameters where cointegration was also identified are reported in Appendix G and discussed in the chapter for consideration where applicable. Overall, a larger number of significant relationships was seen for the mother Granger-causing the child's values and the interactions observed in that direction were primarily between CU traits and other child characteristics (Appendix G). For the child Granger-causing the mother's values, the interactions were primarily between CU traits and maternal characteristics, particularly maternal warmth.

5.5.1 ICU and pitch median

In the pitch domain, child CU traits exerted a main negative effect on mother-child cointegration on a key emotion relevant parameter: median pitch. For each unit increase in ICU Total Score, the odds of a dyad being cointegrated (having a "1" on the dependent variable) decreased by a factor of 0.880 (exponent of β). However, for predictors with a negative β value it is clearer to interpret the odds ratio in the opposite direction; therefore for each unit increase in Total ICU Score the odds of a mother-child dyad *not* being cointegrated (having a "0" on the dependent variable) increased by a factor of 1.136 (1 / 0.880). Consistent with the finding for CU, GEM cognitive empathy saw a main positive effect on median pitch. For each unit increase in GEM cognitive empathy, the odds of a mother-child dyad being cointegrated on this key pitch feature (having a "1" on the dependent variable) increased by a factor of 1.265.

As outlined in Chapter 4, the Granger causality analyses tested the direction of information flow between speakers. Table 4.9 showed that mothers Granger-caused their child's median pitch values at approximately twice the rate that children Granger-caused their mothers median pitch across the sample (11.71% vs 7.35%, $p < .05$; 20.59% vs 11.76%, $p < .10$), with a small number of dyads identified as displaying bidirectional effects (2 dyads $p < .05$ or 3 dyads $p < .10$). Study 2 found that for each unit increase in ICU Total Score, the odds of the mother *not* Granger-causing the child's values on this parameter (having a "0" on the dependent variable) increased by a factor of 1.072 (1 / 0.069) controlling for the mother's dismissiveness.

For the minority of high CU children who do cointegrate with their mother on this key emotion relevant parameter, the mother was considerably more likely to Granger-cause the child's pitch values if she was low on dismissiveness in the emotion talk (Figure 5.1). In contrast, a high level of dismissiveness predicted a markedly reduced probability that the mother would Granger-cause the child's pitch values in conversation with these children.

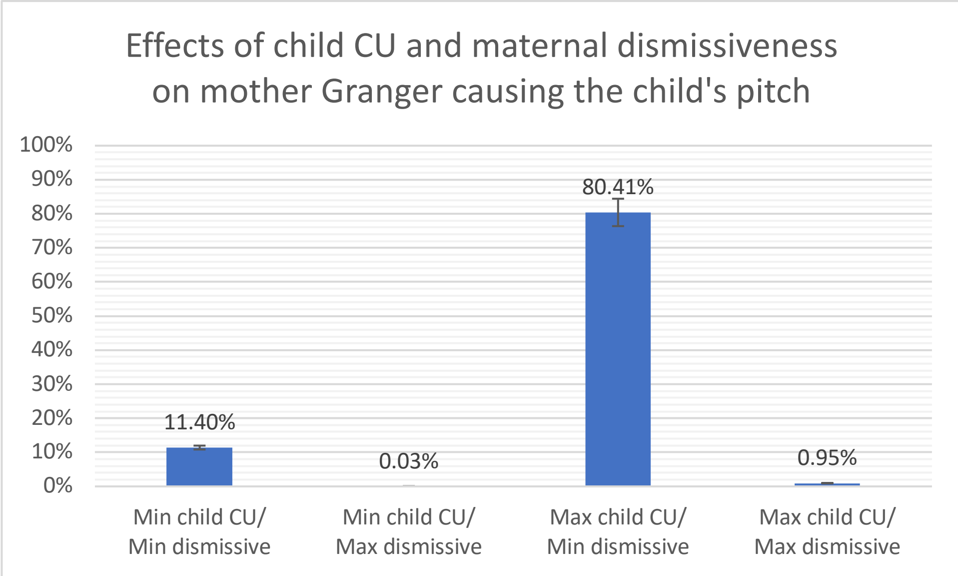

Figure 5.1 Probability of Granger causality on median pitch for separate partial effects of CU traits and maternal dismissiveness

At the subscale level of analysis, a significant interaction was observed in the high dimensional analyses between callousness and unemotionality on the probability of cointegration on this vocal parameter (Table 5.2). In terms of the relative contributions of each subscale, Figure 5.2 indicates that the probability of cointegration on median pitch is more strongly influenced by callousness, but that the additive impact of both dimensions was particularly deleterious to the probability of mother-child cointegration on this key emotion relevant parameter. This was the only significant result relating to the ICU subscales.

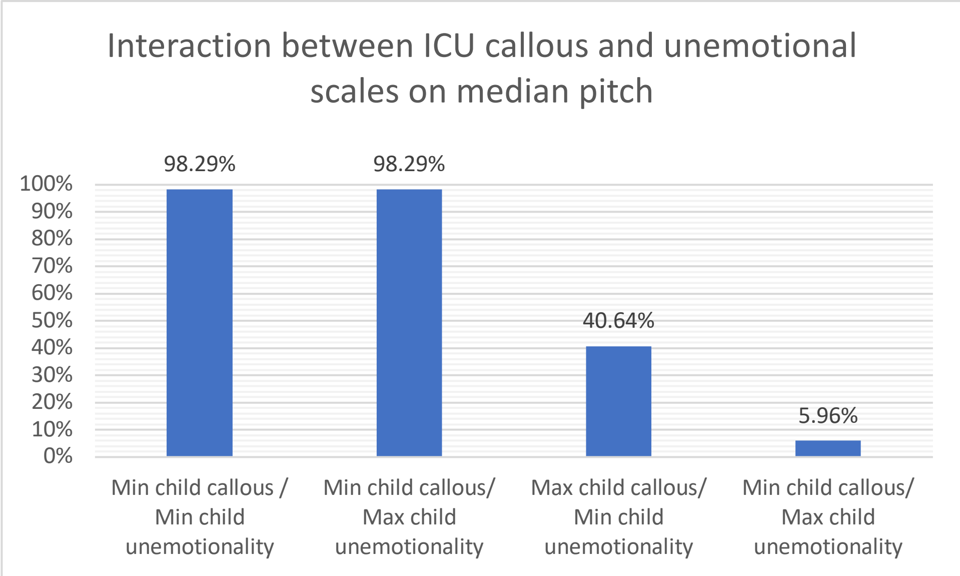

Figure 5.2 Probability of cointegration on median pitch for the interaction between ICU callous and unemotional scales

In terms of maternal factors, the mother's depression level showed a negative main effect, or separate partial effect, on the probability of cointegration on this pitch parameter (Table 5.1). The effects with ICU Total in this model were additive rather than interactive. For each unit increase in ICU Total, the odds of a mother-child dyad not being cointegrated (having a "0" on the dependent variable) increased by a factor of 1.127 (1 / 0.887) when controlling for the presence depression, with the additive effect of both child CU and maternal depression predicted to be particularly deleterious (Figure 5.3).

If child CU traits were high but the mother had few depressive symptoms, there remained approximately one in three probability that the child would still cointegrate with their mother on median pitch (29.16%). In contrast, if both CU traits and maternal depression were high, the probability of cointegration on median pitch reduced markedly. Intriguingly, children with minimal CU traits interacting with their highly depressed mothers were predicted to maintain an approximately 50% probability of cointegrating with their mothers on median pitch. This result suggests that low CU children retain a considerable likelihood of cointegrating on this feature of the depressed mother's prosody.

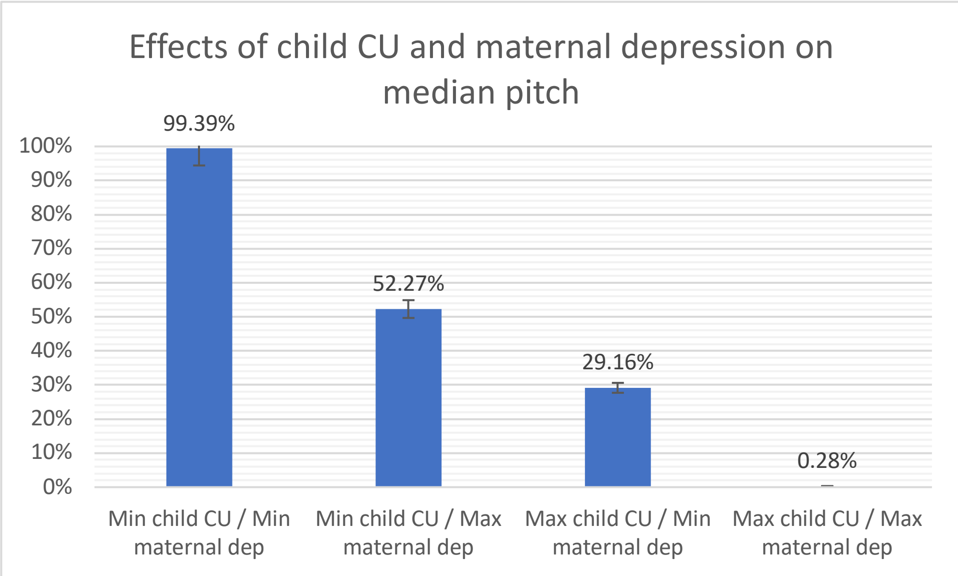

Figure 5.3 Probability of cointegration on median pitch for separate partial effects of CU traits and maternal depression

Similarly, the high dimensional tests identified the presence of a mental health history as having a significant direct negative effect on this key pitch parameter. For each unit increase in ICU Total, the odds of a mother-child dyad not being cointegrated (having a "0" on the dependent variable) increased by a factor of 1.135 (1 / 0.881) when controlling for a history of mental health problems reported by the mother; if the mother did report a history of mental health problems, the odds of *not* being cointegrated on this key parameter increased by a factor of 7.246 (1 / 0.138) when controlling for child CU traits.

For children with low CU traits, the predicted probability of cointegration was high for dyads in which mothers reported a history of mental health difficulties (Figure 5.4); this result compares to approximately 50% in dyads in which the mother is highly depressed. It is important to note that many mothers who reported a mental health history are not currently depressed, and that a mental health history captures a broader range of diagnoses than only depression.

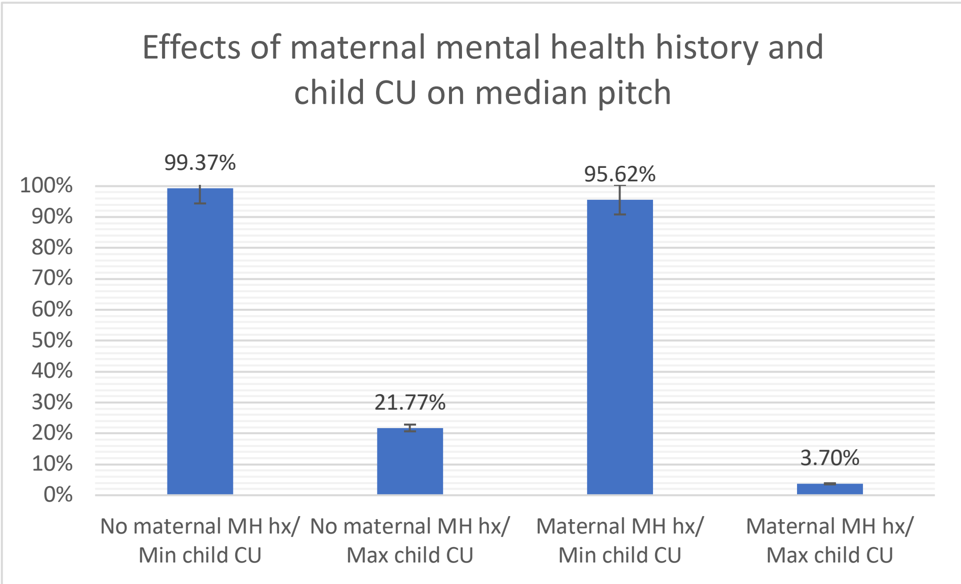

Figure 5.4 Probability of cointegration on median pitch for separate partial effects of CU traits and maternal mental health history

Table 5.2 also identifies a significant effect for CU traits on median pitch when interacting with maternal vocal warmth, however this result is more tentative as CU traits were the only first order relative used in the model. As can be seen in Figure 5.5, the probability of cointegration on median pitch remains strongly influenced by CU traits with maternal vocal warmth providing a small additive effect for children in the high CU group.

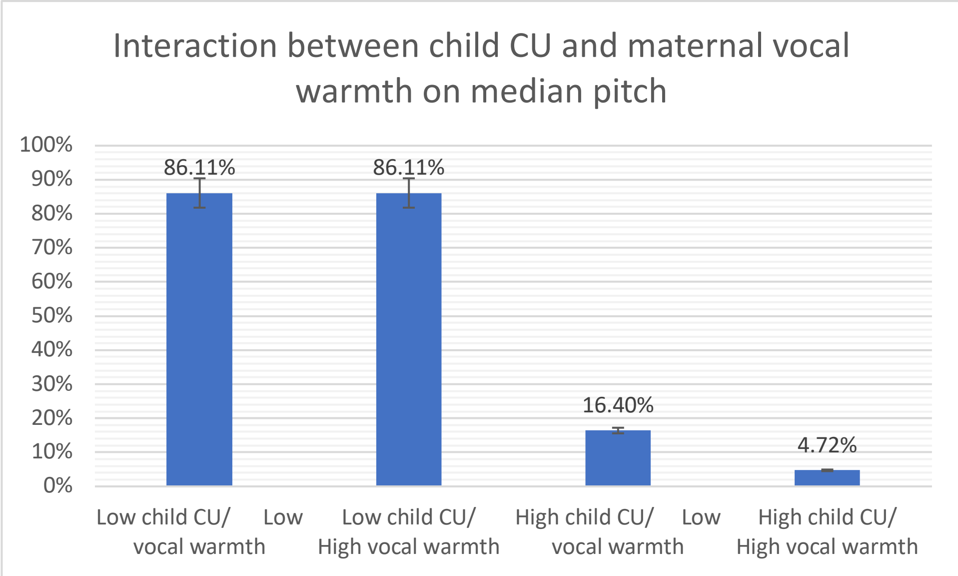

Figure 5.5 Probability of cointegration on median pitch for the interaction between CU traits and maternal vocal warmth

5.5.2 ICU and pitch maximum

Pitch maximum was identified as another key emotion relevant parameter associated with disruption to cointegration for CU traits. Specifically, there was a significant interaction between child CU traits and child age (Table 5.1). As can be seen in Figure 5.6, the likelihood of cointegration on this parameter is more strongly influenced by CU traits than age, but the probability of cointegration for high CU children was predicted to more than double on this parameter for the oldest children in the group, suggesting a moderating effect over time.

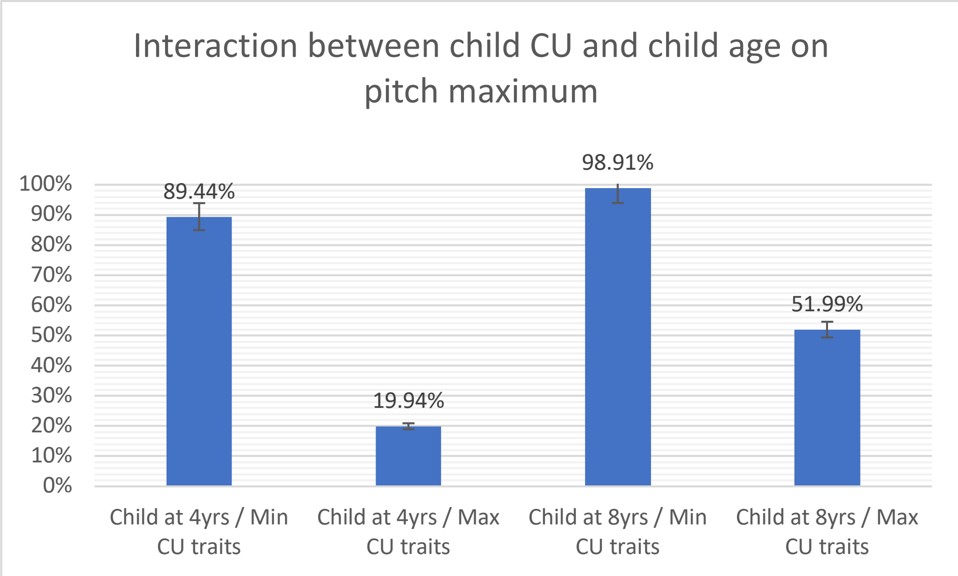

Figure 5.6 Probability of cointegration on pitch maximum for the interaction between CU traits and child age

Table 5.2 also identifies a significant effect for CU traits on pitch maximum when interacting with child emotion regulation, noting that this result is more tentative as CU traits were the only first order relative used in the model. As can be seen in Figure 5.7, the probability of cointegration on maximum pitch remains more strongly influenced by CU traits, with emotion regulation providing a small buffer against cointegration for children low in CU traits.

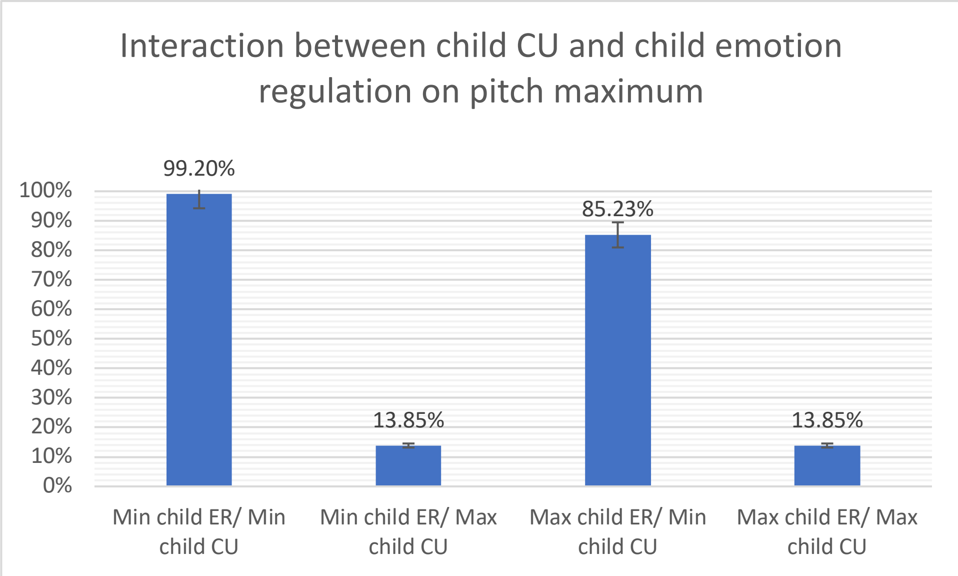

Figure 5.7 Probability of cointegration on pitch maximum

for the interaction between CU traits and child emotion regulation

Consistent with the finding for CU, GEM cognitive empathy and affective empathy saw main positive effects on pitch maximum. For each unit increase in GEM cognitive empathy, the odds of a mother-child dyad being cointegrated on this key pitch feature (having a "1" on the dependent variable) increased by a factor of 1.192. For each unit increase GEM affective empathy, the odds of a mother-child dyad being cointegrated on this key pitch feature (having a "1" on the dependent variable) increased by a factor of 1.078. Figure 5.8 suggests that it is the empathic component, and not the behavioural component, that is disruptive to cointegration on this parameter.

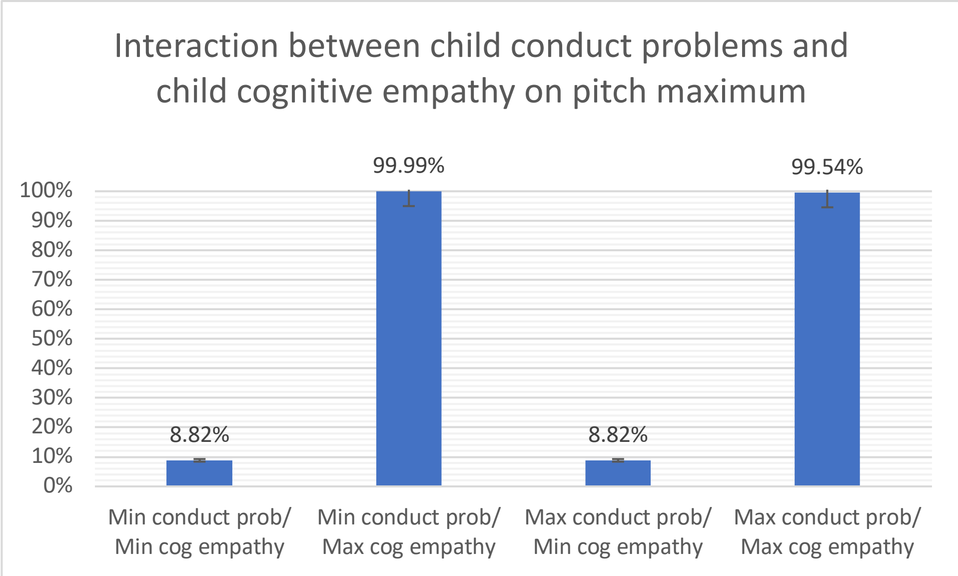

Figure 5.8 Probability of cointegration on pitch maximum for the interaction between conduct problems and child cognitive empathy

Notably, a high probability of cointegration (above 50%) was observed for dyads in which the child was particularly high in affective empathy and the mother highly depressed (Figure 5.9), suggesting that synchrony on this key emotion relevant parameter is maintained for many dyads in which the mother is clinically depressed. In contrast, the presence of low affective empathy in the child in dyads with highly depressed mothers resulted in very low likelihood of cointegration.

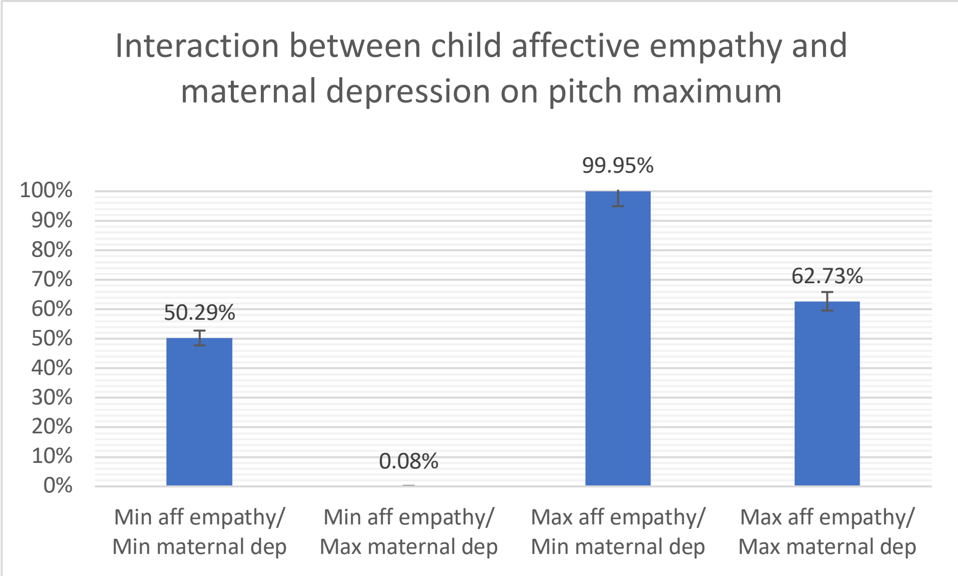

Figure 5.9 Probability of cointegration on pitch maximum for the interaction between affective empathy and maternal depression

5.5.3 ICU and the energy profile 0Hz-250Hz

As reported in Chapter 4, this energy parameter in the bottom end of the spectrum showed a high rate of cointegration across the total mother-child sample (Table 4.8), and Study 2 found that CU traits exerted strong negative effects and conduct problems exerted strong positive effects on the probability of a dyad being cointegrated (Figure 5.10). Consistent with the findings for CU, the GEM cognitive empathy scale saw a main positive effect on cointegration on this parameter (Table 5.3). Specifically, for each unit increase in GEM cognitive empathy, the odds of a mother-child dyad being cointegrated on this energy feature (having a "1" on the dependent variable) increased by a factor of 1.125.

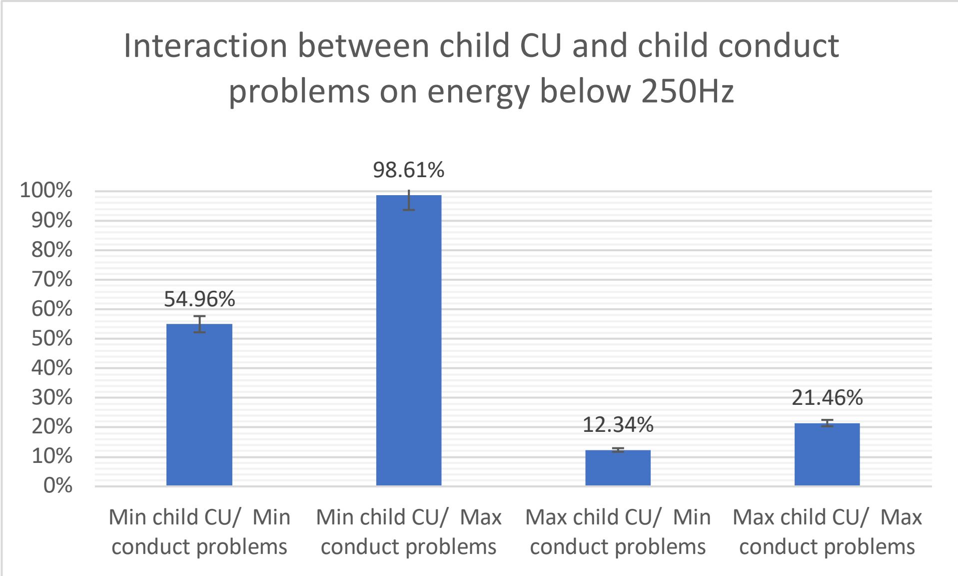

Figure 5.10 Probability of cointegration on energy below 250Hz for the interaction between CU traits and child conduct problems

Similar to conduct problems, child lability / negativity had a positive effect on the probability of cointegration on this energy parameter. As illustrated in Figure 5.11, high child lability with minimal CU traits saw a high probability of cointegration in this low end of the energy spectrum, while the presence of high CU traits substantially moderated this effect.

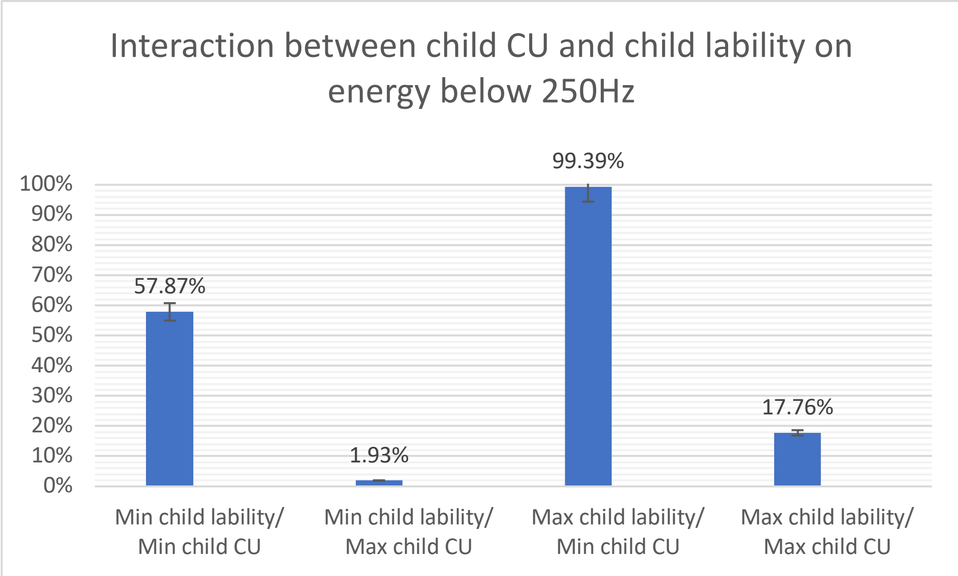

Figure 5.11 Probability of cointegration on energy below 250Hz for the interaction between CU traits and child lability

There was also a significant interaction between CU and maternal dismissiveness on this particular energy parameter (Table 5.2). As seen in other interactions, the probability of cointegration in this very low end of the spectrum was strongly influenced by CU traits. While the presence of dismissiveness in the mother's speech had little impact on the probability of cointegration for dyads in which the child had minimal CU traits, the presence of dismissiveness for the high CU child was associated with further reduction in the probability of cointegration on this energy parameter (Figure 5.12).

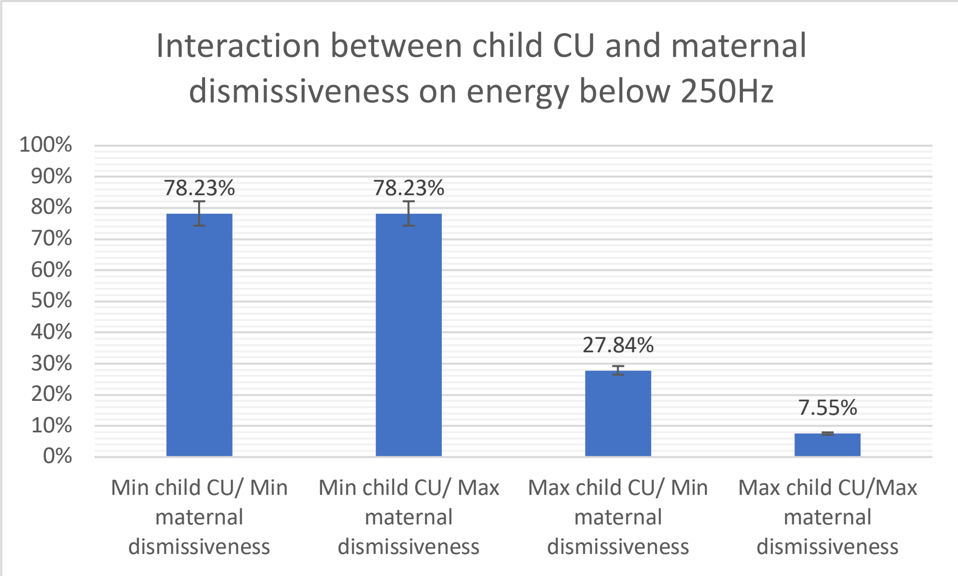

Figure 5.12 Probability of cointegration on energy below 250Hz for the interaction between CU traits and maternal dismissiveness

5.5.4 ICU and formant dispersion (formants 1 to 5)

Formant dispersion refers to concentrations of energy at particular pitch frequencies across the vocal spectrum (approximate spans at each 1000Hz). For this parameter, the testing identified a significant interaction between child CU traits and SDQ child emotional symptoms, a measure which reflects internalising symptoms such as worry, sadness and fear. While callous-unemotional traits exerted a dominant negative influence on the probability of cointegration on the dispersion of formants 1 through 5 (p = .001) for children low on emotional symptoms, if internalising emotions were high, the presence of CU traits made only small difference (Figure 5.13). This result suggests that child internalising problems have a stronger influence than CU traits on the probability of cointegrating on this particular spectral parameter.

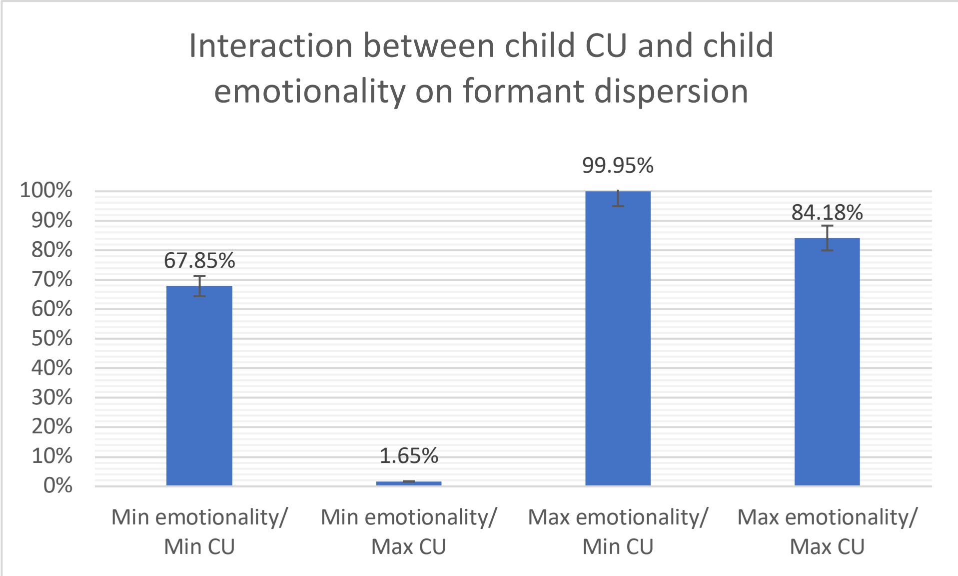

Figure 5.13 Probability of cointegration on the formant dispersion (formants 1 to 5) for the interaction between CU traits and child emotionality

5.5.5 ICU and the amplitude difference between 1st and 2nd harmonics (formant adjusted)

In Chapter 4, approximately three-quarters of the total mother-child sample displayed cointegration on the amplitude difference between 1st and 2nd harmonics (formant adjusted), making it a particular variable of interest in the study of mother-child vocal synchrony. Study 2 found that in dyads with mothers who weren't depressed, child CU traits were associated with strong disruption to this parameter (Figure 5.14). Notably however, the presence of maternal depression exerted a dominant negative impact on the probability of cointegration on this parameter regardless of the level of CU traits.

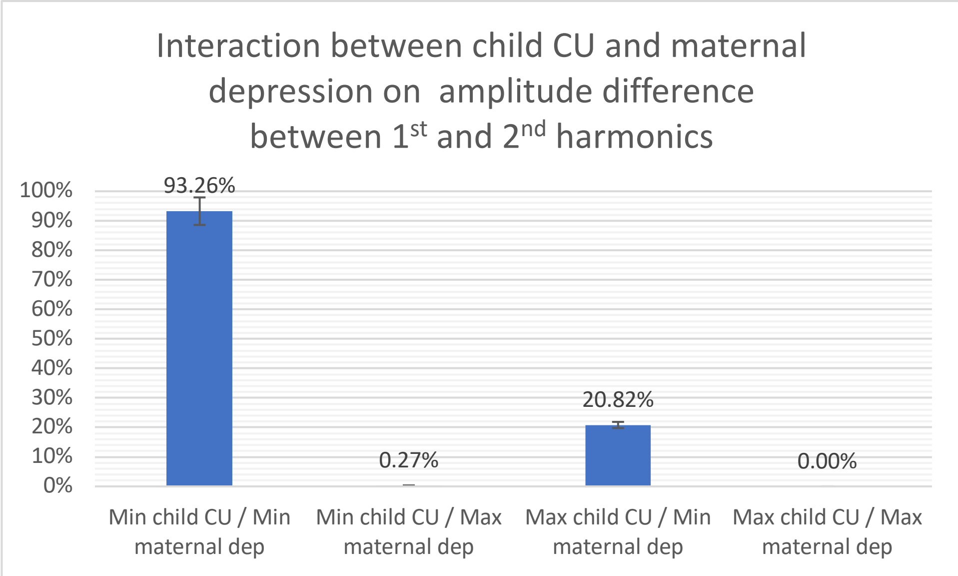

Figure 5.14 Probability of cointegration on the amplitude difference between 1st and 2nd harmonics (formant adjusted) for the interaction between CU traits and maternal depression

5.5.6 ICU and the relative location of f0 peak (maxF0locratio)

This pitch parameter refers to the timing of the pitch peak as a proportion of the duration of the speech turn (maxF0locratio). As can be seen in Figure 5.15, CU traits exerted a dominant negative influence on the probability of cointegration when interacting with the mother's dismissiveness (p = .004). Maternal dismissiveness predicted an increased probability of cointegration for children with minimal CU traits, although the effect was small.

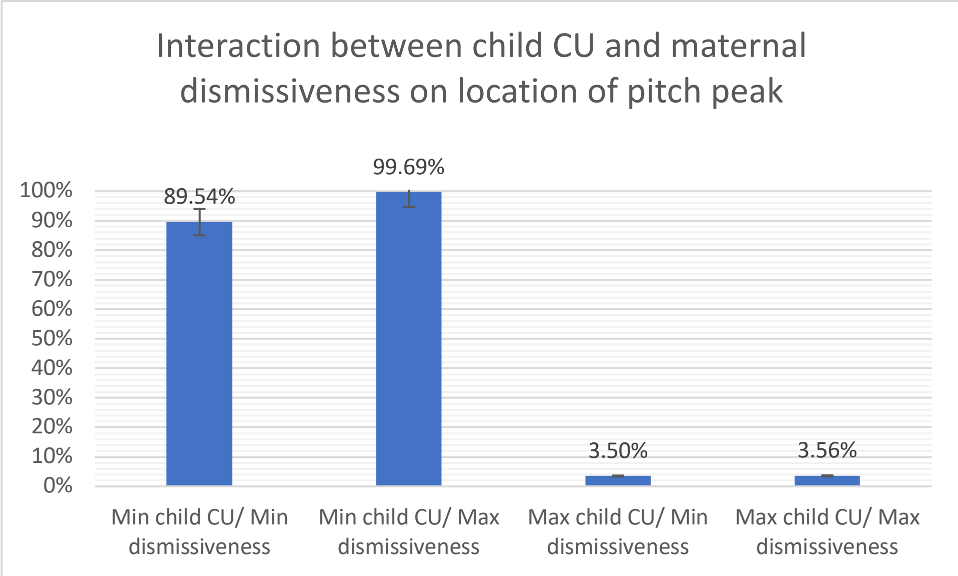

Figure 5.15 Probability of cointegration on the relative location of the f0 peak as a proportion to the duration of the interval for the interaction between CU traits and maternal dismissiveness

5.5.7 ICU and child and maternal factors in secondary models

ICU Total also displayed main negative effects on the probability of cointegration a number of other acoustic-prosodic parameters exclusively in models that did not meet the full marginality principle, i.e., models that met significance for all predictors but with ICU as the only lower order relative when producing the interaction term (Table 5.2). While generalisability is more limited for those models, they contain useful information regarding the trends related to CU traits and the other child and maternal predictors, as well as identifying acoustic-prosodic variables for testing in further samples. Under these conditions, significant negative effects were observed for the following parameters: the second formant, intensity (amplitude) at the midpoint of turns; energy below 500Hz, cepstral peak prominence (cpp), the Hammarberg index, and energy in the spectrum range 1250Hz-1750Hz. Each of these parameters are discussed below. Of the moderating factors, maternal dismissiveness is particularly noted for its adverse additive effect on markedly reducing the probability of cointegration on three parameters (energy below 250Hz, the Hammarberg Index, and cpp) when interacting with CU traits.

5.5.8 ICU and the second formant

Child CU traits were associated with a strong negative effect on the probability of cointegration on the second formant, which refers to a concentration of energy located at approximately 2000Hz (Table 5.2). While the presence of maternal stress and depression made no difference to the already low probability of cointegration for high CU children on this parameter, these maternal mental health factors predicted small increases to this probability for children with low CU traits (Figures 5.16 and 5.17).

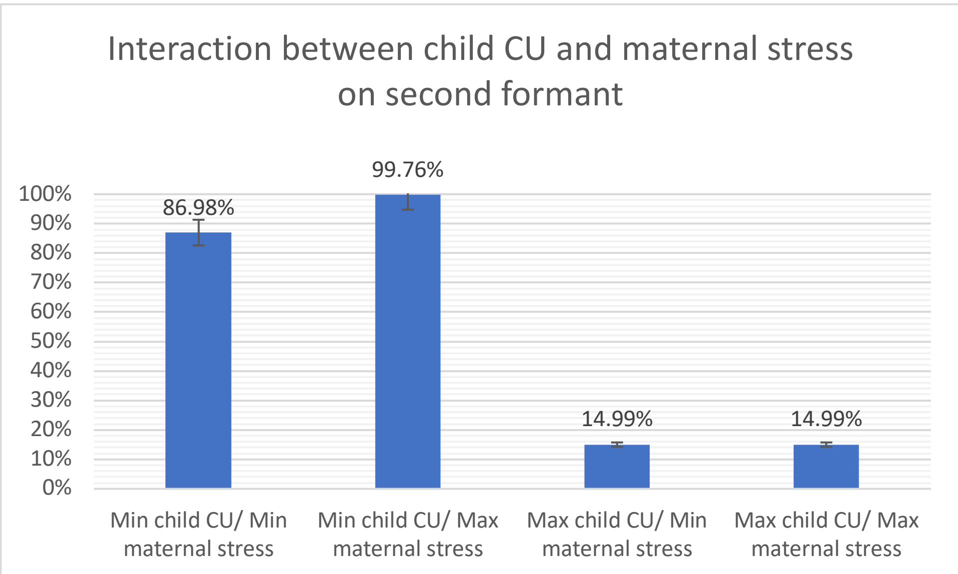

Figure 5.16 Probability of cointegration on the second formant for the interaction between CU traits and maternal stress

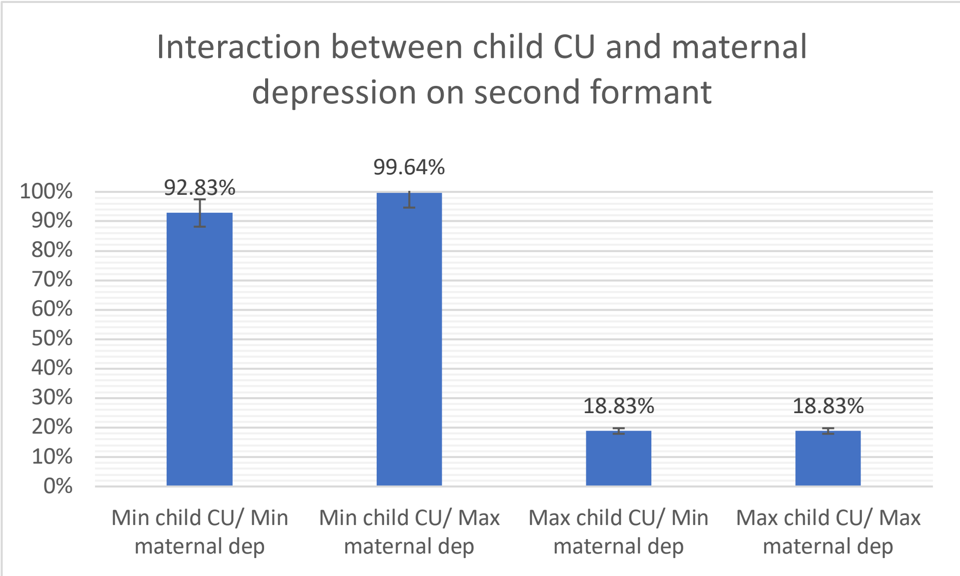

Figure 5.17 Probability of cointegration on the second formant for the interaction between CU traits and maternal depression

Notably, child emotion regulation was associated with a small resistance against cointegration on this parameter for children with low CU traits (Figure 5.18). Consistent with these findings, high levels of child affective empathy were associated with an increased probability of cointegration on this parameter (Table 5.3), while the level of maternal stress made significant but marginal difference (Table 5.4). Therefore children with low CU traits, or high levels of affective empathy, appear to be at particular risk of synchronising on this acoustic-prosodic parameter, including with their highly stressed mothers.

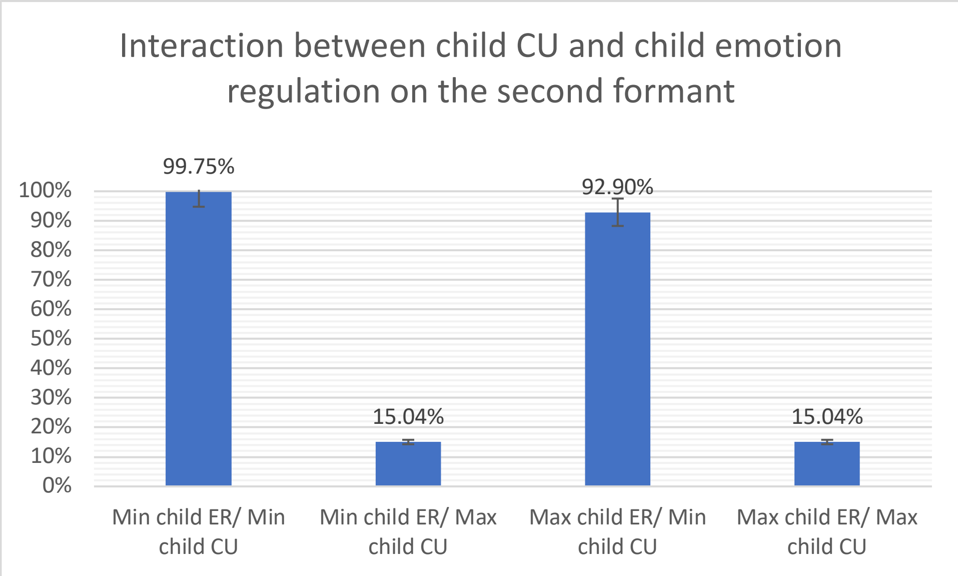

Figure 5.18 Probability of cointegration on the second formant for the interaction between CU traits and child emotion regulation

5.5.9 ICU and intensity

In Chapter 4, intensity (amplitude or energy) midpoint showed a high rate of cointegration across the total mother-child sample at 75% ($p < .01$). In Study 2 a significant interaction was observed between child CU traits and emotion regulation (Table 5.2) on this energy parameter. Where CU traits exerted a dominant negative effect on the probability of cointegration, child emotion regulation was associated with a small buffer against cointegration for children low in CU traits (Figure 5.19).

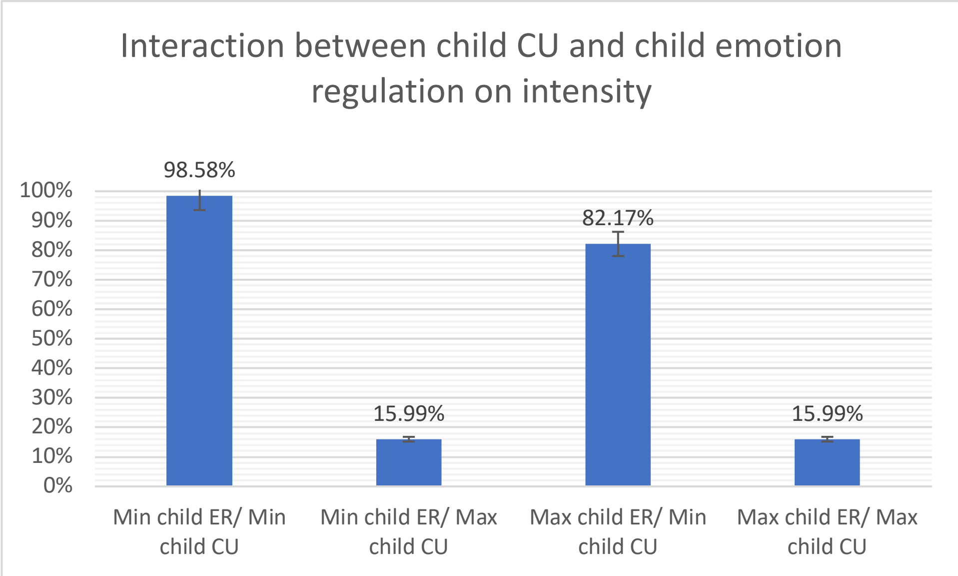

Figure 5.19 Probability of cointegration on intensity midpoint for the interaction between CU traits and child emotion regulation

5.5.10 ICU and the proportion of energy below 500Hz

Similarly, CU traits exerted a dominant negative influence on the probability of cointegration on another energy parameter, the proportion of energy in the profile between 0Hz-500Hz. Maternal stress exerted a significant but marginal effect compared to CU traits in this interaction (Figure 5.20).

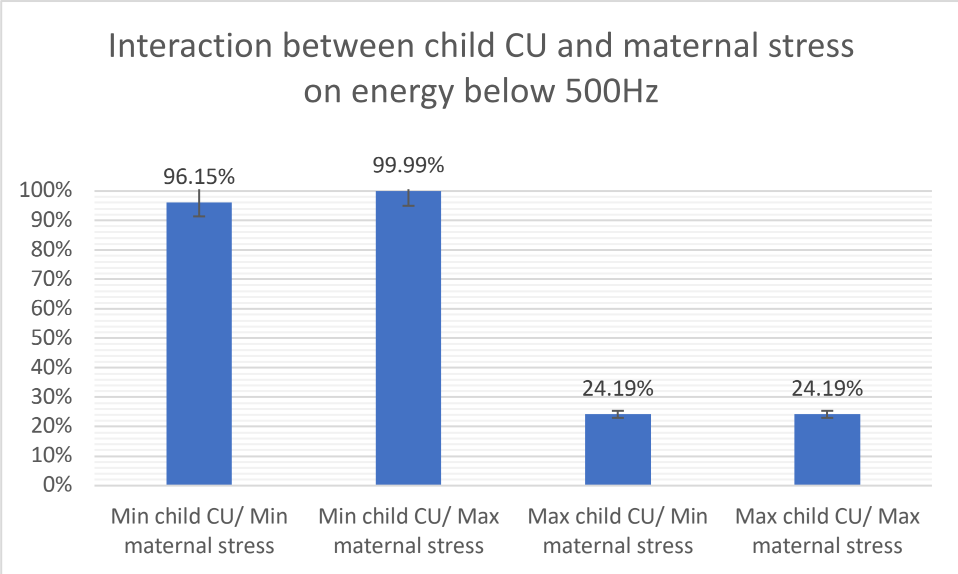

Figure 5.20 Probability of cointegration on the proportion of energy below 500Hz for the interaction between CU traits and maternal stress

This pattern of relationships was replicated for CU traits interacting with maternal depression (Figure 5.21).

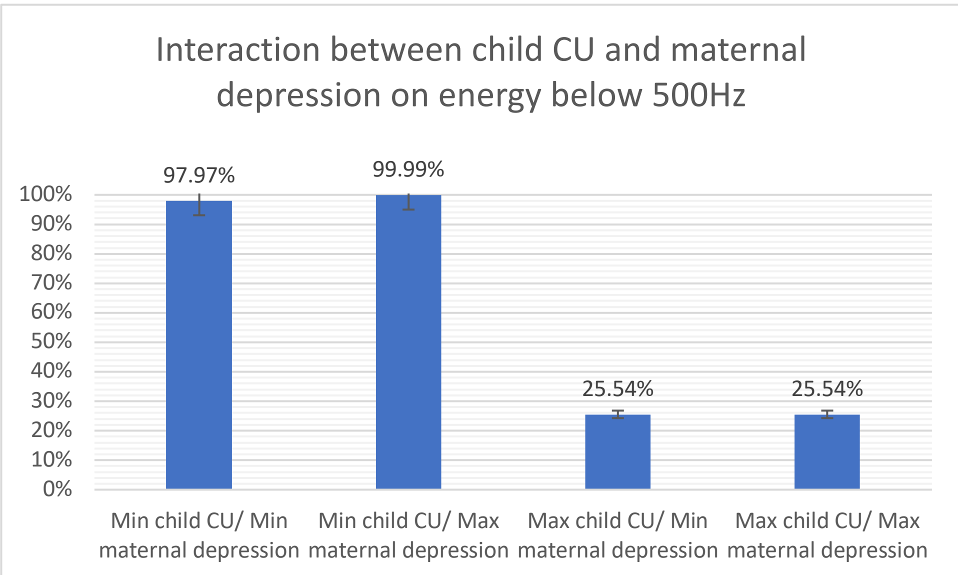

Figure 5.21 Probability of cointegration on the proportion of energy below 500Hz for the interaction between CU traits and maternal depression

As discussed in Chapter 4, the Granger causality results are particularly tentative with significant regression results reported in Appendix G. For the minority of children with high CU traits in which cointegration did occur, the predicted probability that the mother Granger-caused the child's energy below 500Hz was high. There was also a significant interaction with maternal stress and CU traits. Specifically, in the smaller subgroup of high CU children who did cointegrate with their mothers on this particular energy parameter, the mother was more likely to Granger-cause the child's energy in this range if she was highly stressed (Figure 5.22).

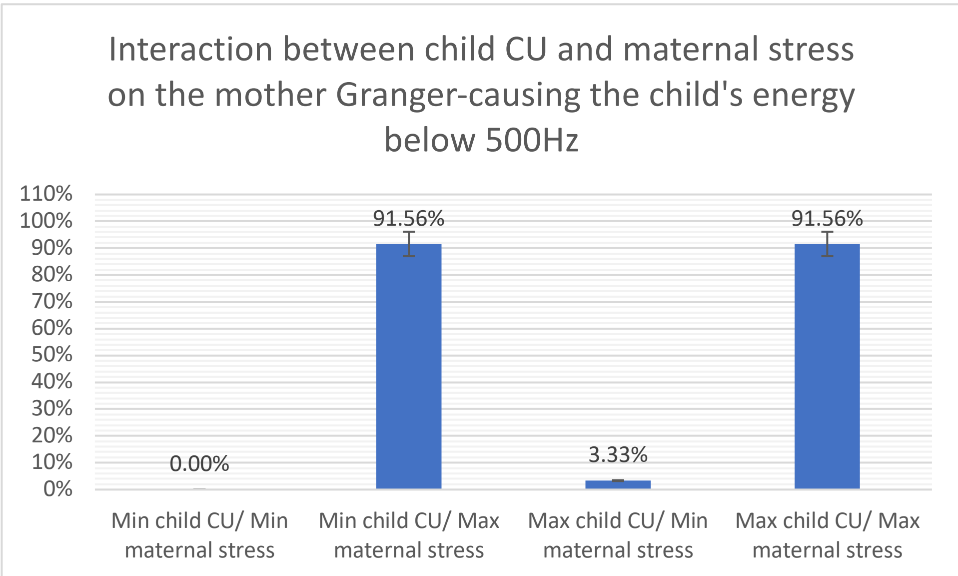

Figure 5.22 Probability of the mother Granger-causing the child's values on the proportion of energy below 500Hz for the interaction between CU traits and maternal stress

5.5.11 ICU and cepstral peak prominence (cpp)

Callous-unemotional traits were also associated with a negative effect on the probability of cointegration on cepstral peak prominence (cpp), a voice quality parameter associated with breathiness. When interacting with maternal dismissiveness, this combination that was particularly deleterious to cointegration for the high CU child (Figure 5.23).

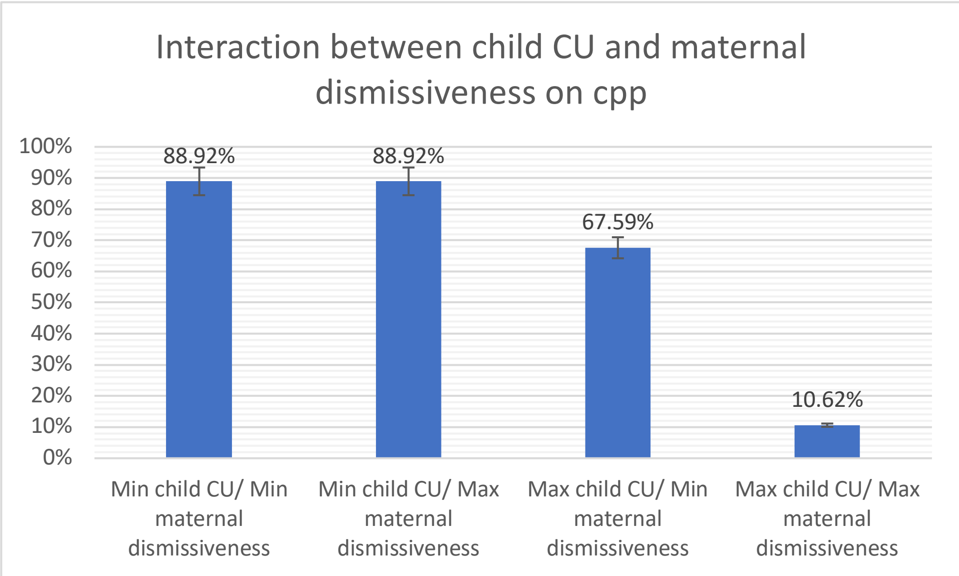

Figure 5.23 Probability of cointegration on cepstral peak prominence (cpp) for the interaction between CU traits and maternal dismissiveness

5.5.12 ICU and the Hammarberg Index

Callous-unemotional traits also predicted a dominant negative effect on the probability of cointegration on the Hammarberg Index. This parameter refers to the difference in maximum intensity (amplitude) in the lower frequency band (0–2000 Hz) compared to the higher frequency band (2000–5000 Hz). While the presence of maternal depression and warmth saw no difference for children in the high CU group (Figures 5.24 and 5.25), high dismissiveness in the mother was particularly deleterious to the probability of cointegration for the high CU child (Figure 5.26).

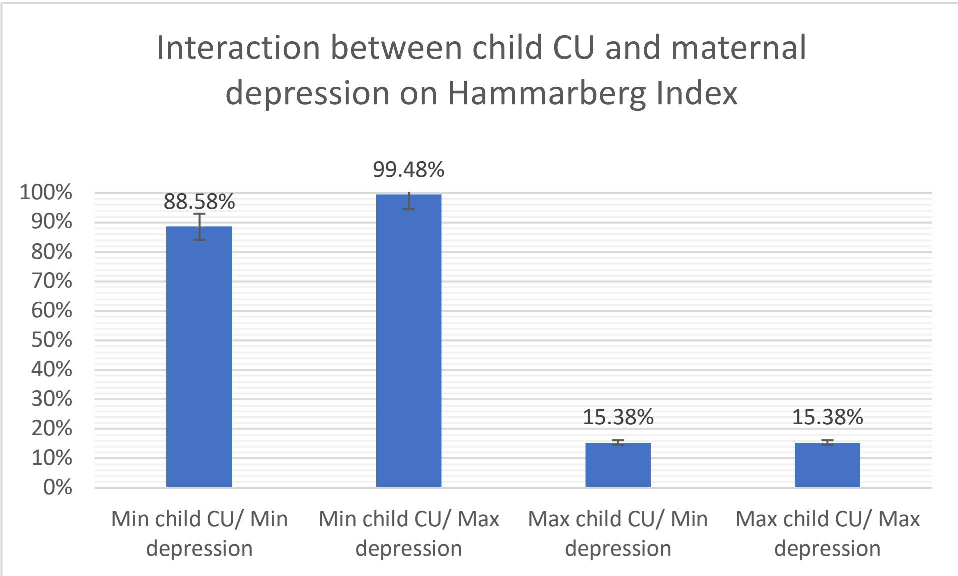

Figure 5.24 Probability of cointegration on the Hammarberg Index for the interaction between CU traits and maternal depression

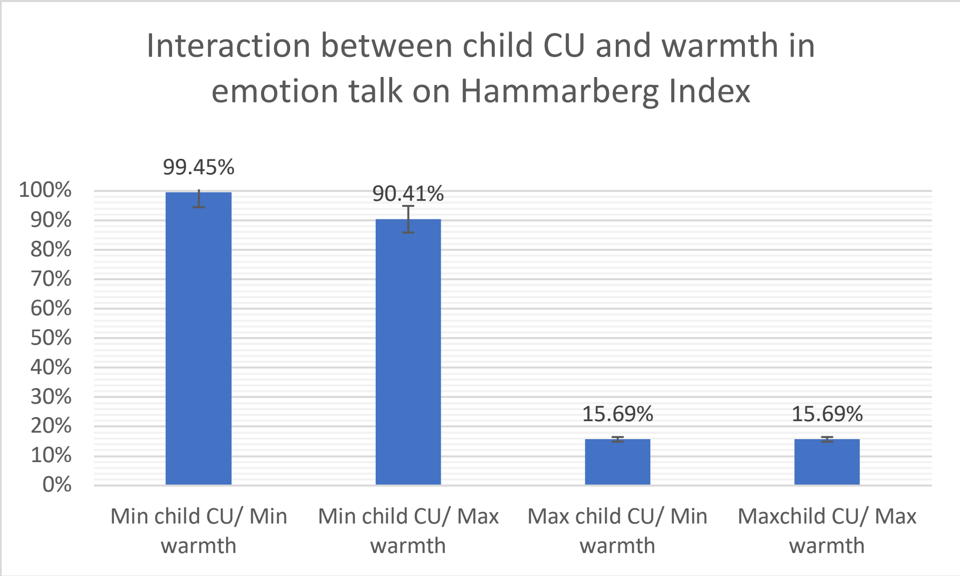

Figure 5.25 Probability of cointegration on the Hammarberg Index for the interaction between CU traits and warmth in the emotion talk

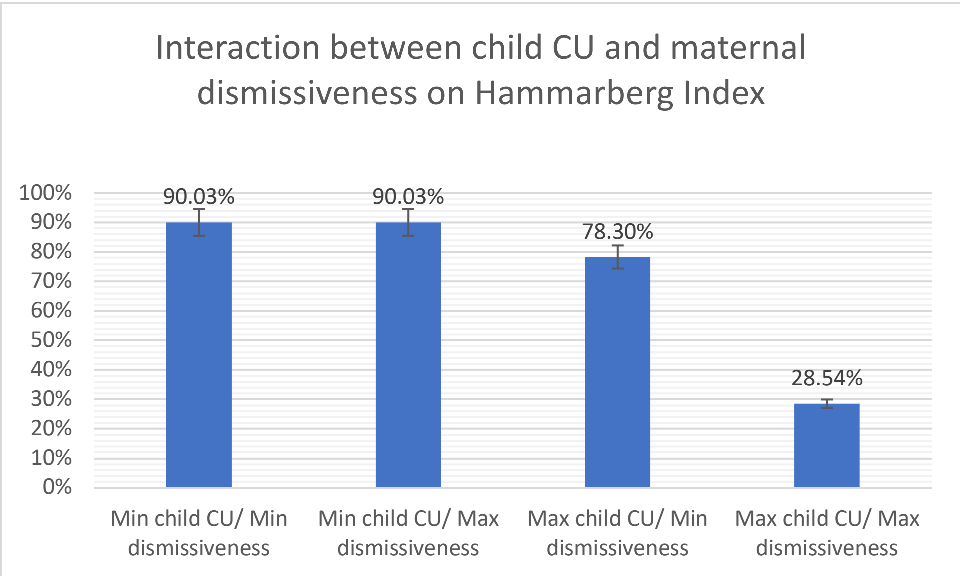

Figure 5.26 Probability of cointegration on the Hammarberg Index for the interaction between CU traits and maternal dismissiveness

5.5.13 ICU and energy in the range 1250Hz-1750Hz

A negative effect was also observed for callous-unemotional traits on the probability of cointegration on energy in the mid-low range 1250Hz-1750Hz. The effect of high CU traits was dominant regardless of the level of maternal dismissiveness (Figure 5.27), however high dismissiveness predicted an increased probability of cointegration if CU traits were low. Consistent with the finding for CU, GEM affective and cognitive empathy saw positive effects on energy in this range in a number of interactions (Table 5.4), including with maternal dismissiveness. Notably, the effects of the other factors were marginal in comparison to the empathy variables.

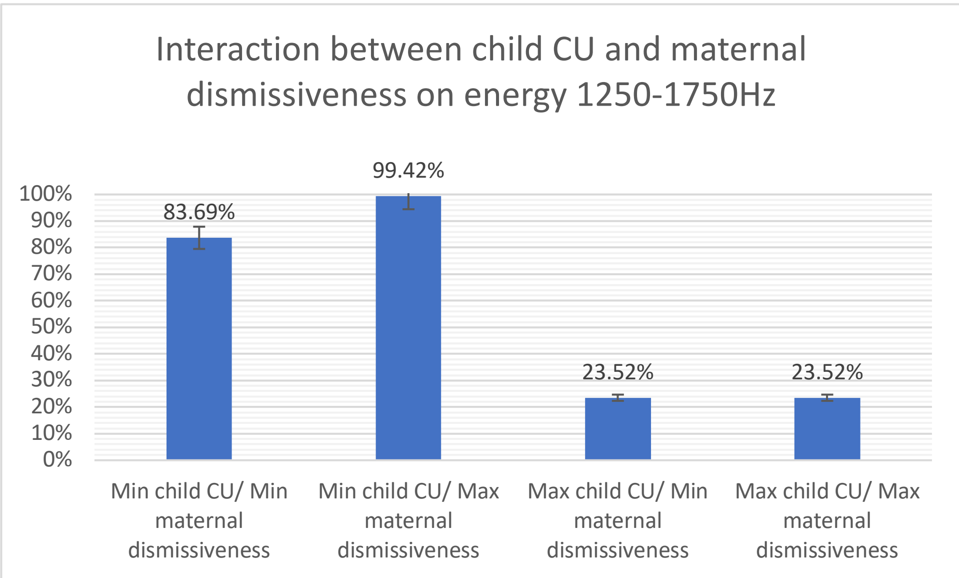

Figure 5.27 Probability of cointegration on energy in the range 1250Hz-1750Hz for the interaction between CU traits and maternal dismissiveness

5.5.14 ICU and energy in the range 2000Hz-2500Hz

Energy in the range 2000Hz-2500Hz was the only acoustic-prosodic variable of the 44 parameters examined in this study to show a main positive effect on the probability of mother-child cointegration for CU traits (Table 5.2). For the high CU cohort cognitive empathy made no difference to the already high likelihood of cointegrating on this energy parameter, however the presence of cognitive empathy was important in increasing the likelihood of cointegration on this parameter for children with low CU traits (Figure 5.28).

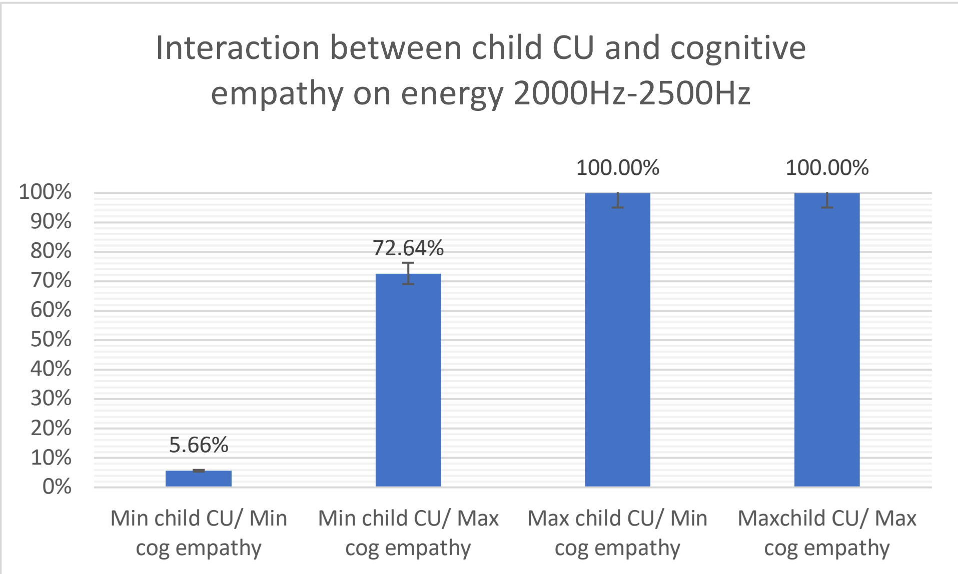

Figure 5.28 Probability of cointegration on energy in the range 2000Hz-2500Hz for the interaction between CU traits and child cognitive empathy

5.6 Results: Oppositional Defiant Disorder and acoustic-prosodic cointegration

In contrast to CU traits, the presence of a child ODD diagnosis was associated with a disruptive effect to cointegration on only three of the 44 parameters, specifically the second formant, cepstral peak prominence (cpp), and jitter (Table 5.5). The second formant was the only parameter to show significance for both the lower order relatives in the model. ODD in isolation was associated with limited disruption to cointegration on these parameters unless paired with high maternal stress, low child emotion regulation, high maternal dismissiveness, or low child empathy.

Table 5.5

ODD significant main and interaction effects for cointegration with ODD as a lower order relative

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	coint 0.01 F2midpt	5.262	-3.699	DiagnosisODD	-0.199	DASSStress	-3.791			2.661	0.160	79.253	0.044	78.11%	21.56%	79.64%	8.87%	75.00%
2	coint 0.01 cpp	2.303	-2.485	DiagnosisODD		ERCEmotReg				2.175	0.194	68.067	0.001	90.91%	90.91%	45.45%	88.00%	75.36%
3	coint 0.01 cpp	2.303	-2.228	DiagnosisODD		CS13Dismissive			2.123		0.172	69.800	0.002	90.91%	90.91%	90.00%	51.85%	75.36%
4	coint 0.01 jitter	0.486	1.817	DiagnosisODD		AffEm100			-2.216		0.114	79.155	0.026	61.90%	61.90%	52.17%	90.91%	68.18%

Note. All predictors and Chi *p* met significance, but with the exception of the second formant (F2midpt), ODD is the only lower order relative in these interaction models. LR^2 refers to Likelihood Ratio test. AIC refers to Akaike Information Criterion. SGoF refers to Sequential Goodness of Fit multi-test correction. EGA refers to extreme group analysis.

5.7 Discussion

Consistent with hypotheses, Study 2 found that child callous-unemotional traits exerted significant negative effects on the probability of cointegration on a number of emotion relevant vocal parameters in mother-child emotion talk. Disruptive effects were observed on both pitch and energy features, particularly median pitch and the proportion of energy in the low end of the spectrum. Consistent with the finding for CU traits, the presence of child empathy as measured by the Griffith Empathy Measure (GEM) predicted positive effects across these same parameters, and also on a number of additional parameters. Those included pitch median, pitch mean, pitch maximum and the second formant, as well as energy across the range 1250Hz-2000Hz.

Overall, the range of parameters associated with disruptive effects supports a hypothesis of a generalised pattern of synchrony problems for child CU traits. These findings are in line with the body of literature identifying positive relationships between empathy and prosocial behaviour and synchrony (e.g., Feldman, 2007a; 2007b; Mogan et al, 2017; Rennung & Göritz, 2016). However where negative effects were seen for callous-unemotional traits on the likelihood of cointegration for a significant number of acoustic-prosodic parameters, a significant positive relationship was observed for energy in the range 200Hz-2500Hz when interacting with GEM cognitive empathy. Therefore it is possible that this parameter may be uniquely relevant in some way to the vocal expressions of children with callous-unemotional traits.

Oppositional Defiant Disorder (ODD), a condition characterised by emotional as well as behavioural dysregulation, was associated with negligible disruption to cointegration across the 44 parameters tested, suggesting that it is the callous-unemotional dimension, rather than externalising or regulatory problems, that is disruptive to synchrony in the vocal channel. Further, the significant result observed between the CU subscales suggests that it is the callous component that mostly moderates the probability of cointegration on a key emotion relevant parameter — median pitch — for children in the high CU cohort.

Pitch and energy features have been identified as central features in studies on vocal affect (Juslin & Laukka, 2003; Juslin & Scherer, 2005), and therefore disruption on related parameters for the high CU cohort would appear to be consistent with the lack of responsiveness to emotion relevant social cues seen previously in visual and vocal channels (Dawel et al, 2012). There was some evidence that the child's emotion regulation abilities may serve as a moderating factor of the effects on CU on some parameters (intensity midpoint, pitch maximum, and the second formant). While the effects of child emotion regulation were comparatively small, it is possible to foresee circumstances in which self-regulation could provide a protective benefit, such as for children interacting with mothers exhibiting high levels of stress.

In particular, it is conceivable that mother-child synchrony could induce stress-related arousal or negative emotions in the child (and the mother) that then require down regulation. Under such circumstances, emotion regulation ability as a characteristic of the child may provide a buffer to disentangle, or dys-synchronise, from their mothers on these vocal parameters. Therefore investigating the relationships between qualities of emotion regulation and vocal synchrony seems to be a particularly worthwhile avenue of future inquiry.

The adverse effects of maternal stress and depression on cointegration observed in this study add to the established body of literature that has reported disruption to mother-child synchronous processes associated with the mother's mental health (e.g., Amole et al, 2017; Woody et al, 2016). The current results suggest that child CU traits were the more disruptive influence. It is particularly notable however that dyads with low CU children but highly depressed mothers retained an approximately 50% probability of cointegrating on a key emotion relevant parameter, median pitch. Given that studies of depression in adults have found a restricted or flattened spectrum in the profiles for pitch and intensity measures (see Cummins et al, 2015a for a review), it is conceivable that a substantial number of dyads with the combination of depressed mothers and high empathy / low CU children are cointegrating on parameters of the mother's restricted prosody.

Therefore, while synchrony on emotion relevant parameters of vocal expression is theoretically positive for the development of child empathy, it remains an open question about whether the potentially "contagious" properties of vocal affect are helpful for other aspects of child development, such as child internalising problems. In general, the results suggest that further study of the main effects of maternal stress and depression on vocal cointegration is warranted. Of note, the presence of a past mental health diagnosis for the mother was far less predictive than her current depression level for disruption to cointegration on median pitch, suggesting that treating the mother's depression is likely to have a positive impact on the capacity for these mother-child dyads to cointegrate on this key emotion parameter.

An important limitation of the study is that variations in speaker distance from the microphone cannot be excluded as a potential confounder to the findings for cointegration on intensity parameters. The Toda-Yamamoto (1995) approach to cointegration intentionally overfits the model with "augmented" lags when testing for a pattern of predictability between speakers, which results in a loss of power but provides greater tolerances. However it is conceivable that children with CU traits and/or mothers with depression may be moving their face away from each other (and thus the microphone) more often than other children and mothers and that it is this behaviour that accounts for the disruption observed on intensity parameters. It is not clear that any such pattern of movements, should it be occurring, would not be indicative of a more generalised pattern of dys-synchrony for those groups, i.e., across multiple non-verbal modalities including eye contact, gesture and vocal affect, however such movements cannot be excluded as an alternative explanation for the observed findings on intensity parameters.

As outlined in Chapter 4, the low numbers of Granger causality are likely to reflect low power arising from an insufficient number of turns rather than a true absence of effects, and therefore the generalisability of the Granger causality results is particularly limited. This problem arose from the pre-existing dataset with a lack of a standard minimum length for the emotion talk task. With this limitation in mind, for the minority of high CU children who showed cointegration on two key parameters — median pitch and energy below 500Hz — the Granger causality results suggest that the mother was more likely to Granger-cause the child's values if she was either low on dismissiveness (pitch) or high on stress (energy).

In terms of caregiving qualities, maternal warmth and attunement had no significant impact on the likelihood of cointegration for children with high CU traits, however dismissiveness further reduced this already compromised probability on three parameters: energy in the very low end of the spectrum (0Hz to 250Hz), the Hammarberg Index, and cepstral peak prominence (cpp). In particular, the proportion of energy in the bottom end of the spectrum showed high rates of cointegration in Study 1, and has been previously shown to be associated with reduced intelligibility (Hazan & Markham, 2004; Krause & Braida, 2004). Therefore, it is conceivable that disruption to synchrony on the proportion of energy in this range may have implications for aspects of language learning.

Elaborative emotion talk has been positively linked to self-regulation (see Salmon et al, 2016 for a review) as well as the development of child insight and moral judgement (Reese et al, 2007), therefore it would seem possible that even subtle or unconscious compromise to the intelligibility of the interlocutor's message may have effects on child development over time. Impairment in language function has also been linked to severe behavioural and emotional problems (Yew & O'Kearney, 2013), further suggesting that this energy parameter is of particular relevance for subsequent studies in the high CU population.

In sum, child CU traits exerted dominant negative effects on the probability of cointegration on a number of the parameters examined in this high dimensional study, while child empathy exerted a trend of significant positive effects. In this way, children displaying high CU traits in early childhood appear to be more resistant to the effects of emotional contagion on vocal parameters, including with their depressed or stressed mothers. The study also identifies a subset of vocal parameters of particular interest for the CU cohort, and lends support to the hypothesis that disruptions to synchrony in the vocal channel may be indicative of reduced affect contagion and serve as a possible risk marker for child empathy development.

For example, Blair et al (2005) propose that there may be a type of reciprocal feedback loop between the activation of the amygdala and the sensory representational units that are tied to emotion recognition and that it is this cycle that is disrupted in the amygdala dysfunction observed in CU traits. Whether CU traits disrupt cointegration in vocal affect, or whether disruption might somehow contribute to or maintain high CU traits, cannot be inferred in this observational study. However the results are consistent with findings relating to deficits in the recognition of emotion relevant social cues in this population, and therefore warrant further investigation in new samples.

Where cointegration refers to a process, specifically a mechanism of transfer for acoustic-prosodic values between two speakers, the nature of those values speaks to what is being transferred. The location and positioning of those values in the vocal spectrum, for example pitch and intensity values, is central to models of vocal emotion advanced by Juslin and Scherer (2005) and others (e.g., Eyben et al, 2016; Goudbeek & Scherer, 2010). Study 2 did not examine those values, therefore the nature of what is being transferred in these mother-child dyads is unclear. More broadly, there are many questions about the expression of vocal affect in children with callous-unemotional traits as this is an unexamined area in the literature. We now turn to those questions.

CHAPTER 6: CHARACTERISTICS OF THE CHILD AND ACOUSTIC-PROSODIC FEATURES OF THE CHILD AND OF THE MOTHER

6.1 Chapter outline

This chapter investigates the expression of vocal affect in the emotion talk of mothers and their children aged 4 to 8 years. Specifically, Study 3 examines the acoustic-prosodic parameters that differentiate the emotion talk of four groups of children: children with high CU traits and the comparison group of children with high levels of prosocial behaviour, and children with Oppositional Defiant Disorder (ODD) and the comparison group of children with high levels of emotion regulation. Results are reported separately for the child and for the mother due to the relevance of each speaker's vocal features to the synchrony construct. The findings are discussed in relation to the affective component of CU traits and the implications for emotion contagion in mother-child dyads.

6.2 Introduction

Callous-unemotional (CU) traits have been associated with key deficits in the recognition of emotion in facial expressions and in vocal qualities (Dawel et al, 2012). In the vocal channel, Stevens et al (2001) found selective impairments in the recognition of vocal sadness in a small sample of children with psychopathic traits (*n*=9), but not deficits for angry, fearful or happy vocal tones. In contrast, Blair et al (2005) identified selective impairment in fearful vocal affect in a sample of 22 children with psychopathic traits, a result that mirrored their earlier finding in adult offenders (Blair et al, 2002). Overall however, the number of studies on vocal affect recognition in this group is very small. Even fewer studies have examined the expression, rather than the recognition, of vocal emotion for individuals with these traits (Louth et al, 1998), and none have examined vocal affect expression in children with high CU traits.

The unemotional component of the CU construct implies restricted affective expression, a view that has been tied to the amygdala dysfunction hypothesis (Blair, 2001; Blair et al, 2006) and is consistent with studies that have identified physiological hypoarousal in such youths (e.g., Gostisha et al, 2014; Raine, 2002). In line with this view, Louth et al (1998) found that male psychopaths spoke with less intensity compared to non-psychopathic offenders, and that the prosodic expression of psychopathic offenders did not vary between neutral and emotional words. Therefore Hypothesis 1 is that children with high CU traits will display restriction on key emotion relevant features in their emotion talk compared to children with low CU traits.

In contrast to this unemotional component in the high CU construct, the interactions of children with Oppositional Defiant Disorder (ODD) tend to be characterised by heightened levels of negative affect and behavioural dysregulation (American Psychiatric Association, 2013). Although callous-unemotional traits can be present in a subgroup of children with ODD (Hawes et al, 2014; O'Kearney et al, 2017), the affective expressions of children with a diagnosis of ODD are of comparative clinical interest due to the high levels of emotional lability and negativity that typify this group of children. Hypothesis 2 is that children with ODD will display a heightened range of values on emotion relevant parameters compared to children without a diagnosis of ODD.

6.2.1 Analytical approach: Associations

Tests of Pearson's correlation were conducted to identify significant relationships between the ICU Total score and acoustic-prosodic values of the child and of the mother at the session level of the emotion talk. Results relating to the ICU Total Score are presented alongside those relating to the comparative child measures in order to test for the contribution of externalising dimensions to significant associations with acoustic-prosodic features. Tests of partial correlation were conducted and reported in the chapter where significant findings in the child's speech overlapped between the ICU Total and other child characteristics.

The Conduct Problems and Hyperactivity subscales of the Strengths and Difficulties Questionnaire (SDQ) were used to examine the relative contribution of a broader externalising dimension to the CU results. For both exploratory and comparative purposes, measures of child emotionality were included to capture the dimensional components of emotion in ODD. These measures were the Emotional lability/ negativity scale of the Emotion Regulation Checklist (ERC), which captures self-awareness and expression of emotions, and the Emotional symptoms subscale of the SDQ, which captures internalising symptoms such as sadness and anger. For exploratory purposes and as a comparative measure of the acoustic-prosodic values associated with CU traits, significant associations with the SDQ Prosocial scale and the Griffith Empathy Measure (GEM) are also reported. Finally, as a comparative measure against ODD, significant acoustic-prosodic parameters associated with the measure of child emotional regulation are also reported.

6.2.2 Feature reduction

Descriptive discriminant analysis (DDA) was used to conduct a multivariate analysis of variance test of the hypothesis that children with CU traits differ significantly from children with low CU traits on a linear combination of the child's acoustic-prosodic features at the session level. The DDA approach is closely aligned to the study of effects in multivariate analysis of variance (MANOVA) and has been used previously as a classification tool for vocal expression in developmental studies (Katz et al, 1996). In

MANOVA, the analysis identifies only that groups are different, whereas DDA identifies the nature of that difference through feature reduction and classification of one or more latent variables that discriminates between groups (Huberty, 1994).

In contrast to predictive discriminant analysis (PDA), in DDA fewer variables do not yield greater separation between the groups (Huberty, 1994), and deleting variables based on pre-selection can potentially remove variables with poor individual classification performance that may otherwise be important for categorisation purposes when considered alongside the other variables. However variable selection methods are important when there are more variables than observations available (West, 2003), a particular problem for high dimensional data. Therefore, in line with Huberty (1994), acoustic-prosodic variables relating to overlaps were initially removed from the child and mother datasets in order to focus on the unique features of each speaker, and the remaining predictors with the largest F entered the model in a stepwise approach.

As outlined in Chapter 3, a high CU grouping variable was established based on cut-offs for the ICU Scale from the literature using a large community-based sample of school aged children (Kimonis et al, 2014), and the high/ low group variable used in Descriptive Discriminant Analyses (DDA) of acoustic-prosodic features. The DDA test was then repeated to test the hypothesis that the speech of mothers of children with CU traits differs significantly from the speech of mothers of children with low CU traits on a linear combination of her acoustic-prosodic features at the session level.

The Oppositional Defiant Disorder (ODD) diagnostic group was established using the clinician ratings from the clinical interview on the DISCAP-IV, and descriptive discriminant analysis conducted to test the hypothesis that the emotion talk of children with an ODD diagnosis differed significantly from children without ODD on a linear combination of the child's vocal parameters at the session level. The descriptive discriminant analysis was then repeated for the mother's speech and ODD at the session level.

For secondary analyses, descriptive discriminant analysis was also conducted on both the child's and the mother's acoustic-prosodic features in high prosocial groups to investigate the vocal profiles associated with positive child characteristics. A high prosocial grouping variable was established on the SDQ Prosocial scale using cutoffs established from literature (Table 3.3) and used in descriptive discriminant analyses for cross-validation with the CU groups and to test the hypothesis that children with high levels of prosocial behaviour and their mothers can be identified on a linear combination of acoustic-prosodic features at the session level. In a similar fashion, a high emotion regulation grouping variable was established on the Emotion Regulation (ER) scale of the ERC using cutoffs established from literature (Table 3.3) for comparative study against the ODD group. Results for these groups are located in Appendix H and the findings discussed in relation to the implications for emotion contagion in these groups of children.

6.3 Results: Acoustic-prosodic features in the emotion talk of children with CU traits

Table 6.1 summarises the acoustic-prosodic parameters of the child's speech that showed significant unconditional associations with CU traits and with the comparative child measures. Only parameters identified as significant against the child measures are displayed and are highlighted in green. The complete list of acoustic-prosodic parameters tested in the linear regressions are detailed in Appendix B.

Table 6.1

Significant associations between child characteristics and the child's acoustic-prosodic parameters

Parameter (Child)	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	ERC Emotion regulation	SDQ Emotional symptoms	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Pitch Range span (ST)	-.415**	-.288*	-.227*	-.388**	.335**	-.152	.264*	.271*	.191	-.092
Standard of pitch values (ST) where values are min and max pitch in ST for each syllable	-.346**	-0.197	-0.171	-.288*	0.191	-0.056	0.023	0.075	0.057	-0.147
Pitch bottom (Hz) based on 2 stylization values per nucleus	.300**	.337**	.392**	.379**	-.288**	.084	-.156	-.254*	-.280*	-.171
Pitch Bottom of raw pitch values based on 2 raw F0 values (Hz)	.299**	.322**	.353**	.402**	-.270*	.129	-.178	-.273*	-.332**	-.239*
Pitch range (ST) as normalised pitch value of start of nucleus	-.128	-.295**	-.095	-.192	.058	-.018	-.003	.187	.082	.098
Pitch Top (ST) top of pitch range in ST	.023	.131	.225*	.170	-.061	.039	-.007	-.097	-.202	-.297**
PitchTop as top of pitch range in Hz	.040	.166	.237*	.195	-.046	-.021	-.044	-.132	-.173	-.318**
Mean of pitch values (ST) of minimum and maximum pitch in nucleus	.158	.082	.217*	.171	-.184	.101	-.092	-.118	-.158	-.004
Mean mean (Hz) of raw pitch values based on 2 raw F0 values	.068	.088	.229*	.172	-.114	.039	-.064	-.091	-.218*	-.276*
Median pitch (Hz) of raw pitch values per syllable	.071	.062	.215	.147	-.124	.026	-.066	-.077	-.214	-.255*
TrajInterZ (ST) Time-normalized pitch trajectory intersyllabic variations (z score)	.124	.001	.075	.100	-.223*	.125	.005	-.131	-.211	-.090
TrajIntraZ (ST) Time-normalized pitch trajectory of intrasyllabic variations (z score)	.293**	.200	.256*	.288**	-.234*	.135	-.102	-.157	-.101	.158
TrajPhonZ (ST) Time-normalized pitch trajectory of all pitch variations (z score)	.269*	.096	.182	.205	-.319**	.155	-.074	-.199	-.211	.073
Rises proportion (%) of syllables with pitch rise (> 4ST)	-.219*	-.091	-.009	-.135	.160	-.229*	.054	-.021	.165	-.101
Number of speaker turns	.186	.192	.124	.171	-.178	.062	-.103	-.134	-.300**	-.020
Child turn duration (ProsPro)	.090	-.018	.138	.053	-.060	-.144	-.303**	-.117	-.035	-.016
Percentage of time speaks in the emotion talk	.237*	.233*	.003	.093	-.177	-.157	-.327**	-.219	-.252*	-.093
Percentage of time speaks in first half of emotion talk	.232*	.172	-.091	.060	-.214	-.082	-.241*	-.151	-.265*	-.019
Percentage of time speaks in second half of emotion talk	.146	.185	.046	.023	-.073	-.147	-.257*	-.144	-.127	-.099
Speech turn time in second half of emotion talk	.101	.105	.091	.025	.005	-.176	-.310**	-.151	-.127	-.165
SpeechRate (syllables/ second)	.183	.050	.181	.220*	-.224*	.166	-.074	-.130	-.239*	-.012
InterNuclDur - sum of durations between successive syllables	.179	.234*	.158	.199	-.183	.034	-.114	-.126	-.277*	.020

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; F0 refers to fundamental frequency; Significant relationships are shown in green; **Correlation significant at the .01 level (2-tailed); *Correlation significant at the .05 level (2-tailed).

Table 6.1 continued.

Parameter (Child)	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	ERC Emotion regulation	SDQ Emotional symptoms	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Average intensity midpoint of turn (dB)	**.231***	.157	**.316****	.195	**-.228***	.071	-.154	-.218	-.149	.018
Mean intensity (dB) (ProsPro)	.145	.026	.209	.104	-.103	-.091	**-.246***	-.122	-.021	.022
Proportion of energy < 500Hz	.134	-.011	.132	.112	-.158	**.275***	.031	.028	.001	**.379****
Excursion size (ST)	.141	.100	**.229***	.110	-.124	-.012	-.189	-.186	-.060	.015
Maxf0 loc ms (ProsPro) - time of f0 peak relative to the onset of an turn in milliseconds	.098	-.028	.127	.040	-.060	-.154	**-.254***	-.168	-.077	-.011
H1A3 (dB) (amplitude difference between 1st harmonic and 3rd formant)	.144	.003	.028	.071	-.172	.167	-.124	.001	-.073	**.219***
H1A1 (dB) (relative amplitude of first harmonic and first formant)	.149	-.133	-.079	.043	-.128	.201	.013	.035	-.008	**.446****
Jitter	.206	.153	**.294****	**.258***	**-.235***	**.374****	-.042	-.174	-.188	.119
Shimmer	.215	.200	**.261***	**.265***	**-.233***	**.359****	-.076	-.162	-.191	.121
Energy Profile 0-250Hz	.188	.173	**.336****	.160	-.172	.051	-.190	**-.235***	-.060	.047
Energy 0-500Hz	.143	.186	**.331****	.141	-.140	-.030	-.226	**-.243***	-.072	-.100
Energy 250-750Hz	.159	**.234***	**.322****	.153	-.154	-.064	**-.280***	**-.305****	-.124	-.187
Energy 500-1000Hz	.113	.203	**.266***	.097	-.109	-.104	**-.239***	**-.300****	-.096	**-.226***
Energy 750-1250Hz	.102	.174	**.267***	.097	-.086	-.111	-.217	**-.294***	-.063	**-.216***
Energy 1000-1500	.115	.166	**.285****	.109	-.078	-.121	**-.230***	**-.305****	-.062	**-.213***
Energy 1250-1750Hz	.136	.184	**.312****	.120	-.070	-.134	-.226	**-.321****	-.050	-.193
Energy 1500-2000Hz	.099	.163	**.292****	.084	-.042	-.155	-.177	**-.299****	-.029	-.155
Energy 1750-2250Hz	.079	.150	**.280***	.067	-.031	-.146	-.139	**-.274***	-.028	-.140
Energy 2000-2500Hz	.069	.136	**.265***	.057	-.023	-.138	-.107	**-.256***	-.024	-.165
Energy 2250-2750Hz	.061	.125	**.265***	.063	-.019	-.131	-.090	**-.236***	-.009	-.181
Energy 2500-3000Hz	.059	.123	**.271***	.075	-.018	-.125	-.081	-.215	.000	-.170
Energy 2750-3250Hz	.066	.132	**.279***	.078	-.028	-.127	-.078	-.209	-.002	-.147
Energy 3000-3500Hz	.055	.125	**.275***	.062	-.022	-.137	-.074	-.192	.001	-.146
Energy 3250-3750Hz	.038	.110	**.244***	.042	-.003	-.158	-.077	-.183	.000	-.155

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; F0 refers to fundamental frequency; Significant relationships are shown in green; **Correlation significant at the .01 level (2-tailed); *Correlation significant at the .05 level (2-tailed).

6.3.1 CU traits and significant associations in the child's speech

Callous-unemotional traits showed significant relationships across both pitch and temporal parameters, but only three remained uniquely significant after accounting for the influence of other child characteristics in partial correlations: the child's pitch range in semitones, the standard deviation of the child's pitch range, and the percentage of time the child spoke in the first half of the emotion talk, typically the period in which the mother and child establish task rapport.

Notably, these parameters were also inversely associated with measures of child empathy. As can be seen in Table 6.1, child empathy was positively associated with a wider child pitch range in semitones, shorter child speech turns, and negatively with the percentage of time the child speaks, particularly in the first half of the emotion talk. Indeed, an overall inverse pattern of associations with acoustic-prosodic parameters was observed in the emotion talk of children high in empathy compared to those for CU traits.

6.3.1.1 Child pitch range

This parameter assesses the pitch range covering 2%-98% percentiles of the speaker's total syllables as measured on the semitone scale. In comparison to the more common Hertz measurement system, the semitone scale is particularly useful as a psychoacoustic measure of pitch as it uses a logarithmic transformation of the physical Hertz scale to represent equal perceptual intervals in the human auditory system (Mertens, 2004). Zero-order correlations between the continuous measure of ICU Total and the child's pitch range identified a moderate, negative correlation which was statistically significant ($r(73) = -.415$, $n = 75$). On the externalising scales, both SDQ Conduct problems and SDQ Hyperactivity also showed significant zero order correlations on this parameter, and partial correlation analyses were conducted to examine these relationships further.

Controlling for child conduct problems, there remained a moderate, negative partial correlation between ICU Total and the child's pitch range which was statistically significant (r(72) = -.328, N = 75, $p < .01$). Similarly, after controlling for child hyperactivity, a moderate, negative correlation remained between ICU Total and the child's pitch range (r(72) = -.354, N = 75, $p = .002$). Controlling both child conduct problems and hyperactivity together, the moderate, negative relationship with Total ICU and the child's pitch range remained (r(71) = -.311, N = 75, $p = .008$).

The ERC Emotional lability/ negativity also showed a significant zero order correlation with the child's pitch range (-.388, $p = < .01$). Controlling for this characteristic, there remained a moderate, negative partial correlation between ICU Total and the child's pitch range which was statistically significant (r(71) = -.232, N = 74, $p < .05$). Controlling for both child conduct problems and emotional lability/ negativity together, the relationship between Total ICU and the child's pitch range also remained (r(70) = -.234, N = 74, $p < .05$). These results suggest that CU traits explained a narrower child pitch range beyond the contribution of both conduct problems and child emotional lability/ negativity.

At the subscale level of analysis, all ICU subscales also showed significant negative relationships with the child's pitch range, with the strongest of these being the ICU Callous subscale (-.395, $p = < .001$). Measures of child empathy were also examined due to their characteristically inverse relationship to CU traits. Moderate, positive relationships were identified with cognitive empathy (.271, $p < .05$) and affective empathy (.264, $p < .05$) and the child's pitch range, providing additional validation for the significant negative relationship between child pitch range and CU traits. Child age did not show any significant relationships with either the ICU Total score or with the child's pitch range.

6.3.2 CU traits, expressive vocabulary and child pitch range

Interactions were examined using the high dimensional methods and dichotomised predictor variables (Table 3.3 and Appendix E) which identified a significant effect for a control variable in the study, child expressive vocabulary. The EVT-2 (Williams, 2007) is an individually administered test of expressive vocabulary and word retrieval for children older than 2 years and 6 months and was used in the original data collection to control for individual differences in child language ability. Separate partial effects were identified for ICU Total on the child's pitch range (β = -.188, $p < .001$) and (β = .123, $p = .021$) and the model identified an interaction effect for the high CU/low EVT group with the model explaining 22.48% of the variance (R2 adjusted = .224 $F(3,73)=8.34$, $p < .001$).

The mean pitch range across all children in the study was 17.92 ± 4.10ST ($N = 79$), for the high CU group was 16.33ST ± 4.01ST ($N = 36$), and for the low CU group was 19.39ST ± 3.64ST ($N = 39$). In terms of the predicted values of y based on the four high/low groups, if Total ICU was low (below the cutoff of 24) and EVT was above the norming group mean (100), the child's pitch range in semitones was noticeably above the low CU group mean (23ST vs M = 19.39ST). However if the ICU was above the clinical cutoff for the high EVT group, the range dropped noticeably below the high CU group mean (13ST vs M = 16.33ST). The greatest narrowing of pitch range was seen for children with high CU traits and low expressive vocabulary, dropping well below the high CU group mean (11ST vs M = 16.33ST). Figure 6.1 illustrates the trends using the overall sample mean (M = 17.92ST).

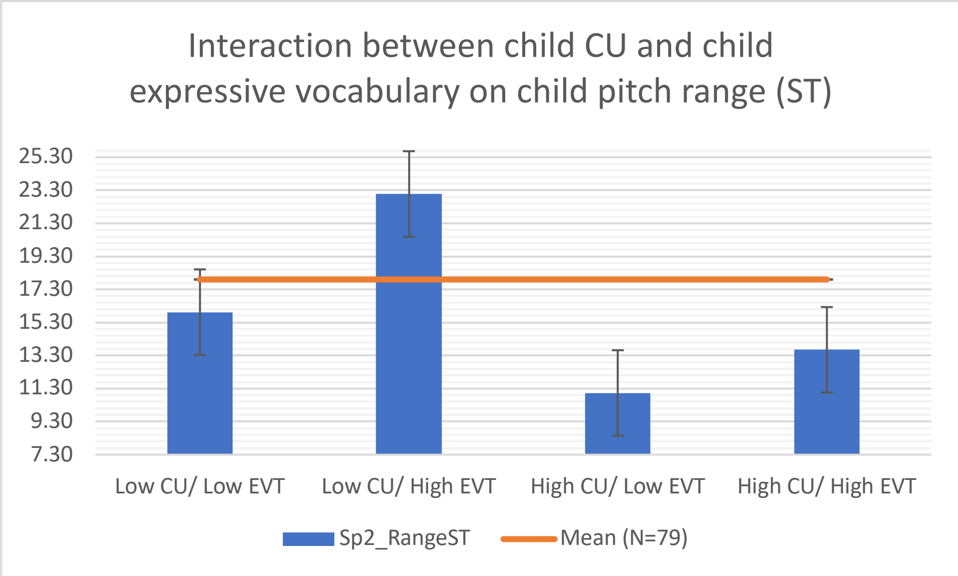

Figure 6.1 Interaction between CU traits and expressive vocabulary for child pitch range in semitones

6.3.2.1 Standard deviation of child pitch (ST)

Zero order correlations also identified a moderate, negative correlation between the continuous measure of ICU Total (25.69 ± 10.69) and the child's standard deviation in semitones (4.01ST ± 1.01ST) which was statistically significant (r(72) = -.350, n = 74, p = .002). This variable assesses the standard deviation of pitch values for each syllable, where values are the minimum and maximum measured in the semitone sale. There was also moderate, negative relationship with ERC lability/ negativity on this acoustic-prosodic variable (-.288, p = .012). Controlling for child lability (3.92 ± 2.38), the moderate, negative partial correlation between the child's pitch deviation and ICU Total remained statistically significant (r(71) = -.230, N = 74, p = .05). Neither SDQ Conduct problems nor SDQ Hyperactivity had significant associations with this feature.

6.3.2.2 Percentage of time the child speaks in the first half of the emotion talk

In terms of the temporal measures, the percentage of time the child spoke in the first half of the emotion talk was uniquely associated with Total ICU (.232, $p = < .05$) and not to any other externalising or internalising scales. At the level of ICU subscale analysis significant associations were also seen on the uncaring (.314, $p < .01$) and callous (.259, $p = < .05$) subscales. ICU Total and SDQ Conduct Problems showed significant relationships with the percentage of time the child spoke at the overall session level, however neither relationship remained significant after controlling for the other.

6.3.2.3 Child pitch rises (ST)

Total ICU showed a significant negative association with child pitch rises (0.015 ± 0.016), a variable referring to the percentage of syllables with a pitch rise greater than 4ST (-.264, $p = .022$). While there were no significant correlations with child externalising dimensions on this pitch feature. SDQ emotional symptoms showed a significant negative relationship on this parameter (-.253, $p = .027$). However controlling for SDQ emotional symptoms, the relationship with Total ICU no longer met significance ($r(72) = -.201$, $N = 75$, $p = .086$)

6.3.2.4 CU traits and acoustic-prosodic expression relating to overlaps

Acoustic-prosodic features relating to overlaps were examined separately in this study due to their potential to confound the discriminant functions for each individual speaker. Table 6.2 provides the significant associations between the child-initiated ("12") overlaps and Table 6.3 provides the associations between the mother-initiated ("21") overlaps. Mother-initiated overlaps as a percentage of all overlaps showed a unique positive relationship with

CU traits. Longer syllable duration and a higher intensity peak (in decibels) in child-initiated overlaps were also positively associated with CU traits, and not with externalising or internalising scales, and intensity peak in child-initiated overlaps was inversely associated with child emotion regulation.

Child externalising behaviour, particularly hyperactivity, was associated with a wide band of energy across the spectrum in both child-initiated and mother-initiated overlaps, and this was an opposite pattern to that seen for the GEM child empathy measures. A range of acoustic-prosodic features associated with overlaps also displayed significance on measures associated with prosocial child empathy. These overlap features were negatively associated with child emotion regulation and child empathy, but displayed positive relationships with child age. In general, these relationships were for primarily for energy features in both child-initiated overlaps, and mother-initiated overlaps.

Table 6.2

Significant associations between child characteristics and acoustic-prosodic parameters for child-initiated overlaps

Parameter (Child-initiated overlaps "12")	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Sp12 Duration of nucleus	**.287***	0.130	0.150	0.225	0.127	**-.311****	-0.311	-0.241	-0.145	0.132
Sp12 Number of speaker turns	0.084	**.239***	**.316****	0.167	-0.034	-0.049	-0.233	-0.114	-0.198	**-.405****
Sp12 Difference between second half and first half in overlap time	.028	-.012	-.062	-.025	**.230***	-.096	.111	0.236	.045	.062
Sp 12 Intensity peak (dB) across syllables	**.304****	0.167	**.256***	**.274***	0.199	**-.350****	-0.036	-0.163	-0.177	0.135
Sp12 Intensity midpoint of turn	0.219	0.074	0.169	0.136	0.100	**-.260***	-0.213	-0.111	-0.132	0.131
Sp12 Sum of upward pitch intervals (ST) in syllables	**.248***	0.216	**.283***	**.277***	0.158	-0.208	-0.145	-0.138	-0.019	0.072
Sp12 Sum of pitch intervals (ST) in syllables (rises and falls add up)	**.311****	0.147	0.142	0.178	0.173	-0.112	-.102	-.197	-.104	-0.046
Sp12 Maximum velocity (ST)	0.032	-0.107	**-.221***	-0.069	-0.129	-0.006	0.038	0.072	0.074	0.168
Sp12 H1A1 (dB) (amplitude difference between 1st harmonic and 1st formant)	**.255***	.050	.143	.196	.146	-.151	.025	-.108	.072	**.261***
Sp12 H1A3 (dB) (amplitude difference between 1st harmonic and 3rd formant)	.159	.061	.113	.174	**.258***	**-.286****	-.022	.021	-.066	**.246***
Sp12 Cepstral peak prominence (cpp)	.103	.070	.131	.178	**.233***	**-.240***	-.087	.002	-.093	**.218***
Sp12 Hammarberg (dB) - maximum energy 0-2000Hz vs 2000-5000Hz	.065	.036	.020	.095	**.248***	**-.218***	.016	.089	-.057	**.230***
Sp12 Proportion of energy below 1000Hz	.106	.055	.106	.162	**.259***	**-.244***	-.044	.043	-.101	**.261***
Sp12 Formant dispersion (formants 1 to 3)	.105	.040	.117	.171	.215	**-.238***	-.074	.034	-.111	**.221***
Sp12 Jitter	.175	.120	**.258***	.186	**.254***	-.162	-.094	-.046	-.120	.112
Sp12 Shimmer	.127	.102	.163	.194	**.271***	**-.258***	-.079	.003	-.103	.203
Sp12 Energy Profile 250Hz	.162	.143	**.239***	.200	.139	-.204	-.123	-.107	-.089	.179
Sp12 Energy 0-500Hz	.137	.153	**.217***	.192	.135	-.206	-.154	-.105	-.094	.140
Sp12 Energy 250-750Hz	.159	.214	**.249***	**.222***	.129	**-.224***	-.199	-.144	-.102	.095
Sp12 Energy 500-1000Hz	.166	**.254***	**.265***	.217	.091	-.184	**-.235***	-.196	-.075	.004
Sp12 Energy 750-1250Hz	.190	**.278***	**.262***	**.233***	.051	-.170	**-.247***	**-.256***	-.065	-.046
Sp12 Energy 1000-1500Hz	.187	**.260***	**.293****	**.228***	-.021	-.141	**-.251***	**-.310****	-.067	-.098
Sp12 Energy 1250-1750Hz	.217	**.236***	**.330****	**.230***	-.053	-.131	**-.276***	**-.365****	-.063	-.108

Note. ST refers to semitones; Hz refers to Hertz; dB refers to decibels; Sp12 refers to speaker 2 (the child) overlapping speaker 1 (the mother) for the duration of turn; Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

Table 6.2 continued.

Parameter (Child-initiated overlaps "12")	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Sp12 Energy 1500-2000Hz	.193	.196	**.300****	.195	-.095	-.096	**-.245***	**-.346****	-.071	-.104
Sp12 Energy 1750-2250Hz	.146	.205	**.303****	.168	-.099	-.047	**-.229***	**-.302****	-.069	-.104
Sp12 Energy 2000-2500Hz	.119	.199	**.295****	.151	-.120	.001	**-.242***	**-.272***	-.062	-.131
Sp12 Energy 2250-2750Hz	.120	.189	**.316****	.153	-.160	.017	**-.235***	**-.259***	-.043	-.147
Sp12 Energy 2500-3000Hz	.125	.205	**.321****	.160	-.159	.011	**-.240***	**-.258***	-.032	-.157
Sp12 Energy 2750-3250Hz	.105	.202	**.295****	.130	-.171	.035	-.196	**-.248***	.002	-.160
Sp12 Energy 3000-3500Hz	.094	.176	**.276***	.100	-.193	.046	-.167	**-.241***	.016	-.168
Sp12 Energy 3250-3750Hz	.100	.156	**.251***	.093	-.203	.048	-.199	**-.249***	.008	-.159

Note. ST refers to semitones; Hz refers to Hertz; dB refers to decibels; Sp12 refers to speaker 2 (the child) overlapping speaker 1 (the mother) for the duration of turn; Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

Table 6.3

Significant associations between child characteristics and acoustic-prosodic parameters for mother-initiated overlaps

Parameter (Mother-initiated overlaps "21")	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
First half mother initiated overlaps as a percentage of all overlaps	.068	.134	.060	.125	.230*	.021	-.007	.040	-.031	.099
Second half mother initiated overlaps as a percentage of all overlap time	.170	.024	.106	.070	.054	-.227*	.231	.003	-.098	.255*
Difference in number of overlaps between the second half and first half	-.057	-.072	-.098	-.021	.271*	-.049	.071	.029	.056	.118
Difference between halves as a percentage of all turns	.104	.006	.085	.124	-.021	-.254*	.256	.017	-.087	.123
Sp21 Intersyllabic interval (ST)	0.190	0.066	-0.013	0.114	0.126	-.267*	-0.310	-0.112	-0.142	0.090
Sp21 Energy Profile 250Hz	.223*	.153	.249*	.185	.076	-.262*	-.140	-.130	.021	.313**
Sp21 Hammarberg (dB) Maximum energy 0-2000Hz vs 2000-5000Hz	.095	-.033	.101	.064	.058	-.190	.051	.106	.085	.363**
Sp21 Proportion of energy below 500Hz	.146	-.046	.062	.073	.168	-.238*	.065	.029	.049	.455**
Sp21 Proportion of energy below 1000Hz	.150	.062	.131	.150	.125	-.244*	-.063	.015	.027	.361**
Sp21 Formant dispersion (formants 1 to 3)	.100	.043	.125	.140	.131	-.235*	-.022	.065	.050	.370**
Sp21 Formant dispersion (formants 1 to 5)	.180	.086	.166	.261*	.184	-.275*	-.082	-.060	-.059	.219*
Sp21 h1 asterix h2 asterix (dB) Formant-adjusted h1-h2	-.110	-.191	-.026	-.183	-.108	.054	.331**	.209	.122	-.011
Sp21 H1A1 (dB) (amplitude difference between 1st harmonic and 1st formant)	.092	.046	-.134	.079	.257*	-.162	.143	-.032	.010	.280**
Sp21 H1A3 (dB) (amplitude difference between 1st harmonic and 3rd formant)	.073	.046	.074	.111	.134	-.192	.035	.110	.113	.375**
Sp21 Cepstral peak prominence (cpp)	.136	.083	.136	.180	.135	-.260*	-.079	.013	.012	.334**
Sp21 Jitter	.000	-.175	-.064	-.057	-.001	-.079	.142	.020	-.005	.192
Sp21 Maximum pitch (ProsPro)	.157	.150	.151	.236*	.057	-.199	-.186	-.104	-.028	.139
Sp21 Minimum pitch (ProsPro)	.094	.085	.098	.191	.055	-.248*	-.068	.003	-.020	.178
Sp21 Excursion size (ST) (ProsPro)	.193	.147	.155	.207	.050	-.168	-.247*	-.157	-.003	.157
Sp21 Final pitch - indicator of target height (ProsPro)	.143	.170	.130	.247*	.096	-.244*	-.125	-.058	-.043	.111

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; Sp21 refers to speaker 1 (the mother) overlapping speaker 2 (the child) for the duration of speech unit. Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

Table 6.3 continued.

Parameter (Mother-initiated overlaps "21")	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Sp21 Mean intensity (dB) (ProsPro)	.165	.131	.156	.198	.055	**-.264***	-.158	-.088	.001	**.233***
Sp21 Mean duration (milliseconds) (ProsPro)	**.262***	.105	.173	**.261***	.125	**-.314****	-.217	-.119	-.080	**.247***
Sp21 Maximum velocity (ST) (ProsPro)	.114	.044	.049	.098	**.256***	.013	.066	-.163	-.019	-.029
Sp21 Maxf0 loc ms - Time of pitch peak relative to onset of turn in milliseconds	**.312****	**.232***	.143	**.328****	**.264***	**-.370****	-.177	-.169	-.157	.153
Sp21 Maxf0locratio - Relative location pitch peak as proportion to turn duration	.035	-.137	-.048	-.013	.039	-.129	.137	.012	-.017	**.215***
Sp21 Energy 0-500Hz	.178	.144	**.243***	.171	.034	**-.218***	-.154	-.092	.033	**.242***
Sp21 Energy 250-750Hz	.189	.179	**.266***	.198	.014	**-.227***	-.191	-.135	-.008	.189
Sp21 Energy 500-1000Hz	.214	**.248***	**.300****	.217	-.012	**-.230***	**-.249***	-.178	-.048	.109
Sp21 Energy 750-1250Hz	**.223***	**.251***	**.299****	**.229***	-.005	**-.240***	**-.260***	-.221	-.076	.036
Sp21 Energy 1000-1500Hz	**.242***	**.267***	**.286****	**.238***	.005	**-.252***	**-.302****	**-.295***	-.120	.034
Sp21 Energy 1250-1750Hz	**.261***	**.257***	**.254***	.204	-.003	**-.239***	**-.329****	**-.347****	-.139	.037
Sp21 Energy 1500-2000Hz	**.234***	**.251***	**.224***	.185	-.022	-.206	**-.315****	**-.355****	-.153	-.004
Sp21 Energy 1750-2250Hz	.208	**.240***	**.226***	.172	-.026	-.145	**-.283***	**-.362****	-.129	-.052
Sp21 Energy 2000-2500Hz	.198	**.223***	.209	.150	-.055	-.115	**-.259***	**-.370****	-.123	-.068
Sp21 Energy 2250-2750Hz	.208	**.219***	.205	.153	-.034	-.121	**-.262***	**-.376****	-.111	-.068
Sp21 Energy 2500-3000Hz	**.220***	**.226***	.211	.176	.012	-.151	**-.270***	**-.370****	-.129	-.065
Sp21 Energy 2750-3250Hz	.206	**.240***	.211	.178	.007	-.162	**-.246***	**-.351****	-.147	-.107
Sp21 Energy 3000-3500Hz	.128	.186	.163	.093	-.051	-.097	-.188	**-.288***	-.102	-.140
Sp21 Energy 3250-3750Hz	.062	.141	.125	.043	-.079	-.034	-.158	**-.232***	-.061	-.125

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; Sp21 refers to speaker 1 (the mother) overlapping speaker 2 (the child) for the duration of speech unit. Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

6.3.3 CU traits and the discriminant function of the child's speech

Descriptive discriminant analysis (DDA) was used to conduct a multivariate analysis of variance test of the hypothesis that the acoustic-prosodic expression of children in the high CU group differed significantly on a linear combination of features in their emotion talk from children in the low CU group. The purpose of the test was to identify the combination of acoustic-prosodic parameters (i.e., the canonical discriminant function, or latent variable) which contribute to the maximal separation between the high and low CU groups. Overlaps were not included. The overall Chi-square test was significant (Wilks $\lambda = .485$, Chi-square = 50.629, df = 6, Canonical correlation = .718, $p < .001$) and identified that the function that separated the groups and explained 51.5% of the discrimination between groups, where $r^2 = (.718)^2 = .515$.

The structure matrix (Table 6.4) reveals the strongest correlations between the discriminant function, or the latent variable, and the child's acoustic-prosodic parameters. The matrix variables can be considered similar to factor loadings in factor analysis, and assist with assigning meaning to the functions by indicating which acoustic-prosodic parameters discriminate between the high/low groups. The strongest correlations with the latent variable (above .30, as with factor loadings) were measures of the child's pitch range both across and at the start of the syllable nucleus measured in semitones. The parameters in the child's speech that best discriminate the high CU group from the low CU group was confirmed as the child's pitch range in semitones, indicating that the discriminant function might be best described as pitch constriction.

Table 6.4

Structure matrix showing the significant correlations of child parameters with the discriminant function for child CU traits

	Function
	1
Pitch range (ST) - span based on 2 stylization values per nucleus - child	0.393
Pitch range (ST) - normalised pitch value of start of nucleus - child	0.369

Note. ST refers to semitones.

Table 6.5 shows the two functions at the group centroids (the mean discriminant scores for each group), indicating that children in the high CU group produce a mean score of -1.058 and therefore individual cases close to this centroid are predicted to belong to the high CU group. Table 6.6 displays the cross-validation results which uses a "jack-knife" technique (also referred to as "leave one out") to iteratively test all cases but one for group membership. This process is used to determine the overall accuracy of the function in predicting group membership, and is also referred to as the hit ratio. Reclassification of cases based on the function was highly successful, finding that 84.0% of the original cases were correctly classified. This combination of the child's acoustic-prosodic parameters showed that both specificity (87.2%) and sensitivity (80.6%) were reasonably strong. False negatives for the high CU group were considerably higher (19.4%) than false positives (12.8%).

Table 6.5

Functions at group centroids for the child's parameters and CU traits

High Low CU	Function
	1
Low CU	0.976
High CU	-1.058

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.6

Hit ratio for cross-validation for CU traits and the child's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low CU	39	34 (87.2)	5 (12.8)
High CU	36	7 (19.4)	29 (80.6)

Note: Percentages for each group in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.3.4 CU traits and significant associations in the mother's speech

Table 6.7 summarises the acoustic-prosodic parameters of the mother's speech that showed significant zero order associations with CU traits and with the comparative measures. In contrast to the child's vocal expressions, the mother's pitch range did not show significant associations with child CU traits or with child conduct problems. Child CU traits were positively associated with a number of the mother's pitch measures, specifically the mother's pitch minimum, maximum (Hz), median and mean, as well as her mean intensity peak (dB) in syllables and intensity at the midpoint of her turns, however these relationships were not significant when accounting for the influence of conduct problems. The mother's spectral energy features across the vocal spectrum were associated with externalising problems, particularly with child hyperactivity. A number of the mother's amplitude variables, specifically the mother's shimmer (micro-perturbations in amplitude), h1-h2 (amplitude difference between 1st and 2nd harmonics), and H1-AI (amplitude difference between 1st harmonic and 1st formant) were positively associated only with child emotional symptoms, while child prosocial behaviour was associated with a lower pitch floor in the mother's speech.

In contrast to CU traits, negative relationships were seen between child empathy values and the mother's pitch minimum, maximum, median and mean, her pitch excursion size, and the mean intensity in her speech turns (Table 6.8). Child affective and cognitive empathy were also associated with less energy in the mother's spectrum from 500Hz to 2000Hz, and for cognitive empathy through to 3500Hz. Negative relationships were also seen between child empathy and large pitch movements (up and down) for the mother, particularly for pitch rises greater than or equal to 4 semitones, in the mother's emotion talk, and there was no significant relationship for the child's speech on these pitch measures.

Table 6.7

Significant associations between child characteristics and the mother's acoustic-prosodic parameters

Parameter (Mother)	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Average pitch min (Hz) across nuclei before stylization	**.279***	**.276***	.163	.206	-.005	-.175	-.094	**-.235***	-.166	-.082
Pitch median (Hz) across syllables before stylization	**.278***	**.274***	.162	.206	-.006	-.176	-.096	**-.234***	-.164	-.082
Pitch mean (Hz) across syllables before stylization	**.279***	**.274***	.160	.205	-.005	-.177	-.096	**-.235***	-.164	-.083
Average pitch min (Hz) across syllables after stylization	**.278***	**.274***	.162	.206	-.006	-.176	-.096	**-.234***	-.164	-.082
Average pitch max (Hz) across syllables after stylization	**.278***	**.274***	.162	.206	-.006	-.176	-.096	**-.234***	-.164	-.082
Average pitch midpoint of turn (Hz)	.203	.204	**.242***	**.271***	.169	**-.240***	-.150	-.094	-.163	.000
Average value of first formant at midpoint of turn	.193	.171	.212	**.256***	.147	**-.261***	-.151	-.149	-.163	.061
Standard deviation in ST of pitch values in syllables (ST)	-0.225	-0.213	-0.146	**-.421****	**-.274***	**.261***	0.13	0.125	0.122	-0.118
Mean of pitch values in ST using min and max pitch for each syllable	.170	.144	.170	**.218***	.168	**-.237***	-.097	-.076	-.133	.103
Sum of upward pitch intervals (ST) of tonal segments in syllables	.195	.178	.140	.111	.014	-.178	**-.246***	**-.244***	-.169	-.019
PitchBottom (in Hz) based on 2 stylization values per syllable	.071	.043	.077	.070	**.257***	-.197	.046	.009	-.163	.107
Mean pitch (Hz) based on 2 raw F0 values per syllable	.158	.171	**.235***	.213	.131	-.207	-.115	-.102	-.139	-.054
Median pitch (Hz) of raw pitch values per syllable	.166	.175	**.249***	**.236***	.142	**-.221***	-.134	-.089	-.144	-.055
Top 98 percentile in pitch range	.151	.176	**.218***	.157	.053	-.194	-.100	-.152	-.114	-.065
Bottom 2nd percentile in pitch range (based on 2 raw pitch values)	**.237***	**.281***	**.268***	**.359****	**.230***	**-.304****	-.130	-.171	**-.233***	-.023
PitchTop (in Hz)	.152	.186	**.229***	.167	.042	-.190	-.095	-.153	-.089	-.056
Median pitch (Hz) (ProsPro)	.111	.162	**.225***	.201	.203	-.210	-.126	-.052	-.125	-.008

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

Table 6.7 continued.

Parameter (Mother)	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Maximum pitch	.134	.090	.185	.139	-.036	-.136	**-.228***	-.106	-.039	.032
Pitch excursion size	.160	.108	.192	.169	.011	-.144	**-.241***	-.145	-.054	.059
Mean pitch	.131	.083	.198	.141	-.031	-.130	**-.231***	-.086	-.028	.025
TrajInterZ (ST) Time-normalized pitch trajectory intersyllabic variations (z score)	.105	.165	**.242***	**.240***	.075	-.127	-.179	-.098	-.038	.064
TrajIntraZ (ST) Time-normalized pitch trajectory of intrasyllabic variations (z score)	**.232***	**.256***	.165	**.339****	**.238***	**-.262***	-.221	-.172	-.215	.128
TrajPhonZ (ST) Time-normalized pitch trajectory of all pitch variations (z score)	.193	**.235***	**.222***	**.326****	.172	**-.222***	-.220	-.151	-.144	.104
Gliss - proportion of syllables with large pitch movement (≧ 4ST)	.092	.162	.107	.069	-.068	-.044	**-.250***	-.156	.023	.035
Rises - proportion (%) of syllables with pitch rise (≧ 4ST)	.123	.165	.073	.087	-.077	-.126	**-.253***	**-.245***	-.079	.061
Average intensity midpoint of turn (dB)	**.243***	**.217***	**.263***	**.273***	.155	**-.281***	-.151	-.175	-.141	.119
Average intensity peak (dB) across syllables	**.235***	**.261***	.172	.186	-.049	-.155	-.113	-.150	-.113	-.046
Mean intensity (dB) (ProsPro)	.160	.072	.191	.157	-.032	-.155	**-.241***	-.104	-.024	.090
Proportion of energy < 500Hz	.031	-.039	.061	.050	**.236***	-.045	.077	.096	.043	**.224***
h1 h2 (amplitude difference between 1st and 2nd harmonics)	.122	.094	.119	.150	**.272***	-.065	.033	-.022	.026	.120
H1A1 (dB) (relative amplitude of first harmonic and first formant)	.149	-.040	.000	.146	**.378****	-.128	.073	.005	.028	**.376****
H1A3 (dB) (amplitude difference between 1st harmonic and 3rd formant)	.102	.054	.029	.132	**.260***	-.179	-.079	.042	-.044	**.248***
Cepstral Peak Prominence (cpp)	.129	.133	.148	.199	**.233***	**-.247***	-.133	-.071	-.138	.136
Center of gravity (Hz) Spectral center of gravity	.082	.087	.119	.155	.107	**-.230***	-.154	-.120	-.147	.003
Formant dispersion (formants 1 to 3)	.098	.105	.135	.164	**.233***	**-.219***	-.087	-.003	-.102	.152
Shimmer	.206	**.231***	**.241***	**.282***	**.315****	**-.240***	-.158	-.149	-.205	.097

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

Table 6.7 continued.

Parameter (Mother)	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability / Negativity	SDQ Emotional symptoms	ERC Emotion regulation	GEM Affective empathy	GEM Cognitive empathy	SDQ Prosocial	Child age
Number of speaker turns	.114	.061	.092	.213	.251*	-.159	.101	-.017	-.121	.199
Difference in mother total speaking time between second half vs first half	.079	.070	-.030	-.011	-.302**	-.088	-.163	-.046	-.141	-.255*
Duration of syllables (milliseconds)	.226*	.143	.171	.242*	.147	-.284**	-.143	-.090	-.093	.194
Inter-Nucleus duration (sum of durations between successive syllables)	.189	.193	.159	.350**	.177	-.223*	.025	-.095	-.131	.197
Nucleus duration (sum of durations for syllables)	.198	.179	.167	.342**	.178	-.227*	.024	-.075	-.097	.249*
Mother-initiated overlaps as a percentage of all overlaps (first half)	.068	.134	.060	.125	.230*	.021	-.007	.040	-.031	.099
Mother-initiated overlaps as a % of all overlaps (second half)	.244*	.076	.116	.110	.088	-.283*	.183	-.029	-.137	.261*
Mother-initiated overlaps as a percentage of all overlap time	.170	.024	.106	.070	.054	-.227*	.231	.003	-.098	.255*
Energy Profile 250Hz	.165	.201	.308**	.199	.100	-.178	-.152	-.187	-.029	.076
Energy 0-500Hz	.154	.210	.281*	.181	.036	-.192	-.192	-.200	-.056	.015
Energy 250-750Hz	.186	.285**	.321**	.239*	.021	-.238*	-.257*	-.269*	-.107	-.031
Energy 500-1000Hz	.194	.296**	.342**	.230*	-.016	-.207	-.259*	-.304**	-.091	-.080
Energy 750-1250Hz	.173	.268*	.298**	.200	-.042	-.170	-.240*	-.344**	-.078	-.110
Energy 1000-1500Hz	.190	.263*	.297**	.211	-.059	-.167	-.253*	-.382**	-.097	-.114
Energy 1250-1750Hz	.211	.260*	.311**	.212	-.067	-.173	-.242*	-.394**	-.111	-.106
Energy 1500-2000Hz	.180	.223*	.293**	.165	-.093	-.148	-.186	-.356**	-.091	-.101
Energy 1750-2250Hz	.140	.191	.290**	.126	-.129	-.101	-.134	-.318**	-.054	-.115
Energy 2000-2500Hz	.104	.175	.285**	.102	-.154	-.052	-.095	-.292*	-.016	-.135
Energy 2250-2750Hz	.095	.176	.292**	.106	-.142	-.054	-.099	-.273*	-.002	-.140
Energy 2500-3000Hz	.101	.183	.299**	.111	-.133	-.070	-.115	-.249*	-.004	-.150
Energy 2750-3250Hz	.095	.180	.297**	.096	-.138	-.055	-.109	-.228*	.003	-.161
Energy 3000-3500Hz	.074	.155	.275*	.073	-.145	-.020	-.094	-.218	.021	-.165
Energy 3250-3750Hz	.060	.139	.257*	.062	-.147	-.006	-.094	-.214	.030	-.160

Note. ST refers to semitone measurement scale; Hz refers to Hertz measurement scale; Significant relationships are shown in green; **Correlation is significant at the .01 level (2-tailed); *Correlation is significant at the .05 level (2-tailed).

6.3.5 CU traits and the discriminant function of the mother's speech

The discriminant analysis for the emotion talk of mothers of children with CU traits identified a linear combination of acoustic-prosodic features that formed a latent variable. The overall Chi-square test was significant (Wilks $\lambda = .282$, Chi-square = 83.602, df = 14, Canonical correlation = .847, $p < .001$) indicating that the group means differed significantly and the single function explained 71.7% of the discrimination between groups (i.e., where $r^2 = (.847)^2 = .717$). Overlaps were not included. The structure matrix (Table 6.8) showed that no parameters performed above the accepted cutoff of .30. From an exploratory point of view, the strongest correlations above .20 were the mother's second formant (clusters of energy at approximately 2000Hz), and similarly, energy in the mid-range of the spectrum (between 1500Hz-2500Hz). These variables can be considered akin to factor loadings in factor analysis, and therefore the function in the mother's speech that best discriminates high CU traits might be conceptualised as energy in mid-range of the spectrum.

Table 6.8

Structure matrix for CU traits and the mother's parameters

	Function
	1
Second formant (F2) midpoint of turn - mother[a]	0.241
Sp1 1500-2000Hz[a]	0.238
Sp1 1750-2250Hz[a]	0.238
Sp1 2000-2500Hz[a]	0.226
Sp1 1250-1750Hz	0.224
Sp1 2750-3250Hz[a]	0.214
Sp1 2250-2750Hz[a]	0.208
Sp1 2500-3000Hz[a]	0.207
Intensity midpoint of turn - mother	0.205
Sp1 3000Hz-3500Hz	0.202

Note. Sp1 refers to mother; Hz refers to Hertz; [a] This variable not used in the analysis to produce the function; Variables ordered by absolute size of correlation within function; no values > .30; values > .20 reported.

Given the low correlations in the structure matrix, the discriminant function coefficients were also examined as an alternative indication of the importance of each parameter to the function (Table 6.9). These coefficients reflect the partial contribution of each acoustic-prosodic parameter to the function when all other variables are controlled , but is often considered to be less accurate than the structure matrix. The highest performing parameters against the discriminant variable were the mother’s energy in the bottom and lower ends of the spectral range 0Hz-250Hz and 1250Hz-1750Hz, her cepstral peak prominence, the intensity at the midpoint of her turns, her center of gravity, mother-initiated overlaps as a percentage of all overlaps, and her H1-A1 (a measure of spectral tilt, or the relative amplitude of the first harmonic and the first formant).

Table 6.9

Standardised canonical discriminant function coefficients for CU traits and the mother's parameters

	Function
	1
Sp1 Energy Profile 0-250Hz	-2.839
Sp1 1250-1750Hz	1.853
Sp1 Cepstral peak prominence	1.373
Intensity midpoint of turn - mother	1.361
Sp1 center of gravity	-1.348
Mother-initiated overlaps as a percentage of all overlaps	0.847
Sp1 H1 A1 (relative amplitude of first harmonic and first formant)	0.842
Turn duration - mother	-0.677
Difference - mother percentage of turns second half vs first half	0.633
First formant (F1) value at midpoint of turn - mother	0.547
Intensity midpoint of turn - mother overlaps child	0.443
Turn duration - mother overlaps child	0.409
Intrasyllabic interval (ST) within nucleus - mother speaks over child	0.319

Note. Sp1 refers to mother; Hz refers to Hertz.

Table 6.10 shows the high/ low CU group means for the predictor variables and Table 6.11 displays the results of the cross-validation analysis. Reclassification of cases based on the new canonical variables was highly successful, with 90.7% of the original grouped cases correctly classified. The mothers acoustic-prosodic features predicted high CU group membership (94.4%) with high rates of specificity (87.2%) and sensitivity (94.4%). False positives (12.8%) were higher than false negatives (5.6%) for the mother’s parameters.

Table 6.10

Functions at group centroids for CU traits and the mother's parameters

High Low CU	Function
	1
Low CU	-1.513
High CU	1.639

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.11

Hit ratio for cross-validation for CU traits and the mother's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low CU	39	34 (87.2)	5 (12.8)
High CU	36	2 (5.6)	34 (94.4)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.4 Results: Acoustic-prosodic features in the emotion talk of children with ODD

6.4.1 ODD and significant associations in the child's speech

A number of continuous measures were considered to be associated with characteristics of ODD, specifically ERC Emotion lability/ negativity, SDQ Conduct problems, and as part of a broader externalising dimension, SDQ Hyperactivity. As can be seen in Table 6.1, a number of child pitch parameters showed significant moderate relationships across these scales, particularly a narrower child pitch range in semitones (ST), a higher pitch floor, a higher pitch mean and pitch ceiling, a sharper pitch trajectory, and more jitter (micro-perturbations of pitch associated with vocal stress).

In terms of energy parameters, relationships across a wide band of the child's spectral energy from low in the audible spectrum (0Hz-250Hz) through to the peak height measured in this study (4000Hz) were particularly significant for child hyperactivity, as well as more shimmer in vocal expression (micro-perturbations of energy associated with vocal stress). This pattern of energy features was similar to that seen for child-initiated overlaps (Table 6.2) and also for mother-initiated overlaps (Table 6.3). Temporally, the percentage of time the child speaks in the emotion talk was positively associated with both CU traits and conduct problems. Scales relating to emotion regulation, child empathy (particularly cognitive empathy), and child prosocial behaviour showed relationships in the opposite direction on many of the same acoustic-prosodic features as those relating to characteristics of disruptive behaviour.

6.4.2 ODD and the discriminant function of child's speech

Descriptive discriminant analysis (DDA) was conducted on the child's acoustic-prosodic features to examine if children with ODD differed significantly in a linear combination of acoustic-prosodic variables in the emotion talk with their mother. The overall Chi-square test was significant (Wilks $\lambda = .694$, Chi-square = 23.973, df = 3, Canonical correlation = .554, $p < .001$) which accounted for 30.6% of the variance between groups. A large number of variables were correlated with the discriminant function in the structure matrix, and are ordered by the absolute size of the correlation (Table 6.12). The matrix shows the strongest correlations were the associated with the child's pitch parameters, particularly the pitch range, pitch floor, and spread of pitch across the energy spectrum, and measures of voice stress and micro-instability (jitter and shimmer).

Table 6.12

Structure matrix from the discriminant analysis for ODD and the child's parameters

	Function
	1
Pitch range normalised pitch value of start of nucleus - child	0.723
Pitch Range (in ST) based on 2 stylization values per nucleus - child	0.575
Standard deviation of ST in ST for each syllable - child[a]	0.423
Bottom 2nd percentile in pitch range (2 raw F0 values per nucleus) - child[a]	-0.665
Pitch Bottom (in Hz) based on 2 stylization values per nucleus - child[a]	-0.597
Child Formant dispersion formants 1 - 3[a]	-0.453
Child cepstral peak prominence[a]	-0.442
Child shimmer[a]	-0.440
Child energy below 1000Hz$_a$	-0.437
TrajIntraZ - pitch trajectory in syllabic nuclei ST scale (z-score) (in sd/s)a - child[a]	-0.418
Number of speaker turns - child speaks over mother[a]	-0.417
Child Formant dispersion formants 1 - 5[a]	-0.394
Child Energy Profile 250Hz[a]	-0.379
Child median pitch	-0.360
Child Hammarberg index[a]	-0.356
Child energy below 500Hz[a]	-0.352
Child 0-500Hz[a]	-0.35
Intensity midpoint of turn - child[a]	-0.313
Child jitter[a]	-0.311

Note. ST refers to semitones; [a] This variable not used in the analysis to produce the function.

Table 6.13 shows the group centroids and together with the structure matrix indicates that the function that discriminates ODD in the child's speech might be conceptualised as narrow, heightened and stressed. Table 6.14 displays the cross-validation results. Reclassification of cases based on the new canonical variables was successful with 79.7% of the original grouped cases correctly classified. While sensitivity was high (88.7%) specificity was poor (50%), with the latent variable considerably stronger at predicting ODD group membership than those children without an ODD diagnosis (50.0% false positives).

Table 6.13

Functions at Group Centroids for ODD and the child's parameters

ODD diagnosis	Function
	1
No ODD	1.192
ODD	-0.360

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.14

Hit ratio for cross-validation for ODD and the child's parameters

		Predicted group membership	
Actual group	No. of cases	No ODD	ODD
No ODD	16	8 (50)	8 (50)
ODD	53	6 (11.3)	47 (88.7)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.4.3 Overlaps in ODD: A sign of dysregulation?

To investigate if the proportion of variance and the specificity of the discriminant function for ODD could be improved, the DDA was rerun with the addition of child-initiated overlaps. This wider dataset of both child-only parameters and parameters relating to child-initiated overlaps were entered in a stepwise fashion with the largest F entered first. The overall Chi-square test was significant (Wilks λ = .457, Chi-square = 42.725, df = 7, Canonical correlation = .737, $p < .001$) and the single function that was extracted accounted for 54.3% variance between the groups, an increase of 23.7% over child-only parameters. Seven acoustic-prosodic parameters formed a latent variable and these were dominated by pitch parameters in overlaps, including the maximum pitch in the child-initiated overlaps, the relative location of the F0 peak as a proportion of the duration of the speech unit both in child-initiated overlaps as well as in the child's own speech, the quantity of child-initiated overlaps, the child's pitch range at the start turns, and the child's median pitch in turns (Table 6.15).

Table 6.15

Standardised canonical discriminant function coefficients for ODD and the child's parameters (including overlaps)

	Function
	1
Sp12 maximum pitch (ProsPro)	-1.537
Pitch range normalised pitch value of start of nucleus - child	1.114
Sp12 maxf0 loc ratio (relative location of f0 peak as a proportion of duration of turn) (ProsPro)	1.068
Child maxf0 loc ratio (relative location of f0 peak as a proportion of duration of turn) (ProsPro)	0.807
Child-initiated overlaps as a percentage of total time	0.799
Child median pitch	-0.527
Intersyllabic interval (ST) end of previous nucleus to start of current one - child over mother	-0.420

Note. F0 refers to fundamental frequency (pitch).

Variables in the structure matrix (Table 6.16) are ordered by the absolute size of the correlation based on the contribution to structure definition, and together with the means at the group centroids (Table 6.17) indicates that the function that best discriminates ODD group membership in the child's speech might be conceptualised as vocal stress, heightened pitch floor and poorer child self-regulation (i.e., more overlaps).

Table 6.16

Structure matrix from the discriminant analysis for ODD and the child's parameters (including overlaps)

	Function
	1
Child jitter	-0.411
Child shimmer	-0.380
Pitch Bottom (Hz) based on 2 stylization values per nucleus - child	-0.374
Bottom 2nd percentile in pitch range (raw F0 values per nucleus) - child	-0.331
Number of speaker turns - child speaks over mother	-0.320
Child Formant dispersion formants 1 to 3	-0.298

Note. Hz refers to Hertz.

Table 6.17

Functions at group centroids for ODD and the child's parameters (including overlaps)

ODD diagnosis	Function
	1
No ODD	2.039
ODD	-0.564

Note. Unstandardised canonical discriminant functions evaluated at group means.

Cross-validation of cases based on the new canonical variables was successful, with 88.3% of the original grouped cases correctly classified (Table 6.18). Similarly to the child only features, the addition of child-initiated overlap features was stronger at predicting ODD group membership (93.6%) compared to the group of children without an ODD diagnosis (69.2%), but were significantly improved compared to using the child only parameters, particularly for reducing the rate of false positives (Table 6.14).

Table 6.18

Hit ratio for cross-validation for ODD and the child's parameters (including overlaps)

		Predicted group membership	
Actual group	No. of cases	No ODD	ODD
No ODD	13	9 (69.2)	4 (30.8)
ODD	47	3 (6.4)	44 (93.6)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.4.4 ODD and significant associations in the mother's speech

A large number of pitch measures were significant in the speech of mothers interacting with characteristics of children with ODD, including the mother's pitch minimum, pitch maximum, median and mean (Table 6.7). These heightened pitch features in the mother's speech, as well as the mother's mean intensity peak (dB) in syllables, were associated with child conduct problems but not with other externalising or internalising scales, with the exception of CU traits as discussed earlier. Shimmer (micro-instability in amplitude) and energy from the bottom to top of the spectrum was associated with child conduct problems, and patricianly the SDQ hyperactive scale. Similarly, child externalising scales were associated with a wide band of energy across the spectrum in mother-initiated overlaps.

6.4.5 ODD and the discriminant function of the mother's speech

Descriptive discriminant analysis (DDA) was conducted on the mother's acoustic-prosodic to test the hypothesis that mothers interacting with children with an ODD diagnosis would differ significantly on a linear combination of acoustic-prosodic features in emotion talk with their child. A latent discriminant function was identified. The overall Chi-square test was significant (Wilks $\lambda = .244$, Chi-square = 86.792, df = 11, Canonical correlation = .870, $p = .000$), and the single function extracted accounted for 75.6% of the variance between groups, which was large. The structure matrix (Table 6.19) reveals that the mother's pitch floor (bottom 2^{nd}) and the pitch range were most highly correlated with the latent variable, indicating that the function that discriminates ODD membership in the mother's speech might be conceptualised as heightened and narrow pitch.

Table 6.19

Structure matrix from the discriminant analysis for ODD and the mother's parameters

	Function
	1
Pitch range (in ST) based on 2 stylization values per nucleus - mother[a]	-0.352
Bottom 2nd percentile in pitch range (2 raw F0 values per nucleus) - mother	0.304
Stdev of ST - standard deviation of pitch values in ST for each syllable - mother[a]	-0.301

Note. ST refers to semitones; [a] This variable not used in the analysis to produce the function.

Due to the high proportion of variance explained by the function, the unique (partial) contribution of each parameter in forming the latent variable using the standardised discriminant function coefficients was examined in addition to the structure matrix (Table 6.20). As with the structure matrix, the mother's pitch floor (both before and after stylisation) contributed the most weight in discriminating ODD group membership in the mother's speech, with the addition of the mother's median pitch and formant dispersion (formants 1 through 5).

Table 6.20

Standardised canonical discriminant function coefficients for ODD and the mother's parameters

	Function
	1
Bottom 2nd percentile in pitch range (2 raw F0 values per nucleus) - mother	2.269
Pitch bottom (Hz) based on 2 stylization values per nucleus - mother	-1.570
Sp1 median pitch	1.511
Sp1 Formant dispersion formants 1 to 5	-1.382
Mother-initiated overlaps as a percentage of total time	-1.009
Mother-initiated overlaps as a percentage of all overlaps	1.266
Average intensity midpoint of turn - mother overlaps child	0.995
Mean in Hz of raw pitch values (based on 2 raw F0 values per nucleus) - mother	-0.978
Sp1 500-1000Hz	0.934
Inter-Nuclei Duration - sum of durations between successive nuclei - mother	0.533
Sp1 final velocity	0.302

Note. F0 refers to fundamental frequency (pitch); Hz refers to Hertz.

Table 6.21 shows the group centroids. Cross-validation of cases based on the new canonical variables was highly successful: 94.2% of the cases were correctly reclassified into their original categories, showing similar strength at predicting both ODD group membership (96.2%) and non-ODD diagnosis (87.5%) and with few false negatives (3.8%) (Table 6.22).

Table 6.21

Functions at group centroids for ODD diagnosis and the mother's parameters

ODD Diagnosis	Function
	1
ODD	-3.158
No ODD	0.953

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.22

Hit ratio for cross-validation for ODD and the mother's parameters

		Predicted group membership	
Actual group	No. of cases	No ODD	ODD
No ODD	16	14 (87.5)	2 (12.5)
ODD	53	2 (3.8)	51 (96.2)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.5 Discussion

Reminiscing emotion talk between parents and their young children has been found to be positively associated with the child's capacities for emotion knowledge, self-regulation and prosocial behaviour (Fivush et al, 2006; Salmon & Reese, 2016). The emotion talk task in this study required mothers and their children to discuss primarily negative emotional events that the child had experienced and the acoustic-prosodic characteristics of the task offer an objective measure of the affective tone of these conversations. This study examined a large number of acoustic-prosodic measures with a view to capturing any important differences in the affective qualities of the talk between mothers and their children with CU traits and ODD, comparatively. The findings are observational and hypothesis generating in the nascent fields of childhood affective prosody and acoustic-prosodic characteristics of mother-child emotion talk. The significant results relating to each of the groups are discussed below.

6.5.1 Callous-unemotional traits

This is the first study to identify a narrower pitch range in the vocal expression of children with CU traits. Using the semitone (ST) measurement scale, high CU children maintained a perceptually narrower pitch range in the emotion talk compared to low CU children, and this result was evident on both the continuous ICU Total measure as well as for children in the High CU grouping variable. There were no significant effects associated with child age however expressive language did have a small moderating effect on the pitch range of high CU children. While there was some shared variance between child CU traits and child conduct problems, there were only small contributions to the child's pitch range made by the externalising scales in the emotion talk. Conversely, child pitch range displayed positive relationships with child empathy and with child emotion regulation.

Hypothesis 1, that children with high CU traits would show restricted expression on emotion relevant parameters such as intensity and pitch, was partially supported. Studies of speaker pitch are typically conducted using the physical Hertz measurement scale, however the semitone scale is considered to be a particularly useful measure of the perceptual experience of listeners as the human auditory system is non-linear. As such, listeners are more likely to perceive increases or decreases that have been identified using the semitone measurement system. It is therefore plausible that the narrower pitch range feature of the child's prosody may be contributing to parent ratings of unemotional traits in these children, possibly even beyond the listener's conscious awareness.

These results suggest that the ICU Total score may be capturing a general dimension of reduced affective expression. High CU children, particularly those with good expressive vocabulary, also spoke for a notably greater percentage of time in the first half of the emotion talk with their mothers. This is typically the period in which the mother builds task rapport. This relationship was inverse to that seen on the child empathy measures, which was associated with shorter child speech turns and a reduced percentage of time the child speaks, particularly in the first half of the emotion talk. These patterns on the measures raise questions about the importance of child listening versus speaking for the development of child empathy in mother-led interactions.

Notably, there were no acoustic-prosodic parameters of the mother that were associated with high CU traits after controlling for child externalising behaviour and emotional symptoms, with the exception of mother-initiated overlaps as a percentage of all overlaps. Noting the finding that high CU children spoke for a significantly, and likely, perceptible greater percentage of time than their low CU and high empathy peers, it may be that mothers of high CU children are simply required to interrupt more to meet the demands of conversational pragmatics. Nonetheless, it raises questions about what impact, if any, this pattern of maternal interrupting may have on modelling turn-taking for the child. To this end, it was observed that the percentage of child-initiated overlaps was important to the discriminating function for child high CU traits, suggesting that there may be a dynamic relationship at play.

Significant associations were also seen between CU traits, and longer syllable duration in child-initiated overlaps and a higher intensity peak (in dB) in child-initiated overlaps, and these relationships were not present with externalising or internalising scales and were inversely associated with child emotion regulation. There is evidence to suggest that prosodic prominence in overlaps is associated with turn-competitiveness (Hilton, 2016; Kurtić, Brown & Wells, 2013), that is, interruptions that are intended to challenge control of the conversational floor. Therefore the current findings open up potential questions in relation to how children with CU traits might be engaging in challenge or control aspects of interpersonal communication.

The discriminant analysis for the mother's acoustic-prosodic features identified primarily energy rather than pitch features. The mother's energy in the spectral range 0Hz-250Hz and 1250Hz-1750Hz, the intensity at the midpoint of her turns, her cepstral peak prominence, her center of gravity, and her H1-A1 (amplitude difference between 1st harmonic and 1st formant) formed a latent variable that showed high rates of specificity and sensitivity. This was in contrast to the zero level correlations for these features, which did not show significant relationships with CU traits after controlling for conduct or emotional problems. Together, these particular acoustic-prosodic parameters are of further interest to the synchrony findings.

In general, the GEM child empathy scales showed relationships in the opposite direction on many of the same acoustic-prosodic features as those relating to characteristics of CU traits, including a wider child pitch range measured in semitones (ST), but also less intensity from the low end of the spectrum across the middle of spectrum in both the child's and the mother's speech. Child cognitive empathy was associated with a lower pitch floor for the child as well as negative relationships with energy across the child's spectrum from 0Hz through to 3000Hz in the emotion talk, a similar patter seen to that of mothers. Given that child empathy measures were positively associated with cointegration on these parameters in Study 2, the findings suggest that it is on these lower pitch and energy values that the emotion talk of mothers and their children with low CU traits are synchronising.

6.5.2 Oppositional Defiant Disorder

A number of pitch features in the child's speech showed significant associations with characteristics of ODD, including a higher pitch floor and ceiling, and a sharper pitch trajectory. There was strong classification performance in discriminating the ODD group of children from the non-ODD group. Median pitch was strongly correlated with the latent variable for ODD, as was a narrower pitch range, which likely reflects the significant proportion of high CU children with ODD. Similarly, a large number of pitch measures emerged as significant in the speech of mothers interacting with their children with ODD, including the mother's pitch minimum, pitch maximum, median and mean. These heightened pitch features, as well as the mother's mean intensity peak (dB) in syllables, were associated with child conduct problems but not with other externalising or internalising scales, with the exception of CU traits discussed earlier. Hypothesis 2, that children with ODD would show an expanded range of values on emotion relevant parameters such as intensity and pitch, was supported.

Pitch is widely considered to be a principal indicator of emotional arousal in vocal expression (Goudbeek & Scherer, 2010; Juslin & Laukka, 2003) and is also indicative of increased vocal effort (Liйnard & Di Benedetto, 1999). In combination with other acoustic-prosodic parameters it has been described as a fairly reliable indicator of emotional stress (Giddens et al, 2013). Both mothers and their children with ODD showed a greater energy formant energy dispersion in their emotion talk, and this spread has also been associated with more effortful vocal expression (Liйnard & Di Benedetto, 1999). Based on these measures, it might be said that the emotion talk of the ODD children and their mothers was characterised by a heightened level of emotional arousal, and by more effortful speech. These features suggest that there are likely greater physiological demands on both speakers.

Problems with compliance are a defining feature of disruptive behaviour disorders, particularly Oppositional Defiant Disorder (American Psychiatric Association, 2013; O'Kearney et al, 2017). Therefore it is possible that acoustic-prosodic characteristics displayed in this task, especially of the mother, reflect behaviour management demands as much as the content of the emotion talk itself. However, the home environment also has compliance demands, and it is probable that both mother and child bring some characteristic patterns of interacting into the laboratory environment. Given that dyads are discussing largely negative emotional events that the child has experienced, including anger but also fear and sadness, it is possible that heightened levels of emotional arousal in both mother and child may also present a barrier to caregiver efforts to comfort and validate the child's emotional experiences.

Incorporating features of child-initiated overlaps in the analysis of the child's speech improved both the specificity and sensitivity of the discriminant function in the speech of children with ODD. Significant overlap variables related to the percentage of child-initiated overlaps and the maximum pitch of child-initiated overlaps. Such a finding appears consistent with the broader self-regulation problems that are characteristic of children with disruptive behaviour problems (American Psychiatric Association, 2013; Cavanagh et al, 2017), and suggests that a child's tendency to speak over their mother may potentially be a clinically useful characteristic in the assessment or response to treatment of children with ODD. In particular, overlaps reflect established patterns of turn-taking — or disrupted turn-taking — between familiar interlocutors, and theoretically provides opportunity across repeated interactions for the alignment between speakers' vocal content, increasing opportunities for emotion contagion.

The structure matrix in the discriminant analysis for children with ODD identified a disproportionate amount of their vocal energy located in the range below 1000Hz, and energy in this range also contributed to forming the discriminant function of the mother's speech. This is an intriguing finding as speech intelligibility for both adults and children disproportionately improves with energy located above 1000Hz and particularly in the bands from 1000Hz-3000Hz (Hazan & Markham, 2004). This lower part of the spectrum is associated with more vocal power but poorer intelligibility, a term which refers to the how much of the message or meaning has been extracted from the spoken word and sentences by the listener (Viswanathan & Viswanathan, 2005).

Intelligibility is a complex dynamic involving both speaker and listener factors (e.g., Hustad, 2008), however given that there was no disruption to cointegration on this parameter for ODD in Study 2, this finding raises questions about the potential contribution of acoustic-prosodic expression and synchrony to the language difficulties that have been observed in children with conduct problems (Yew & O'Kearney, 2015). For example, it is possible that synchrony between mothers and their children on this parameter facilitates mutual comprehension, but that any such accommodations are occurring unconsciously and are not present when interacting with unfamiliar others (e.g., Flipsen, 1995).

It was observed that a wide range of child and maternal acoustic-prosodic features were associated with both externalising problems and with callous-unemotional (CU) traits, however the contribution of CU traits was no longer significant on most features after controlling for child conduct problems and for child hyperactivity. Features that did remain significant for CU traits are discussed in the following section. Shimmer in both the child's speech and mother's speech was negatively associated with child emotion-regulation, and also showed positive relationships with both child externalising and emotional scales, and was correlated with the latent variable in the speech of children with ODD.

A form of micro-structural irregularity, shimmer is typically associated with expression of negatively valenced emotions such as anger, fear, and sadness (Juslin & Laukka, 2003), and has been shown to be useful in increasing emotion classification accuracy when added to other spectral and energy features (Li et al, 2007). Given its presence in both the child and mother profiles for disruptive behaviour problems, it is of particular interest to the subsequent study of vocal synchrony.

A further notable relationship in the profiles of both children and their mothers relates to spectral energy. In particular, child hyperactivity showed significant associations with measures of both the child's energy and the mother's energy across the entire speech spectrum, ranging from very low in the audible spectrum (0Hz-250Hz) through to the peak height measured in this study (4000Hz). These energy variables may therefore be of particular interest to the future study of mother-child vocal synchrony in children with hyperactivity.

There was also overlap in these bands with conduct problems and child cognitive empathy, suggesting that treatments focusing on effective communication through voice management for mothers and their children with problems in empathy may warrant further consideration. Overall, it can be said that the emotion reminiscing talk of mothers and their children with disruptive behaviour problems was characterised by features indicating higher emotional arousal and increased vocal effort in these dyads.

6.5.3 Prosocial characteristics

In general, many of the acoustic-prosodic features associated with characteristics of ODD were inversely associated with measures of child prosocial behaviour and child emotion regulation (Table 6.1; Appendix H). Child prosocial behaviour was positively associated with shorter child speech turns, and a considerably smaller percentage of time the child speaks, particularly in the first half of the emotion talk. This was an inverse relationship to that seen for CU traits, and raises important questions about the role of child listening versus speaking in the child's empathy development.

Conversations with emotionally regulated children were characterised by a lower pitch floor, slower speech rate, lower intensity at the midpoint of child turns, less jitter and shimmer, and a smoother pitch trajectory both within and between their syllables. This combination suggests a lower level of emotional arousal and vocal stress in the child during the emotion talk. Similarly, the speech of mothers of highly regulated children was characterised by indicators of lower arousal and less forceful speech, including a lower pitch median and mean, a flatter pitch trajectory, lower pitch and lower intensity at the midpoint of turns, and less energy at the first formant (Table 6.7; Appendix H). The results suggest that lower pitch floor and smoother pitch trajectories for both child and mother, along with intensity measures in the midpoint of turns, are particular variables of interest to the future study of emotion regulation and acoustic-prosodic synchrony.

Interestingly, shorter maternal syllables, faster speech rate, and a greater percentage of speech turns by the mother in the emotion talk were all associated with higher levels of child emotion regulation. There is evidence to suggest that speaking rate, and pitch measures and intensity measures interact in important ways to affect judgements made by the listener (Bond et al, 1988). As such, it is plausible that the mother's faster speaking rate and shorter syllables are accommodated by the overall lower pitch and intensity in the emotion talk of mothers interacting with emotionally regulated children, and that mothers of these children may have adapted their speech rate to their child over time.

6.6 Summary of findings

Significant differences were associated with high callous-unemotional traits after controlling for conduct problems on two key acoustic-prosodic parameters in the child's speech: a restricted range of pitch for the child using the semitone (ST) measurement scale, and a markedly greater proportion of child speaking time compared to low CU children. There were no acoustic-prosodic characteristics of the mother associated with child CU traits. In contrast, a number of acoustic-prosodic parameters were identified as distinctive in the emotion talk of mothers and their children with ODD; these were primarily heightened pitch variables for the child, and heightened pitch and energy features for the mother.

These acoustic-prosodic parameters are the first to be empirically associated with the emotion talk of mothers and their children with high CU traits and with ODD. In general, mothers and their children with high empathy and emotion regulation showed an overall inverse pattern of relationships with acoustic-prosodic cues compared to children with CU traits and children with ODD. These results are consistent with the observed phenomena of high levels of arousal in both the ODD child and their mothers however it should be noted that multiple testing adjustments were not made for the correlation tables reported in this naturalistic study (Rothman, 1990). Overall, the findings offer particular direction for future studies of vocal expression in these groups, particularly those relating to caregiver management of interactions with children who display problems in behavioural and emotional regulation.

In terms of limitations, discriminant analyses, with the exception of ODD, did not include acoustic-prosodic data relating to overlaps. There was a large number of significant associations on a range of overlap variables, and it is possible that their inclusion in the analyses may have improved the classification results for a number of groups. As overlaps are not included in the study of synchrony they were not examined further in Study 3. Finally, the purpose of the analyses was primarily exploratory and descriptive. As with the regression equations, the canonical functions should be further validated by testing their efficacy with new samples, as their true discriminatory power will be found only when tested in different groups.

CHAPTER 7: CHARACTERISTICS OF THE MOTHER AND ACOUSTIC-PROSODIC FEATURES OF THE MOTHER AND OF THE CHILD

7.1 Chapter outline

Where Chapter 6 examined relationships between *child* characteristics and the acoustic-prosodic expression of children and their mothers during emotion talk, Chapter 7 examines relationships between characteristics of the *mother* and the acoustic-prosodic expression of mothers and their children during emotion talk. A focus of the chapter is to investigate if vocal qualities associated with maternal characteristics are potentially being mirrored in the voice of the child. Parameters associated with warmth in the mother's speech — and with warmth, attunement, and dismissiveness in the emotion talk — were studied to identify vocal markers that may be relevant to the conveyance of these important relational qualities. As a comparative guide, these findings are considered for their alignment with the existing profile for the vocal emotion of tenderness (Juslin & Laukka, 2003). Further, the effect of these relational qualities on the key acoustic-parameters found to be significant in the speech of children with CU traits or ODD in Chapter 6 were investigated using the high dimensional methods outlined in Chapter 3. This chapter also examines mother and child parameters associated with the mental health characteristics of the mother, due to the important emerging relationship between mental health status and vocal affect expression in adults (Cummins et al, 2015a; Woody, Feurer, Sosoo, Hastings & Gibb, 2016).

7.2 Introduction

Warmth is a quality of maternal behaviour that is widely accepted as promoting child wellbeing and psychological adjustment (Guy et al, 2016; Zhou et al, 2002), and is also a quality that is thought to be important in attenuating the level of CU traits in young children (Hyde et al, 2016; Pasalich, Dadds, Hawes & Brennan, 2011). Yet there is no clearly agreed definition in the literature, and it has been operationalised in many different ways. Common examples include measuring caregiver attitudes expressed about the child in a single speaker task (Daley et al, 2003; Waller et al, 2015), or relying on parent recollections of their own behaviour, such as displays of physical affection toward the child (Guy et al, 2016).

Other approaches include using child recollections of positive caregiver behaviour (Ray et al, 2017), and directly observing displays of positivity and affection during mother-child interactions (e.g., Deater-Deckard et al, 2006). In non-verbal channels, objective markers for the expression of warmth have included counting the frequency and duration of behavioural displays such as parental eye contact (Dadds et al, 2012), smiling and touch (Oveis et al, 2009). Very few studies have attempted to measure warmth in the parental voice, and those that have rely on impressionistic scales to subjectively rate such qualities (e.g., Daley et al, 2003).

Warmth is used in the developmental literature alongside — and sometimes interchangeably — with concepts of caregiver attunement and responsiveness to distress, however the distinction between these constructs is important. In seminal work on child attachment, Mary Ainsworth observed in Ugandan mothers the presence of sensitivity to the child's needs and responsiveness to distress, but not necessarily warmth or affection (Ainsworth, 1967). She elaborated this distinction in further work by describing the caregiver's tendency to tune into and respond sensitively to the child's social signals and bids for attention and comfort as the key necessary ingredient for secure attachment (Ainsworth et al, 1974).

Consistent with this general difference, warmth and attachment have been argued by the evolutionary theorist Kevin MacDonald to be distinct constructs tied to separate biological systems (i.e., reward versus threat respectively) (MacDonald, 1992), and this separation has been increasingly supported by studies with older children examining warmth versus maternal responsiveness to distress (Davidov & Grusec, 2006; Wright, Hill, Sharp & Pickles, 2018). In the vocal channel, a key example of the use of the mother's voice as a tool to manage child distress has been identified by studies on child hormone expression in early-middle childhood following a stressful experience (Seltzer et al, 2010; Seltzer et al, 2012), leading the authors to suggest that the caregiver's voice may have evolved as a substitute to physical touch in down regulating stress in the child. And yet much is unknown about the nature of the vocal qualities that might contribute to such outcomes.

Emotion researchers using computational methods have attempted to assemble a reliable group of acoustic-prosodic parameters indicative of key vocal emotions including anger, sadness, and fear (e.g., Eyben et al, 2016). Warmth and attunement have not been demarcated as distinct constructs in vocal emotion research however a closely aligned quality – tenderness – has been recognised as one of five basic emotion categories identifiable in both speech and music (Juslin & Laukka, 2003; Juslin & Scherer, 2005). Following the criteria for basic emotions proposed by Ekman (1999), Kalawski (2010) has further proposed tenderness as a basic emotion that represents the qualities of love and empathy in caregiving behaviour.

Parameters associated with the vocal emotion of tenderness include low pitch and intensity features and micro-structural regularity (low jitter and shimmer), but also little voice intensity, little high frequency energy, little pitch variability, falling pitch contours, slow speech tempo, and slow voice onsets (tone attacks) (Hammerschmidt & Jürgens, 2007; Juslin & Laukka, 2003; Leinonen et al, 1997; Van Bezooijen et al, 1983). This prosodic profile is primarily drawn from studies using short affect bursts in single speaker actor portrayals, and no reported studies using acoustic-prosodic parameters have examined the vocal emotion of tenderness as it is displayed online during caregiver-child interactions. The current study seeks to bridge this gap by identifying acoustic-prosodic parameters associated with displays judged as high in warmth and attunement during a mother-child conversational task about the child's emotions. More broadly, the current study argues that discovering objective markers in the voice for these types of relational qualities can better standardise empirical research, and potentially inform parenting interventions through technologies such as voice assisted feedback.

In addition to the importance of these positive relational qualities for child development, dismissiveness is a quality of caregiver behaviour that has been found to be particularly adverse for children with CU traits and conduct problems (Pasalich et al, 2014). This type of caregiver responding has been associated with higher levels of child CU traits (Pasalich et al, 2014), more externalising behaviour and lower quality of social competence (Eisenberg et al, 1999), higher levels of physiological arousal in the child (Gottman et al, 1996), and lower child emotion regulation and associated aggressive behaviour (Ramsden & Hubbard, 2002). Broadly, a dismissive responding style is characterised by responses that convey a critical or disapproving attitude toward the child's displays of emotion (Gottman et al, 1996). This type of disapproval is typically studied through self-report by measuring the caregiver's attitudes to the child's emotions (e.g., Havighurst et al, 2015) and online during caregiver-child interactions (Gottman et al, 1996; Pasalich et al, 2014) however there have been no studies on the vocal parameters that might serve to convey this important type of caregiver response style.

The following hypotheses were proposed:

Hypothesis 1 was that acoustic-prosodic features associated with the vocal emotion of tenderness would align with the judges ratings of the mother's vocal warmth and with ratings of warmth and attunement of the emotion talk. Significant parameters in the speech of the mother and of the child were compared for the dyadic measures (warmth and attunement in the interaction) due to the relevance of both speaker's parameters to the synchrony construct. Hypothesis 2 was that mothers of children with high CU traits would display less warmth, as measured by both the judges ratings of warmth and attunement. Hypothesis 3 was that these relational qualities would impact in significant ways on the emotion relevant parameters that were associated with characteristics of the child in Study 3. Finally, acoustic-prosodic parameters associated with the mother's mental health status were examined due to the demonstrated relationship between mental health and vocal affect expression in adults (Cummins et al, 2015a; 2015b). Hypothesis 4 was that mothers reporting high levels of depression, anxiety and stress would display less warmth and attunement in the emotion talk with their children, as measured by the judges ratings scales and by the profile of the mother's acoustic-prosodic features.

7.3 Acoustic-prosodic features associated with the mother's speech

7.3.1 Warmth in the mother's speech

As outlined in Chapter 3, two judges rating scales were used to rate impressions of warmth in the mother's voice. One of the measures controlled for the contribution of lexical content to the judgement of warmth by masking the words of the mother's speech while retaining pitch and intensity features of the acoustic-prosodic envelope (PFMSS Warmth). The other rating required a judgement of warmth while listening to the mother's vocal qualities and speech content (Parent Warmth Expressiveness). Table 7.1 outlines the acoustic-prosodic features of the mother and of the child that displayed significant associations with judges ratings of warmth in the mother's voice.

Table 7.1

Significant associations between warmth in the mother's speech and the mother's acoustic-prosodic parameters

Acoustic-prosodic Parameter **Mother**	**PFMSS Warmth**	**Parent Warmth Expressiveness**
Average turn duration (milliseconds)	**.294****	**.384****
Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus)	**-.232***	-.176
Second formant (F2) midpoint of turn	**.256***	**.301****
Pitch-range normalised start of nucleus	**.240***	.199
Total time of pauses	-.202	**-.233***
Mother-inititated overlaps as a percentage of all turns	.115	**.231***
Pitch trajectory between syllabic nuclei (z-score) (TrajInterZ)	-.215	**-.238***

Note. PFMSS refers to Preschool Five Minute Speech Sample (warmth in the mother's voice); F0 refers to fundamental frequency (pitch); significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Of the two perceptual measures of warmth in the mother's speech, the ratings made where the lexical content was masked (PFMSS) identified fewer significant relationships with the mother's acoustic-prosodic parameters. On this rating scale, mothers judged as vocally warmer displayed a lower mean pitch floor, and this lower pitch minimum was not seen for mothers on the measure of warmth in the mother's voice where the lexical content was retained (Parent Warmth-Expressiveness). Warmth-expressiveness in the mother's speech was negatively associated with the total duration of pauses in the emotion talk, and with a greater number of mother-initiated overlaps as a percentage of all overlaps, and these dimensions may be capturing the component of heightened expressiveness in the mother's speech. Warmth-expressiveness in the mother's speech was also associated with mothers speaking less and children more in the first half of the conversation, and negatively associated with the pitch trajectory between her syllables (TrajInterZ), indicating a smoother sounding pitch profile was associated with warmth in the mother's speech. On both measures of the warmth in the mother's speech, her second formant was higher as warmth increased, and her average turn durations longer.

7.4 Acoustic-prosodic features associated with qualities of the emotion talk

Pearson's associations were run to distinguish significant relationships between the qualities of the interaction and acoustic-prosodic parameters at the session level. Table 7.2 displays the significant relationships in the speech of the mother and Table 7.3 displays significant relationships in the speech of the child. Table 7.4 reports the findings relating to mother-initiated overlaps, and Table 7.5 displays significant relationships relating to child-initiated overlaps. The full list of parameters that were tested are found in Appendix B.

Table 7.2

Significant associations between qualities of the emotion talk and the mother's acoustic-prosodic parameters

Acoustic-prosodic Parameter Mother	**Warm**	**In tune**	**Dismissive**
Median pitch (Hz)	-.181	**-.243***	.035
Median pitch in Hz of raw pitch values per syllable	**-.246***	**-.390****	.032
Mean in Hz of raw pitch values (based on 2 raw F0 values per nucleus)	**-.224***	**-.346****	.033
Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - mother	**-.258***	**-.378****	.117
PitchBottom (Hz) based on 2 stylization values per nucleus	-.147	**-.237***	.068
Mean of ST - mean of pitch values where values are minimum and maximum pitch in ST for each syllable	**-.249***	**-.383****	.043
Pitch at midpoint of turn (Hz)	-.215	**-.355****	.036
Second formant (F2) at midpoint of turn (Hz)	**-.235***	**-.252***	.039
Intensity midpoint of turn (dB)	-.197	**-.234***	.204
Turn duration (milliseconds)	.155	**.227***	-.139
h1 h2 (dB) Amplitude difference between 1st & 2nd harmonics	-.193	**-.224***	.107
Energy Profile 0-250Hz	**-.286***	**-.321****	.204
Energy 0-500Hz	**-.225***	**-.263***	.191
Energy 250-750Hz	-.216	**-.257***	.211
Energy 500-1000Hz	-.215	**-.268***	.221
Energy 750-1250Hz	-.168	**-.229***	.190

Note. Hz refers to hertz; F0 refers to fundamental frequency (pitch); ST refers to semitones; dB refers to decibels; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Table 7.2 continued.

Acoustic-prosodic Parameter	Warm	In tune	Dismissive
Mother			
Energy 500-1500Hz	-.157	**-.222***	.150
Energy 1250-1750Hz	-.190	**-.260***	.130
Energy 1500-2000Hz	-.190	**-.263***	.123
Energy 1750-2250Hz	-.182	**-.253***	.130
Energy 2000-2500Hz	-.169	**-.244***	.132
Energy 2250-2750Hz	-.170	**-.244***	.128
Energy 2500-3000Hz	-.181	**-.244***	.126
Energy 2750-3250Hz	-.189	**-.243***	.129
Energy 3000-3500Hz	-.175	**-.223***	.124
Intersyllabic interval (ST) between end of previous nucleus and start of current one	**-.244***	-.186	**.290****
TrajInterZ - Time-normalized pitch trajectory of intersyllabic variations on ST scale (z-score)	-.157	-.172	**.280***
TrajPhonZ Time-normalized pitch trajectory of all pitch variations on ST scale (z-score)	-.102	-.180	**.328****

Note. Hz refers to hertz; F0 refers to fundamental frequency (pitch); ST refers to semitones; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Table 7.3

Significant associations between qualities of the emotion talk and the child's acoustic-prosodic parameters

Acoustic-prosodic Parameter Child	Warm	In tune	Dismissive
PitchRange (in ST) (2%-98% percentiles of data in nuclei without discontinuities)	.081	.174	**-.275***
Pitch excursion size (ST) (ProsPro)	-.174	-.158	**.277***
Intersyllabic interval (ST) between end of previous nucleus and start of current one	.177	.162	**-.239***
PitchBottom (Hz) based on 2 stylization values per nucleus	-.086	**-.266***	.106
Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus)	-.126	**-.332****	.053
Pitch-range normalised pitch value of start of nucleus (ST)	**.243***	**.320****	-.176
h1 h2 (dB) Amplitude difference between 1st and 2nd harmonics	**-.228***	**-.255***	.021
h1 h2 asterix (dB) Formant aadjusted Amplitude difference between 1st and 2nd harmonics	**-.226***	-.203	.201
Proportion of energy below 500Hz	**-.241***	-.214	.119
Jitter	**-.240***	-.198	.016
Energy Profile 0-250Hz	**-.271***	**-.303****	.210
Energy 0-500Hz	-.203	**-.257***	.177
Energy 1750-2750Hz	-.183	**-.224***	.124
Difference in child talk time between first and second half	-.216	**-.297****	.089
Second formant (F2) at midpoint of turn (Hz)	-.212	**-.300****	.092
Turn duration (milliseconds)	**.330****	.192	.063

Note. ST refers to semitones; Hz refers to hertz; dB refers to decibels; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Table 7.4

Significant associations between qualities of the emotion talk and mother-initiated overlap parameters

Acoustic-prosodic Parameter (Mother-initiated overlaps "21")	Warm	In tune	Dismissive
Sp21 Pitch excursion size (ST) (ProsPro)	**-.222***	-.173	.220
Sp21 Turn duration (milliseconds)	**-.233***	-.187	.114
Sp21 maxf0 loc ms - time of the f0 peak relative to the onset of an interval in milliseconds (ProsPro)	-.169	-.177	**.317****
Sp21 h1 h2 (dB) Amplitude difference between 1st & 2nd harmonics	-.187	**-.242***	.217
Sp21 Energy Profile 0-250Hz	**-.231***	-.205	.186
Sp21 Energy 500-1000Hz	**-.226***	**-.234***	**.228***
Sp21 Energy 1250-1750Hz	-.174	-.200	**.261***
Sp21 Energy 1500-2000Hz	-.167	-.191	**.267***
Sp21 Energy 1750-2250Hz	-.170	-.210	**.274***
Sp21 Energy 200-2500Hz	-.186	**-.237***	**.277***
Sp21 Energy 2250-2750Hz	-.175	**-.226***	**.278***
Sp21 Energy 2500-3000Hz	-.158	-.207	**.268***
Sp21 Energy 2750-3250Hz	-.151	-.207	**.234***
Difference in mother-initiated overlap time second half vs first half	.180	**.246***	-.047

Note. Speaker "21" refers to mother overlapping child for the duration of the speech unit; Hz refers to hertz; f0 refers to fundamental frequency (pitch); dB refers to decibels; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Table 7.5

Significant associations between qualities of the emotion talk and child-initiated overlap parameters

Acoustic-prosodic Parameter (Child-initiated overlaps "12")	Warm	In tune	Dismissive
Sp12 Turn duration (milliseconds)	**-.236***	-.122	.081
Sp12 Number of speaker turns	-.203	**-.368****	.098
Sp12 Intensity peak (dB) across nuclei	**-.264***	-.167	.166
Sp12 Intensity midpoint of turn (dB)	**-.249***	-.137	.130
Sp12 Duration of nucleus (milliseconds)	**-.323****	-.171	**.224***
Sp12 maxf0 loc ms - time of the f0 peak relative to the onset of an interval in milliseconds (ProsPro)	**-.247***	-.171	.134
Sp12 h1 h2 (dB) Amplitude difference between 1st & 2nd harmonics	**-.243***	**-.318****	.039
Sp12 H1 A3 (dB) Amplitude difference between 1st harmonic and 3rd formant	**-.343****	-.181	.172
Sp12 Cepstral peak prominence (cpp)	**-.295****	-.126	.162
Sp12 Hammarberg index (dB) Difference in maximum energy 0-2000Hz vs 2000-5000Hz	**-.276***	-.079	.105
Sp12 Proportion of energy below 500Hz	**-.279***	-.145	.047
Sp12 Proportion of energy below 1000Hz	**-.302****	-.105	.154
Sp12 Formant dispersion formants 1 to 3	**-.253***	-.120	.159
Sp12 Median pitch (Hz)	**-.250***	-.132	.130
Sp12 Jitter	**-.305****	-.191	.130
Sp12 Shimmer	**-.261***	-.101	.110

Note. Speaker "12" refers to child overlapping mother for the duration of the speech unit; dB refers to decibels; Hz refers to Hertz; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

Table 7.5 continued.

Acoustic-prosodic Parameter (Child-initiated overlaps "12")	Warm	In tune	Dismissive
Sp12 Energy Profile 0-250Hz	**-.339****	**-.242***	.213
Sp12 Energy 0-500Hz	**-.307****	-.201	.208
Sp12 Energy 250-750Hz	**-.300****	-.199	**.253***
Sp12 Energy 500-1000Hz	**-.318****	**-.244***	**.285***
Sp12 Energy 750-1250Hz	**-.283***	**-.243***	**.234***
Sp12 Energy 500-1500Hz	**-.272***	**-.264***	.190
Sp12 Energy 1250-1750Hz	**-.246***	**-.289****	.181
Sp12 Energy 1500-2000Hz	-.184	**-.259***	.151
Sp12 Energy 1750-2250Hz	-.141	**-.242***	.170

Note. Speaker "12" refers to child overlapping mother for the duration of the speech unit; Hz refers to Hertz; significant relationships highlighted in green; ** $p < .01$, * $p < .05$

7.4.1 Warmth in the emotion talk

Ratings of warmth in the emotion talk reflect the degree to which *"the overall emotional ambience is warm and positive"*. Compared to the ratings using only the mother's speech, a substantially larger number of parameters for the mother were related to the judges ratings of warmth in the emotion talk. Maternal pitch features, including the pitch median in Hz, minimum pitch in Hz, and mean pitch in ST at the syllable level all displayed significant negative relationships, while mothers in warmer interactions also displayed less energy in the low frequency ranges of 250Hz and 500Hz. Mothers in warmer conversations displayed shorter intervals between their syllables (InterNuclDur), a relationship that was inverse for the mother's dismissiveness. Of note, a key difference was seen between the various warmth measures for the second formant. This parameter refers to a concentration of energy at the second formant, which is located at approximately 2000Hz, although this can vary between speakers. This was significantly higher when only rating warmth in the mother's speech (Table 7.1) but lower in interactions displaying warmer ambience (Table 7.2).

Warmer conversations were also associated with a number of significant relationships in the acoustic-prosodic features of children. This included a longer average turn duration for the child, a smaller amplitude difference between 1st and 2nd harmonics (dB) (h1-h2), a smaller formant-adjusted amplitude difference between 1st and 2nd harmonics, less energy in the child's very low vocal spectrum below 250Hz, and proportionally less of the child's overall vocal energy in the lower end of the spectrum below 500Hz. The child's jitter was also significantly lower, and the child's pitch value at the start of syllables was higher. There were a large number of acoustic-prosodic variables relating to overlaps, particularly child-initiated overlaps that were associated with warmer ambience of the emotion talk. These included a lower mean intensity, lower mean intensity peak, and lower intensity at the midpoint in child-initiated overlaps.

Warmer conversations were also associated with fewer child-initiated overlaps with a smaller amplitude difference between 1st and 2nd harmonics (h1-h2), less duration of the fundamental frequency peak relative to the onset of an interval in milliseconds (max pitch locms), and shorter overlap durations sustained by the child at the turn level and at the syllable level. Warmer interactions were also associated in child-initiated overlaps with lower amplitude difference between the 1st harmonic and 3rd formant (H1-A3), less Cepstral Peak Prominence (cpp), less jitter, and proportionally less vocal energy in spectrum below 1000Hz. In general, less energy in the child-initiated overlaps in each 500Hz interval of the spectrum starting from 0Hz-250Hz through to 1750Hz were significantly related to the warmth to the interaction.

The Hammarberg index (the difference in maximum energy between 0-2000 Hz and 2000-5000 Hz), shimmer, and the proportion of energy below 500Hz in the child-initiated overlaps were also negatively associated with a warmer ambience. A narrower formant dispersion (between formants 1 to 3) and a lower median pitch in child-initiated overlaps were also related to less warm conversations. The only prosodic characteristics of mother-initiated overlaps that were related to interactional warmth were shorter overlap duration sustained by the mother, a narrower pitch excursion size (ST), and less energy in the spectrum from 500-1000Hz.

7.4.2 Attunement in the emotion talk

Ratings of attunement in the interaction reflect the degree to which *"parent and child are in tune with one another"*. More attuned conversations were negatively associated with a large range of pitch and energy features, particularly for the mother. This included the mother's pitch median, pitch mean, pitch minimum, second formant, and pitch value at the midpoint of turns. In terms of the mother's energy features, the intensity value at the midpoint of her turns, and vocal energy from the bottom of the spectrum 0Hz-250Hz through to 3500Hz were negatively associated with mother-child attunement. The mother's h1-h2 was also negatively associated with attunement, while her speech turns were longer as attunement increased. Higher in attunement was also associated with less energy in the very low end of the spectrum 0Hz-250Hz and 0Hz-500Hz of the mother's speech, a pattern similar to that displayed by children in more warmer conversations.

In terms of the child's features, the child's pitch minimum and second formant were negatively associated with ratings of attunement, while the child's pitch range value at the start of syllables was higher as attunement increased. As with the mother, the child's energy in the very low end of the spectrum 0Hz-250Hz was negatively associated with attunement, and with energy in the range 2250Hz-2750Hz. A negative relationship was also seen with the difference in the child average talk time between conversational halves, suggesting that children in more attuned conversations displayed greater equality in the length of turns across both halves. In terms of overlaps, child-initiated overlaps occurred significantly less often in more attuned conversations, but when they occurred the h1-h2 was significantly lower, as was energy in the spectral range from 0Hz-250Hz and from 500Hz through to 2250Hz. Mother-initiated overlaps showed similar, although fewer, relationships on energy features.

7.4.3 Dismissiveness in the emotion talk

Ratings of dismissiveness reflect the degree to which the *"parent disagrees with or is dismissive of the child's emotions"*. Dismissiveness was related to a small number of parameters for both the mother and the child, as well as a number of significant positive relationships associated with energy values for both mother-initiated and child-initiated overlaps. The speech of dismissive mothers displayed a longer duration between stressed syllables, and children interacting with dismissive mothers displayed a shorter interval between stressed syllables, suggesting that there may be a dynamic interplay between the mother and the child values on this parameter as dismissiveness increases. Dismissiveness was also associated with a sharper pitch trajectory between the mother's stressed syllables, an inverse relationship to that seen for ratings of warmth in the mother's speech. Dismissiveness in the mother's speech was also associated with longer child-initiated overlaps, by more spectral energy in both child-initiated and mother-initiated overlaps, and by a pitch peak in the mother-initiated overlaps that was further along (in time) relative to the onset of the speech turn.

In terms of the child's speech, the mother's dismissiveness was associated with a greater pitch excursion size (ST) for the child, while the child's pitch range in semitones (ST) emerged with a significant negative relationship. This variable assesses the pitch range covering 2%-98% percentiles of the speaker's total syllables as measured on the semitone scale, a parameter which relates to intonation and reflects pitch movements upward and downward. Together, the child's speech in dismissive interactions was associated with sharp increases in pitch at the syllable level but an overall narrower pitch range.

Table 7.6 provides a comparative summary of significant associations for the parameters of the mother and of the child for each of the qualities of the emotion talk. These parameters are drawn from the Pearson's correlations throughout the chapter. While both warmth in the emotion talk and attunement in the interaction showed a large number of relationships that aligned with prosodic profile for tenderness (Juslin and Laukka, 2003), the attunement dimension showed the greatest number of matched parameters, suggesting the presence of synchrony occurred on these parameters in more attuned interactions.

Table 7.6

Comparative summary of mother and child parameters associated with qualities of the emotion talk

Acoustic-prosodic parameter **Mother**	**Acoustic-prosodic parameter** **Child**
Warm emotion talk (Connectedness Scale)	
Lower pitch median in Hz, minimum pitch in Hz, and mean pitch in ST at the syllable level for the mother	
Lower second formant at the midpoint of turns for the mother	
Shorter intervals between stressed syllables (InterNuclDur) for the mother	
Less vocal energy in the low frequency ranges of the vocal spectrum below 250Hz and 500Hz for the mother	Less vocal energy in the low frequency ranges of the vocal spectrum below 250Hz and below 500Hz for the child
	Longer turn duration for the child
	Less jitter for the child
	Smaller h1-h2 (amplitude difference between 1st and 2nd harmonics in dB for the child)
	Smaller formant-adjusted amplitude difference between 1st and 2nd harmonics for the child
	Higher pitch value at the start of syllables for the child
	Less vocal energy in child-initiated overlaps and on a number of other intensity related measures in child-initiated overlaps (Hammarberg Index; intensity peak; and spectral balance measures)

Note. Hz refers to hertz; ST refers to semitones; dB refers to decibels; matching mother-child parameters highlighted in green; all parameters included in the table significant at $p < .05$

Table 7.6 continued.

Acoustic-prosodic parameter Mother	Acoustic-prosodic parameter Child
In tune emotion talk (Connectedness Scale)	
Lower intensity value at the midpoint of turns for the mother	
Longer speech turns for the mother	
Less vocal energy in mother-initiated overlaps	
Lower pitch median, pitch mean, pitch minimum, and pitch value at midpoint of turns for the mother	Lower pitch minimum for the child
Lower second formant for the mother	Lower second formant for the child
Less vocal energy in the very low end of the spectrum 0Hz-250Hz	Less vocal energy in the very low end of the spectrum 0Hz-250Hz
Less vocal energy in the range from 250Hz-1000Hz for the mother and through to 3500Hz	Less vocal energy from 250Hz-500Hz and 2250Hz-2750Hz for the child
Less h1-h2 for the mother (amplitude difference between 1st and 2nd harmonics in dB)	Less h1-h2 in child-initiated overlaps (amplitude difference between 1st and 2nd harmonics in dB)
	Fewer child-initiated overlaps
	Wider pitch range value at the start of syllables for the child
	Greater equality in average talk time between halves of the emotion talk for the child

Note. Hz refers to hertz; ST refers to semitones; dB refers to decibels; matching mother-child parameters highlighted in green; all parameters included in the table significant at $p < .05$

Table 7.6 continued.

Acoustic-prosodic parameter Mother	Acoustic-prosodic parameter Child
Dismissive emotion talk (Connectedness Scale)	
Higher maxlocF0ms in mother-initiated overlaps (time of the pitch peak relative to the onset of an interval in milliseconds)	
More energy from 500Hz-3250Hz in mother-initiated overlaps	
Longer interval between stressed syllables for the mother	Shorter interval between stressed syllables for the child
	Higher pitch starting value in stressed syllables for the child (ST)
	Narrower pitch range in semitones for the child (ST)
	Greater pitch excursion size (ST) for the child

Note. Hz refers to hertz; ST refers to semitones; dB refers to decibels; matching mother-child parameters highlighted in green; all parameters included in the table significant at $p < .05$

7.5 Relational qualities and child characteristics: Effects on key acoustic-prosodic parameters

Additive and interaction effects between child characteristics and the qualities of the mother's speech and of the mother-child conversation were examined in multiple linear regression using the high dimensional methods outlined in Chapter 3. The child and maternal characteristics were assigned as the predictor variables and acoustic-prosodic parameters as the response variables, and the results that met significance were examined for their relevance to key acoustic-prosodic parameters that were identified in Chapter 6 as significant in the speech of children with CU traits or Oppositional Defiant Disorder (ODD) . Tables 7.7 to 7.10 report the significant findings and are grouped according to the relational quality being examined. Significant results are determined as those that met $p < .05$ significance for every predictor in the model and for the total model; the p values for each predictor are available in Appendix I. Interactions were examined using the dichotomised low/high groups of the predictor variables (Table 3.3).

Where produced, β D(00) refers to the coefficient for the interaction for values of X1 below the clinical cutoff and for X2 below the clinical cutoff; β D(01) refers to the coefficient for the interaction for values of X1 below the clinical cutoff and for X2 above the clinical cutoff; β D(10) refers to the coefficient for the interaction for values of X1 above the clinical cutoff and for X2 below the clinical cutoff; β D(11) refers to the coefficient for the interaction for values of X1 above the clinical cutoff and for X2 above the clinical cutoff. To aid interpretation the extrapolated value of y is shown for each combination. For example, y(D00) refers to the value of y for the combination of values of X1 below the clinical cutoff and for X2 below the clinical cutoff. Key examples are displayed in figures for visual reference, with the minimum value for the parameter set at the axis origin.

Table 7.7

Main and interaction effects of child characteristics and warmth in the mother's speech on key parameters

Eqn	Parameter	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	R^2	R^2 Adj.	*F*	*F p* SGoF	y(D00)	y(D01)	y(D10)	y(D11)	mean(y)
1	Sp2 RangeST	1.364	PFMSS_Warmth(1to3)	-0.456	ICUCallous					0.205	0.184	9.559	0.000	19.334	11.122	22.063	13.851	17.902
2	Sp2 BottomHz	59.588	DiagnosisODD	-21.772	ParentWarmthExpress			-42.941		0.252	0.222	8.525	0.000	213.779	107.533	230.426	167.121	172.901
3	Sp2 AVGE jitter	0.014	DiagnosisODD	-0.010	PFMSSWarmth			-0.013		0.150	0.116	4.469	0.012	0.050	0.031	0.051	0.044	0.040
4	Sp2 AVGE Energy Profile 250Hz		DiagnosisODD	-4.394	PFMSSWarmth				8.832	0.194	0.173	9.278	0.001	19.073	10.286	19.073	19.117	15.471
5	Sp2 AVGE INTmid	-2.942	PFMSS_Warmth(1to3)	-0.449	CogEm100	-7.544				0.224	0.190	6.458	0.001	72.087	64.380	73.746	58.496	65.432
6	Sp2 AVGE 500	-3.771	PFMSS_Warmth(1to3)	-0.418	CogEm100	-7.652				0.176	0.139	4.754	0.011	23.232	16.688	23.342	9.145	16.132
7	Sp2 AVGE 750	-3.515	PFMSS_Warmth(1to3)	-0.464	CogEm100	-6.638				0.182	0.145	4.966	0.008	21.745	12.619	21.354	5.590	13.275
8	Sp2 BottomHz	-17.268	Vocal_Warmth(1to7)	2.735	ERCLability		-40.479			0.228	0.196	7.276	0.000	201.420	264.862	109.383	213.304	172.901

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$. SGoF refers to Sequential Goodness of Fit multi-test correction.

Table 7.8

Main and interaction effects of child characteristics and warmth in the emotion talk on key parameters

Eqn	Parameter	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	R^2	R^2 Adj.	*F*	*F p* SGoF	y(D00)	y(D01)	y(D10)	y(D11)	mean(y)
1	Sp2 RangeST		CS9Warmth(1to5)	-0.232	ICUTotal			-2.483		0.219	0.198	10.380	0.000	22.621	11.043	20.138	11.043	17.902
2	Ch percent talk time	2.022	CS9Warmth(1to5)	0.203	ICUTotal					0.141	0.118	6.015	0.008	14.755	24.910	22.844	32.999	24.006
3	Sp2 TrajPhonZ	-0.292	CS9Warmth(1to5)		ICUTotal	-1.418				0.136	0.113	6.050	0.028	4.204	5.622	4.452	4.452	4.675
4	Sp2 StDevST		CS9Warmth(1to5)	-0.023	ICUTotal	1.225				0.214	0.193	10.101	0.000	5.554	3.160	4.329	3.160	4.028
5	Ch percent talk time	1.998	CS9Warmth(1to5)	-0.958	SDQProsocial					0.144	0.121	6.285	0.007	24.213	14.630	32.204	22.621	24.006

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$. SGoF refers to Sequential Goodness of Fit multi-test correction.

Table 7.9

Main and interaction effects of child characteristics and attunement in the emotion talk on key parameters

Eqn	Parameter	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	R^2	R^2 Adj.	*F*	*F p* SGoF	y(D00)	y(D01)	y(D10)	y(D11)	mean(y)
1	Ch percent talk time	4.206	CS8 In tune(1to5)	0.217	ICUTotal	11.241	8.519			0.183	0.137	3.976	0.012	18.719	26.839	24.301	35.143	24.006
2	Sp2 InterNuclDur	10.299	CS8 In tune(1to5)		ICUTotal			-30.606	-21.066	0.168	0.135	5.101	0.028	18.592	18.592	29.181	38.721	25.777
3	Ch avge talk time	-0.444	DiagnosisODD	0.159	CS8 In tune		-0.539	0.327		0.151	0.104	3.294	0.029	1.151	1.249	1.033	1.344	1.171
4	Sp2 TopHz	405.189	DiagnosisODD	-63.785	CS8 In tune		390.272	-140.937		0.211	0.168	4.969	0.004	301.785	436.917	566.037	451.833	498.605
5	Ch percent talk time	4.123	CS8 In tune(1to5)	-0.247	AffEm100			-11.638	-9.018	0.221	0.173	4.612	0.006	30.401	14.575	35.255	22.050	24.006
6	Ch percent talk time	4.480	CS8 In tune(1to5)	-1.275	SDQProsocial	8.386	14.075			0.216	0.173	5.024	0.004	26.415	19.355	35.948	23.199	24.006
7	Sp2 TopHz	-60.318	CS8 In tune(1to5)	-28.809	SDQProsocial		278.775	248.756	304.634	0.299	0.250	6.127	0.000	596.749	587.433	604.233	372.019	498.605
8	Prstart 2	2.159	CS8 In tune(1to5)	-0.450	ERCLability					0.233	0.212	11.212	0.000	47.346	30.233	55.982	38.869	45.326
9	Ch avge talk time	0.173	CS8 In tune(1to5)	-0.033	SDQEmotions			-0.485	-0.304	0.197	0.153	4.483	0.006	1.162	0.837	1.370	1.225	1.171

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$. SGoF refers to Sequential Goodness of Fit multi-test correction.

Table 7.10

Main and interaction effects of child characteristics and dismissiveness in the emotion talk on key parameters

Eqn	Parameter	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	R^2	R^2 Adj.	*F*	*F p* SGoF	y(D00)	y(D01)	y(D10)	y(D11)	mean(y)
1	Sp2 RangeST	-1.021	CS13Dismissive(1to5)	-0.183	ICUTotal	-2.412				0.259	0.228	8.391	0.000	20.171	13.409	18.500	9.325	17.902
2	Sp2 RangeST	-2.164	DiagnosisODD	-0.748	CS13Dismissive					0.159	0.137	7.173	0.002	20.175	17.183	18.012	15.020	17.902
3	InterSy 2	-0.129	CS13Dismissive(1to5)	-0.020	ICUTotal	-0.419				0.169	0.135	4.895	0.006	0.536	-0.054	0.437	-0.571	0.395

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$. SGoF refers to Sequential Goodness of Fit multi-test correction.

7.5.1 Interactions between warmth in the mother's speech and child characteristics on key acoustic-prosodic parameters

Child pitch range is a parameter that showed a key relationship with child CU traits in Study 3 (Chapter 6). Although no significant effect was identified between warmth in the mother's voice and ICU Total, the regression analyses identified a significant effect of the mother's vocal warmth on the child's pitch range that was associated with the subscale of child callousness (Table 7.7). As seen in Figure 7.1, the effect of warmth in the mother's voice was similar at both low and high levels of child callousness.

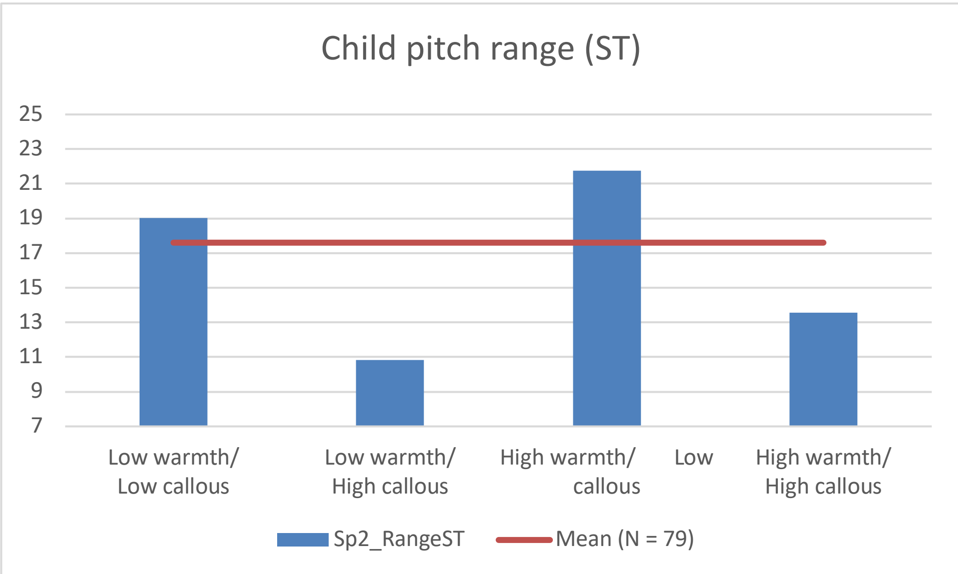

Figure 7.1 Child pitch range for dichotomised groups of ICU callousness and maternal warmth

The child's pitch minimum is a parameter that showed increases associated with the presence of an ODD diagnosis, and negative relationships with the qualities of vocal warmth

(Table 7.7). Each unit increase in warmth-expressiveness in the mother's voice (1-7 scale) predicted a 21.772Hz decrease in the child's pitch floor (Sp2BottomHz) controlling for ODD, while the presence of an ODD diagnosis predicted a 59.588 Hz increase in the child's pitch floor, controlling for parent warmth expressiveness (Figure 7.2). Overall, children interacting with low warmth-expressive mothers displayed a pitch floor substantially above the mean.

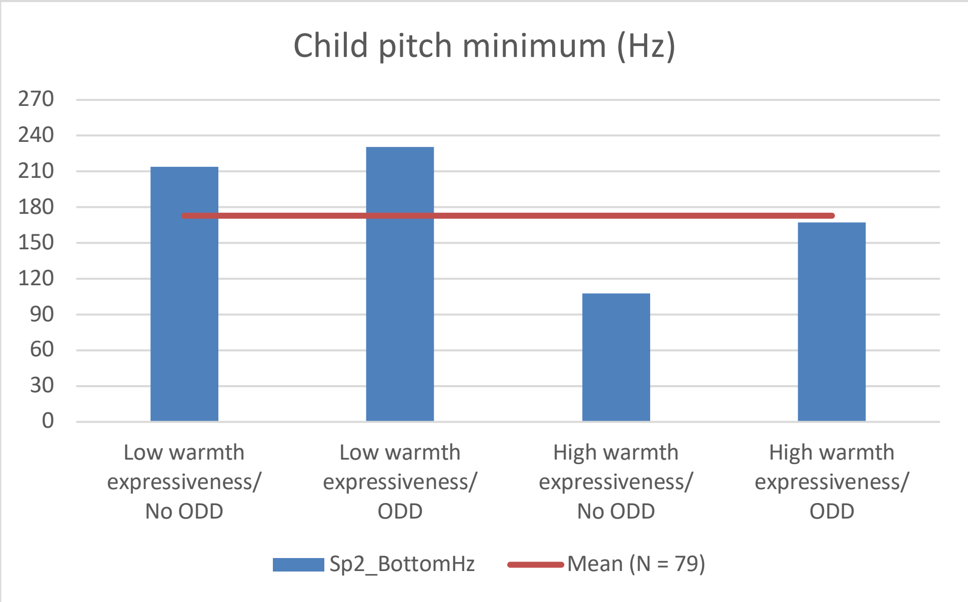

Figure 7.2 Child pitch minimum for dichotomised groups of ODD and maternal warmth-expressiveness

Similarly, in Study 3 (Chapter 6) the child's pitch minimum (Sp2BottomHz) also showed a significant positive relationship with child emotional lability / negativity, while in warmth in the mother's voice was associated with a main negative effect on this parameter (Table 7.7). Each unit increase in the mother's vocal warmth (1-3 scale) predicted a 17.268Hz decrease in the child's pitch floor when controlling for child lability/ negativity; in contrast, each unit increase in child lability predicted a 2.735Hz increase in the child's pitch floor when controlling for the mother's vocal warmth. For the dichotomised groups, the mother's vocal warmth was associated with significant reductions in the pitch floor for both high and low lability children, however the effect was particularly marked for children with low levels of lability (201.420Hz vs 109.383Hz; Figure 7.3). The highest pitch floor was associated with children with high emotional lability interacting with low warmth mothers (264Hz).

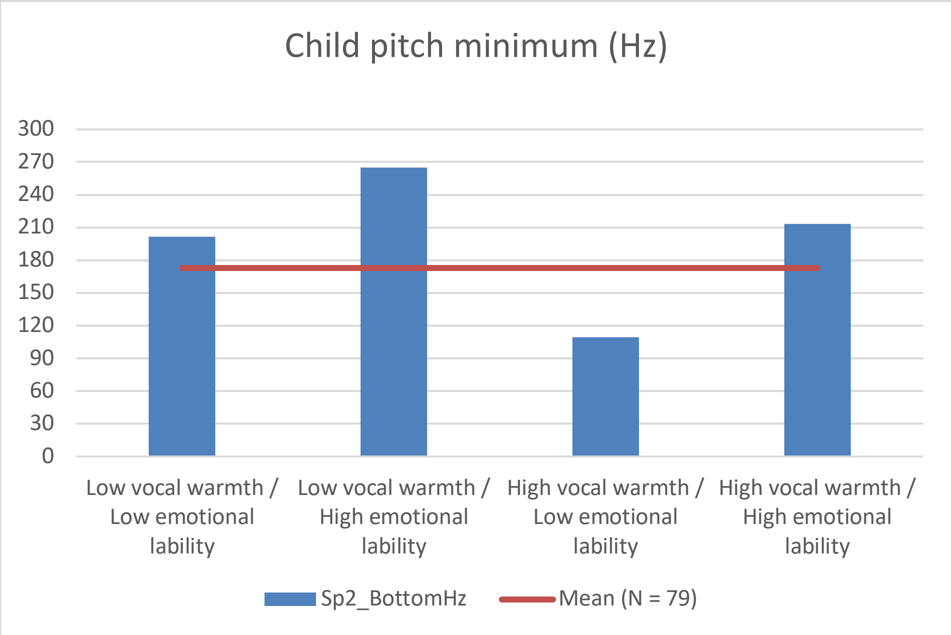

Figure 7.3 Child pitch minimum for dichotomised groups of child emotional lability and maternal vocal warmth

For child jitter (micro-perturbations of pitch often positively associated with stress), the strongest effect was seen for children without an ODD diagnosis, whose predicted jitter was substantially below the mean when accompanied by high levels of vocal warmth in the mother (Figure 7.4).

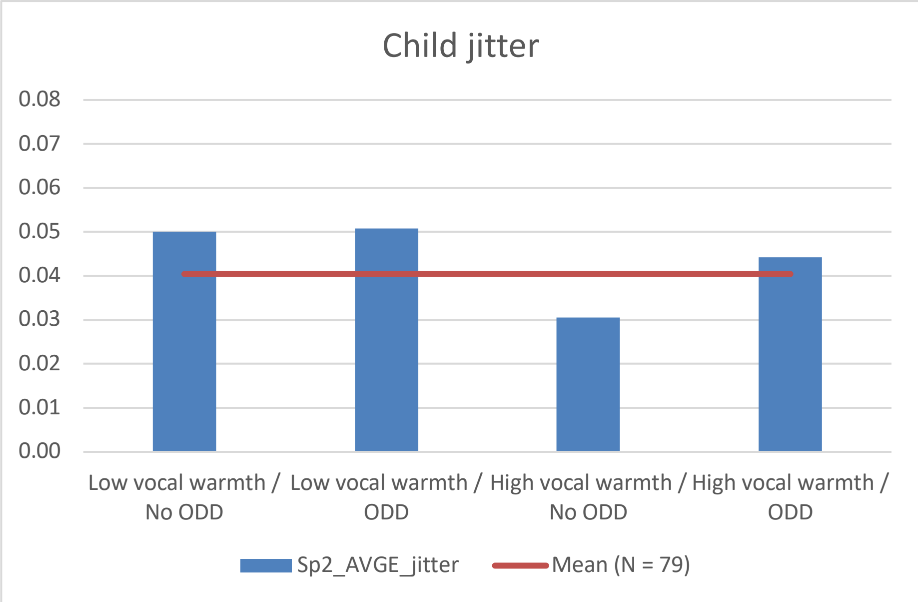

Figure 7.4 Child jitter values for dichotomised groups of ODD and maternal vocal warmth

In Study 3 (Chapter 6), the proportion of energy in the child's speech below 500Hz and below 750Hz — an area of the spectrum associated with reduced intelligibility — emerged with a strong negative relationship with cognitive empathy. In the present study, warmth in the mother's voice also emerged with a negative relationship with the amount of energy in the child's speech below 500Hz and below 750Hz (Table 7.7). Each unit increase in the mother's vocal warmth (1-3 scale) predicted a 3.771 decrease in the proportion of energy below 500Hz in the child's speech when controlling for child cognitive empathy; in addition, each unit increase in child cognitive empathy predicted a .418 percent decrease in the when controlling for the mother's vocal warmth. For children in the low cognitive empathy group, the mother's warmth did not make a noticeable difference on this significant energy parameter, with the proportion of child's vocal energy in this low range of the spectrum predicted to be substantially above the mean (Figure 7.5). In contrast, the mother's vocal warmth was predicted to reduce the proportion of energy in the child's speech in this very low range of the spectrum by almost half for children in the high cognitive empathy group.

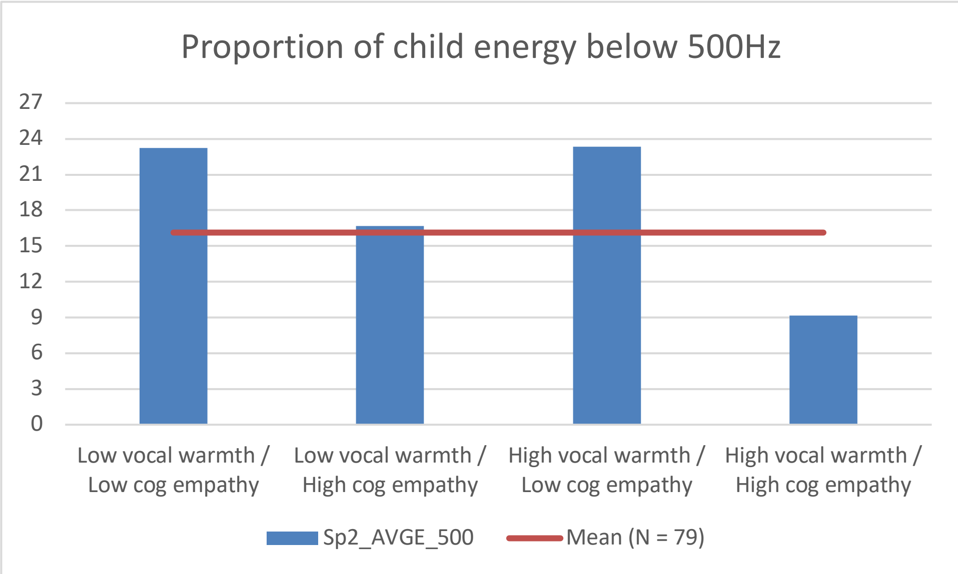

Figure 7.5 Child percentage talk time for dichotomised groups of child affective empathy and maternal vocal warmth

The child's intensity in their speech turns was important to the latent discriminant variable for CU traits in Study 3 (Chapter 6), and was also negatively associated with child affective empathy and with child emotion regulation (significant for both the mother and child values). In the present study, each unit increase in the mother's vocal warmth (1-3 scale) predicted a 2.942dB decrease in intensity in the child's speech when controlling for child cognitive empathy (Table 7.7), and each unit increase in child cognitive empathy predicted a ..449dB decrease in the child's intensity when controlling for the mother's vocal warmth. For the dichotomised groups, for children low on cognitive empathy the mother's vocal warmth was not associated with a significant difference to the child's intensity, however for high empathy children, the mother's vocal warmth was associated with a notable reduction in the child's intensity, emerging below the sample mean (Figure 7.6).

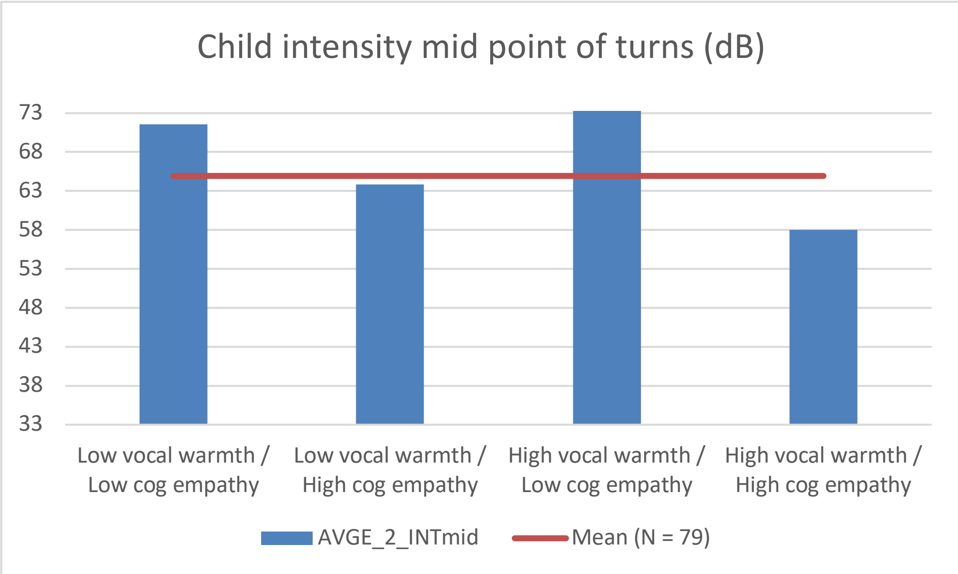

Figure 7.6 Child intensity for dichotomised groups of child cognitive empathy and maternal vocal warmth

7.5.2 Interactions between warmth in the emotion talk and child characteristics on key acoustic-prosodic parameters

Table 7.8 shows that each unit increase in warmth in the emotion talk (1-5 scale) predicted a 2.026 percent increase in the child's percentage of talking time when controlling for child affective empathy; while each unit increase in child affective empathy predicted a .205 percent decrease when controlling for warmth in the emotion talk. The difference in the percentage predicted of child speaking time between high warmth conversations for low empathy children, and low warmth conversations for high empathy children, was particularly large, at almost three times the rate (33.68% vs 12.40%) (Figure 7.7). Warmth in the emotion talk was positively associated with the percentage of time the child spoke across the emotion talk for both low and high empathy children to approximately the same extent, with high empathy children in warmer interactions more closely approaching the mean percentage of child speaking time.

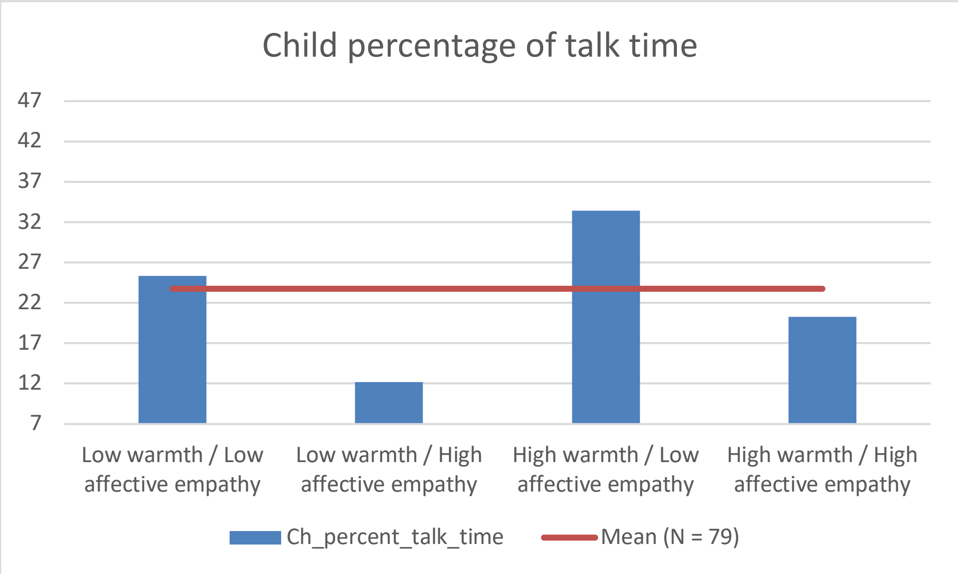

Figure 7.7 Child percentage talk time for dichotomised groups of child affective empathy and warmth in the emotion talk

7.5.3 Interactions between attunement in the interaction and child characteristics on key acoustic-prosodic parameters

High levels of attunement were associated with a reduction in the maximum pitch for children with ODD but an increase in pitch maximum for children without ODD, suggesting that attunement is associated with a reduction in pitch height for ODD children and an increase in pitch height for children without ODD (Figure 7.8).

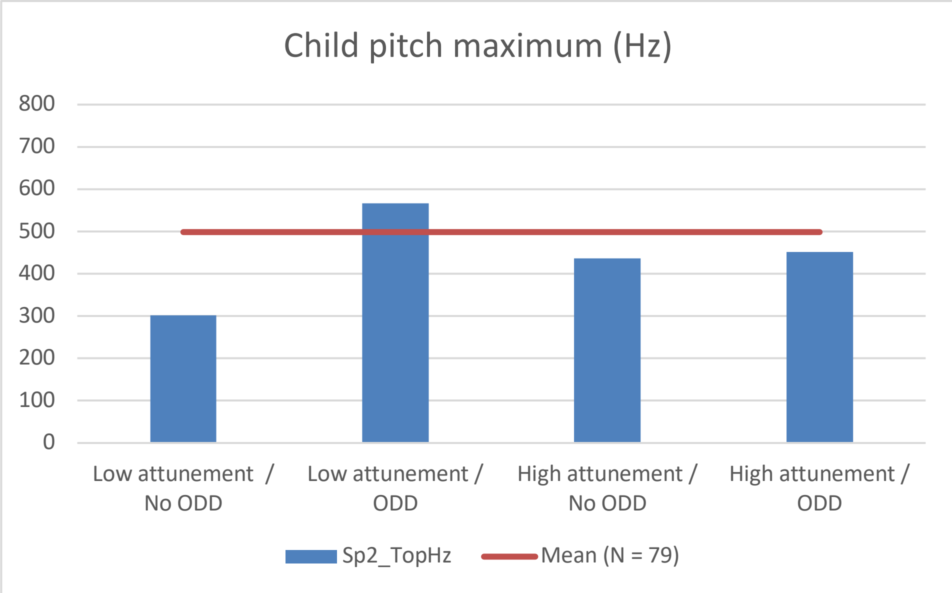

Figure 7.8 Child pitch maximum for dichotomised groups of ODD and attunement

In Study 3, child CU traits were positively associated with the percentage of time the child spoke in the emotion talk. In Study 4, attunement also had a strong positive effect on this temporal feature, with both low and high CU children in more attuned conversations speaking for a greater percentage of the total talk time and for longer duration at the syllable level (Table 7.9). Each unit increase in attunement predicted a 4.206 percent increase in the child's percentage of talking time when controlling for ICU; while each unit increase in ICU predicted a .217 percent increase when controlling for attunement. While attunement had a similar proportional effect on the percentage of speaking time for both low and high CU children, the impact for low CU children was particularly noteworthy in bringing their comparatively poor talk time up to the mean (Figure 7.9).

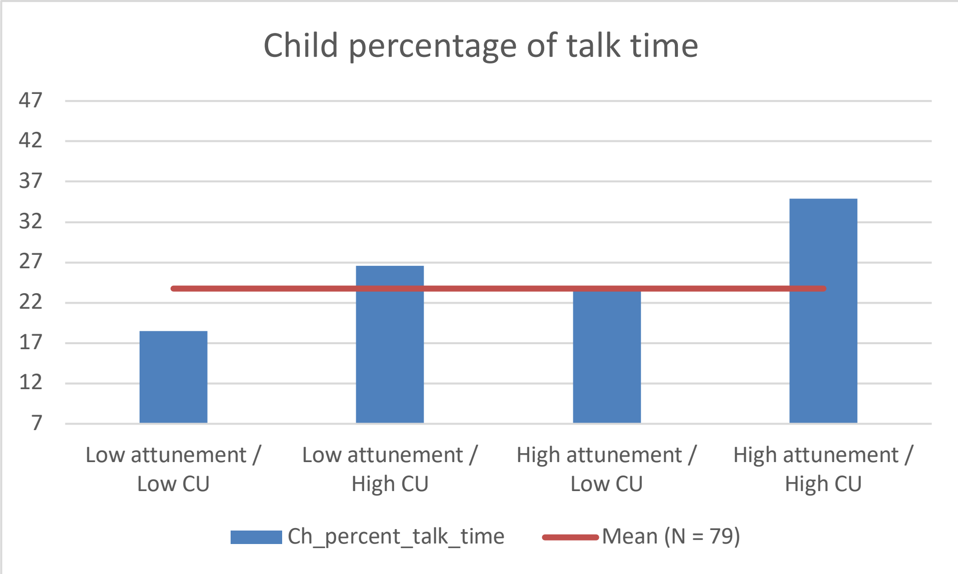

Figure 7.9 Child percentage talk time for dichotomised groups of ICU Total and attunement in the interaction

7.5.4 Interactions between dismissiveness in the interaction and child characteristics on key acoustic-prosodic parameters

In Study 3 the child's pitch range (ST) emerged as a significant parameter in relation to the child's Total ICU score (-.415, $p < .001$). This parameter assesses the pitch range covering 2%-98% percentiles of the speaker's total syllables as measured on the semitone scale. In the current study, a significant relationship was identified between the child's pitch range and maternal dismissiveness (-.275, $p = .014$), and separately, with the mother's stress level (-.270, $p = .020$). As seen in Table 7.10, each unit increase in dismissiveness (1-5 scale) predicted a 1.021 semitone decrease in the child's pitch range (Sp2RangeST) when controlling for ICU, while each unit increase in ICU (0-37 scale) predicted a .183 semitone decrease when controlling for dismissiveness. For predicted values of *y* for groups of children above and below their cutoffs, the mother's dismissiveness was associated with a noticeable effect on the high CU child's pitch range (approximately 4ST). There was a comparatively small effect predicted for dismissiveness on the pitch range of low CU children (Figure 7.10).

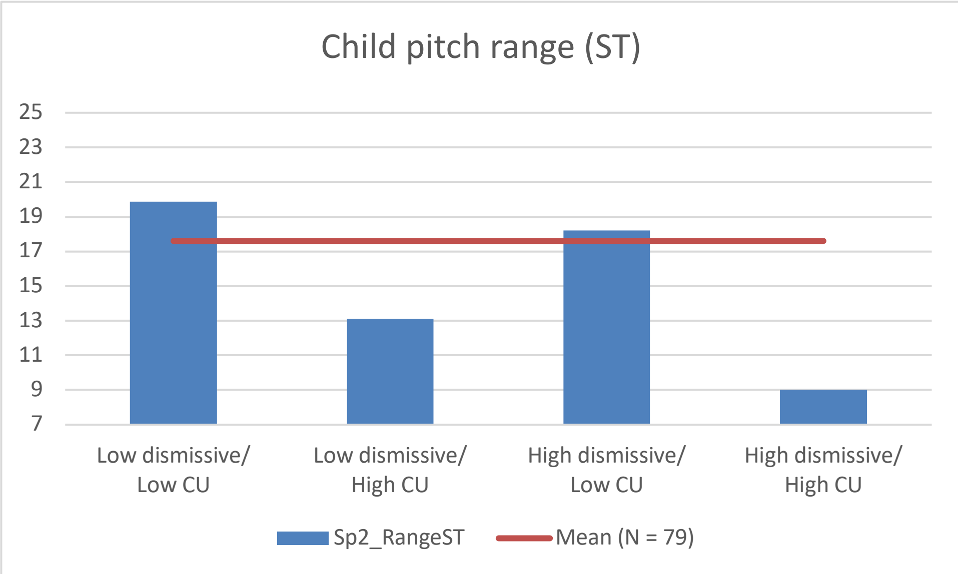

Figure 7.10 Child pitch range for dichotomised groups of ICU Total and maternal dismissiveness

While in Study 3 (Chapter 6) an ODD diagnosis was not a predictor of the child's pitch range, the current study identified the presence of a significant interaction with maternal dismissiveness (Table 7.10). Each unit increase in dismissiveness (1-5 scale) predicted a .748 semitone decrease in the child's pitch range (Sp2RangeST) controlling for ODD, while the presence of an ODD diagnosis predicted a 2.164 semitone decrease in the child's pitch range, controlling for dismissiveness (Figure 7.11).

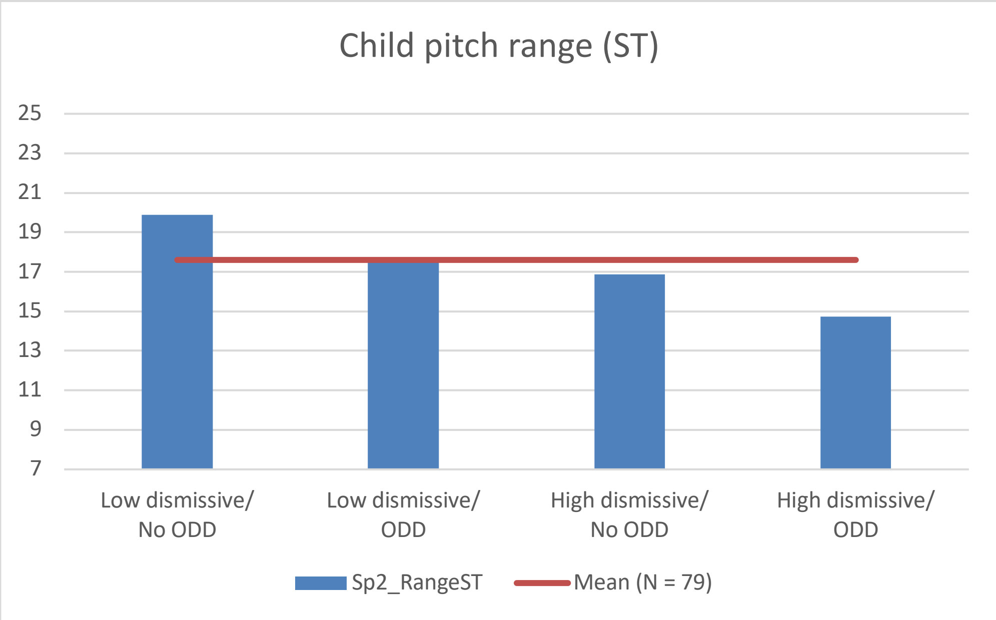

Figure 7.11 Child pitch range for dichotomised groups of ODD and maternal dismissiveness

7.5.5 Associations between relational qualities and child characteristics

Contrary to expectations, there were no significant associations between the judges' ratings of the qualities of the interaction and child CU traits or child age (Table 7.11). Child conduct problems and child lability / negativity were however associated with reductions in warmth in the mother's speech. Attunement in the interaction was negatively associated with child lability / negativity, and with the mother's depression and anxiety. Child conduct problems and hyperactivity were the only characteristics associated with the mother's dismissiveness.

Table 7.11

Significant associations between qualities of the interaction and child characteristics

Relational Quality	ICU Total	SDQ Conduct problems	SDQ Hyperactive	ERC Lability/ Negativity	SDQ Emotional symptoms	GEM Cognitive Empathy	GEM Affective Empathy	ERC Emotion regulation	Child age
PFMSS Warmth	-.154	**-.269***	-.200	**-.250***	-.186	.044	.016	.121	.034
Parent Warmth Expressiveness	-.141	-.212	**-.231***	**-.243***	-.144	.096	.063	.008	.085
Warm emotion talk	-.143	-.064	**-.287***	-.171	**-.294****	.118	.090	.192	-.022
In tune emotion talk	-.168	-.157	**-.348****	**-.233***	**-.253***	.164	.122	.155	.108
Dismissive emotion talk	.197	**.251***	**.239***	.179	.084	.134	.119	-.143	-.011

Note. PFMSS refers to Preschool Five Minute Speech Sample (a measure of warmth in the mother's voice); significant associations highlighted in green; ** $p < .01$, * $p < .05$.

7.6 Acoustic-prosodic features associated with the mother's mental health

7.6.1 Maternal depression

Table 7.12 identifies the parameters from the session level dataset (Appendix B) that were associated with the mental health status of the mother. Maternal depression was related to energy but not pitch variables in the mother's speech, with more energy located in the mother's voice in the lower part of the vocal spectrum, specifically in the range between 250Hz-750Hz as well into the mid-range of the spectrum between 1500Hz-2000Hz. Depression and stress were also associated with a substantial range of acoustic-prosodic features that were significant in both mother-initiated overlaps (Table 7.14) and child-initiated overlaps (Table 7.15). These features related primarily to energy parameters however also included a small number of pitch features for the mother, and for both mother-initiated and child-initiated overlaps the energy in the spectrum from 5000Hz through to 2000Hz. Both maternal depression and stress were associated with longer duration of both child-initiated overlaps as well as mother-initiated overlaps, as well as more energy in the mid-range of the spectrum during these overlaps. Notably, depression was also associated with a. higher proportion of energy in the very low end of the spectrum, and this is the range associated with reduced intelligibility.

Table 7.12

Significant associations between maternal mental health status and the mother's parameters

Acoustic-prosodic Parameter Mother	**DASS Depression**	**DASS Anxiety**	**DASS Stress**
Median pitch (Hz)	.123	**.251***	.058
Median pitch (Hz) of raw pitch values per syllable	.126	**.307****	.128
Mean pitch in Hz of raw pitch values (based on 2 raw F0 values per nucleus)	.148	**.341****	.150
Pitch midpoint of turn (Hz)	.072	**.261***	.088
Second formant (F2) midpoint of turn	.204	.138	**.250***
PitchBottom (Hz) based on 2 stylization values per nucleus	.211	0.174	**.273***
Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus)	.152	**.321****	**.271***
Mean of ST - mean of pitch values where values are minimum and maximum pitch in ST for each syllable	.140	**.326****	.150
Intersyllabic interval (ST) between end of previous nucleus and start of current one	**.242***	.106	**.273***
Energy 0-500Hz	**.250***	.166	.159
Energy 250-750Hz	**.263***	.168	.190
Energy 1250-1750Hz	**.261***	.190	**.229***
Energy 1500-2000Hz	**.258***	.197	**.235***
Proportion of energy below 1000Hz	.074	**.343****	.114
Jitter	.047	**.345****	.119

Note. Significant associations are highlighted in green; ** $p < .01$, * $p < .05$

Table 7.13

Significant associations between maternal mental health status and the child's parameters

Acoustic-prosodic Parameter Child	DASS Depression	DASS Anxiety	DASS Stress
PitchRange (in ST) based on 2 stylization values per nucleus (2%-98% percentiles of data in nuclei without discontinuities)	-.104	-.085	**-.270***
Average second formant (F2) midpoint of turn	.114	.182	**.339****
Pitch-range normalised pitch value of start of nucleus (ST)	-.123	-.137	**-.232***
Intersyllabic interval (ST) between end of previous nucleus and start of current one - child	**-.295***	-.139	**-.294***
Final velocity (ST) (ProsPro)	.063	.098	**.240***

Note. Significant associations are highlighted in green; ** $p < .01$, * $p < .05$

Table 7.14

Significant associations between maternal mental health status and parameters of mother-initiated overlaps

Acoustic-prosodic Parameter **Mother-initiated overlaps ("21")**	**DASS Depression**	**DASS Anxiety**	**DASS Stress**
Sp21 Turn duration (milliseconds)	**.296***	.200	**.302****
Sp21 Intensity midpoint of turn	.205	.174	**.290***
Sp21 Intensity peak (dB) across nuclei -	.158	.112	**.249***
Sp21 Pitch excursion size (ST) (ProsPro)	.214	.122	**.230***
Sp21 Final pitch (indicator of target slope) (ProsPro)	.121	.152	**.255***
Sp21 Mean intensity (dB) (ProsPro)	.197	.124	**.267***
Sp21 Maximum velocity (ST) (ProsPro)	**.253***	.123	0.201
Sp21 maxf0 loc ms (ProsPro) - time of the pitch peak relative to the onset of an interval in milliseconds	**.319****	.132	**.389****
Sp21 Cepstral peak prominence (cpp)	.171	.179	**.268***
Sp21 Formant dispersion formants 1 to 5	.207	.222	**.336****
Sp21 Energy Profile 0-250Hz	**.284***	.213	**.309****
Sp21 0-500Hz	**.242***	.194	**.274***
Sp21 250-750Hz	.218	.173	**.254***
Sp21 500-1000Hz	**.234***	.178	**.258***
Sp21 750-1250Hz	**.294***	.165	**.297***
Sp21 1000-1500Hz	**.312****	.147	**.285***
Sp21 1250-1750Hz	**.280***	.114	**.244***
Sp21 1500-2000Hz	**.244***	.092	0.204

Note. Speaker "21" refers to the speech turn in which the mother spoke over the child for the duration of the speech unit; significant associations are highlighted in green; ** $p < .01$, * $p < .05$

Table 7.15

Significant associations between maternal mental health status and parameters for child-initiated overlaps

Acoustic-prosodic Parameter Child-initiated overlaps ("12")	DASS Depression	DASS Anxiety	DASS Stress
Sp12 Number of speaker turns	.147	**.279***	.169
Child initiated overlaps as a percentage of all overlaps	-.017	**.230***	.177
Child initiated overlaps as a percentage of all overlap time	.095	**.242***	.226
Child initiated overlaps as a percentage of total time	.102	.177	**.301****
Child initiated overlaps average turn time	**.280***	.186	**.284***
Sp12 Duration of nucleus	**.268***	.064	**.232***
Difference in child talk time between first and second half	.154	**.354****	.147
Sp12 Maximum velocity (ST) (ProsPro)	**-.237***	-.056	-.202
Sp12 H1 A3 (dB) Amplitude difference between 1st harmonic and 3rd formant	**.250***	.021	.160
Sp12 Energy Profile 0-250Hz	**.248***	.126	.218
Sp12 0-500Hz	**.243***	.110	.210
Sp12 250-750Hz	**.244***	.145	**.246***
Sp12 500-1000Hz	**.236***	.178	**.231***
Sp12 750-1250Hz	**.252***	.185	**.248***
Sp12 1000-1500Hz	.227	.196	**.234***
Sp12 1250-1750Hz	**.256***	**.249***	**.263***
Sp12 1500-2000Hz	.216	.216	**.236***

Note. Speaker "12" refers to the speech turn in which the child spoke over the mother for the duration of the speech unit; significant associations are highlighted in green; ** $p < .01$, * $p < .05$

7.6.2 Maternal anxiety

Anxiety was associated with a number of unique pitch features in the mother's voice when compared to both maternal stress and depression (Table 7.2). This included a higher pitch at the midpoint of the mother's turns, higher mean pitch at the syllable level measured in semitones as well as higher maternal median pitch in Hertz. Continuing with the pitch measures, a higher pitch floor for the mother (bottom second percentile) was also associated with higher levels of both anxiety and stress. Notably, higher levels of jitter in the mother's voice and a higher proportion of energy in the spectrum below 1000Hz were related to higher maternal anxiety, but not to any other maternal or child characteristic at the session level. Maternal anxiety was also associated with greater child speaking time in the second half of the emotion talk, a finding not evident for either maternal depression or stress. The mother's anxiety was positively associated with the number of child-initiated overlaps and with the percentage of all overlaps in the conversation.

7.6.3 Maternal stress

In terms of pitch features, the mother's stress was positively associated with the second formant at the midpoint of speech turns for both the mother and for the child, a finding inverse to that seen in warmer and more attuned conversations. A higher pitch minimum for the mother (bottom second percentile) was positively associated with stress, but also anxiety. Regarding acoustic energy, maternal stress level was positively associated with energy in the mother's speech in the spectrum from 1500Hz through to 2000Hz. A significant positive relationship was seen between the mother's stress score and the amount of energy in the spectrum between 500Hz and 2000Hz for overlaps initiated by both the mother and the child. Energy of mother-initiated overlaps down into the very low end of the spectrum from 0Hz-250Hz was also positive and significant in its relationship to maternal stress.

In terms of temporal features of the mother, a longer interval between the mother's syllables was negatively associated with both maternal stress and depression. Notably, the same feature on the child's speech was also negatively associated with maternal stress and depression, suggesting the possibility of a synchronous process. The features of mother-initiated overlaps were also more frequently associated with maternal stress compared to the child-initiated overlaps. The mother-initiated overlaps of stressed mothers was associated with linear increases in the formant dispersion (formants 1 to 5), cepstral peak prominence, and mean intensity. The final fundamental frequency in mother-initiated overlaps was also positively associated with maternal stress. The duration of mother-initiated overlaps was positively associated with maternal stress and depression. The timing of the pitch peak relative to the start of the turn (maxlocF0ms) in mother-initiated overlaps was also positively associated with the mother's stress scores, a result that was moderately strong and also seen for maternal depression as well as her dismissiveness.

Maternal stress was associated with a larger number of prosodic features of the child compared to both depression and anxiety (Table 7.3), including a narrower pitch range in semitones for the child and a longer duration of child-initiated overlaps (as a percentage of the total emotion talk time), relationships not shared with any other child or maternal characteristic. Table 7.16 provides a summary of the acoustic-prosodic parameters of both the mother and of the child that were associated with the mother's mental health status identified through Pearson's correlation.

Table 7.16

Comparative summary of parameters associated with mother's mental health status

Acoustic-prosodic parameter Mother	**Acoustic-prosodic parameter Child**
Maternal Depression (DASS)	
More energy for the mother in the range from 0Hz-2000Hz	
Mother-initiated overlaps and a small number of pitch features for the mother	
Longer intersyllabic interval (ST) between end of previous nucleus and start of current one	Shorter intersyllabic interval (ST) between end of previous nucleus and start of current one
Longer duration of mother-initiated overlaps	Longer duration of child-initiated overlaps
More energy in the spectrum from 250Hz-500Hz through to 2000Hz for mother-initiated overlaps	More energy in the spectrum from 500Hz through to 2000Hz for child-initiated overlaps
Maternal Anxiety (DASS)	
Higher median pitch in turns for the mother	
Higher pitch at the midpoint of turns for the mother	
Higher mean pitch at the syllable level measured in semitones	
Higher maternal median pitch in Hertz	
Higher pitch floor for the mother (bottom second percentile)	
Higher levels of jitter in the mother's voice	
Higher proportion of energy in the spectrum below 1000Hz	
	More child-initiated overlaps
	More energy in the range 1250Hz-1750Hz in child-initiated overlaps

Note. Hz refers to hertz; ST refers to semitones; dB refers to decibels; maxf0 loc ms refers to the relative location of the pitch peak as a proportion to the duration of the turn; h1 h2 refers to amplitude difference between 1st and 2nd harmonics (dB); matching mother-child parameters highlighted in green; all parameters included in the table significant at $p < .05$

Table 7.16 continued.

Acoustic-prosodic parameter Mother	**Acoustic-prosodic parameter Child**
Maternal Stress (DASS)	
More energy in the mother's speech in the spectrum from 1250Hz -2000Hz	
Higher pitch minimum for the mother (bottom second percentile)	
More energy of mother-initiated overlaps in the bottom end of the spectrum 0Hz-250Hz	
Higher maxlocF0ms in mother-initiated overlaps (time of the f0 peak relative to the onset of an interval in milliseconds)	
Increases in the formant dispersion (formants 1 to 5) in mother-initiated overlaps	
Increases in cepstral peak prominence in mother-initiated overlaps	
Increases in mean intensity in mother-initiated overlaps	
Increases in final pitch in mother-initiated overlaps	
Higher second formant at the midpoint of speech turns for the mother	Higher second formant at the midpoint of speech turns for the child
Longer interval between syllables for the mother (ST)	Shorter interval between syllables for the child (ST)
More energy in the spectrum between 0Hz-1750Hz for overlaps initiated by the mother	More energy in the spectrum between 250Hz-2000Hz for overlaps initiated by the child
Longer duration of mother-initiated overlaps	Longer duration of child-initiated overlaps
	Higher final pitch velocity (rates of change in the F0 contour measured in ST at fixed time intervals) for the child
	Narrower pitch range in semitones for the child

Note. Hz refers to hertz; ST refers to semitones; dB refers to decibels; maxf0 loc ms refers to the relative location of the pitch peak as a proportion to the duration of the turn; h1 h2 refers to amplitude difference between 1st and 2nd harmonics (dB); matching mother-child parameters highlighted in green; all parameters included in the table significant at $p < .05$

Examining the session level acoustic-prosodic features, ratings of maternal vocal warmth were not associated with any of the same parameters as those of the mother's mental health status, with two notable exceptions. Maternal anxiety was associated with a higher pitch minimum for the mother (bottom 2nd), an association that was also observed for lower levels of warmth in her speech. Interestingly, both the mother's second formant and the child's second formant at the midpoint of turns was positively associated with maternal stress, while notably, a lower second formant was identified in the mother's speech on the measure of interactional warmth. Overall, the mother's acoustic-prosodic profile for stress, and particularly anxiety, was in the opposite direction to those seen in warmer and more attuned interactions, particularly on the mother's median pitch and the second formant. Notably, Study 2 (Chapter 5) identified that cointegration on both these parameters was disrupted by the presence of child CU traits.

7.6.4 Associations between relational qualities and the mother's mental health

The mother's scores on depression, anxiety, and stress scales were not associated with ratings of warmth in the mother's speech. However, significant relationships were identified between the mother's mental health status and warmth and attunement displayed in the emotion talk. Specifically, the mother's depression score was negatively associated with the judges' ratings of interactional warmth and attunement. The mother's anxiety showed a negative relationship with mother-child attunement but not with any other relational quality of the interaction, or with child characteristics such as child CU traits. The mother's stress level was not related to the judges' ratings of vocal warmth or the dyadic qualities of the interaction in Pearson's correlation analyses.

Table 7.17

Significant associations between relational qualities of the interaction and the mother's mental health

Relational Quality	DASS Depression	DASS Anxiety	DASS Stress
PFMSS Warmth	-.034	-.010	-.029
Parent Warmth Expressiveness	-.009	-.039	-.016
Warm emotion talk	**-.331****	-.155	-.165
In tune emotion talk	**-.274***	**-.285***	-.220
Dismissive emotion talk	.113	.035	.152

Note. Significant associations highlighted in green; ** $p < .01$, * $p < .05$

7.7 Discussion

While warmth and attunement are widely used terms in developmental studies, how they are conveyed non-verbally in the vocal channel is poorly defined. Functionally, caregiver responses that are sensitive to and accepting of a child's displays of negative emotions are considered to be a primary mechanism of down regulating stress in the child, a process described as protecting the child's biological system in the face of potentially toxic stress (Feldman, 2017; Schore, 2005). Therefore, this study argues that how mothers speak with their children when discussing emotionally salient events provides a suitable context for an online assessment of warmth and attunement as they are conveyed in vocal cues.

Overall, the largest number of the mother's parameters that resembled the profile for the vocal emotion of tenderness (Juslin & Laukka, 2003) was associated with the Connectedness Scale, in which ratings of warmth and attunement are made based on the contributions of both speakers. The attunement dimension showed the largest number of mother and child matching parameters, and there was a consistent finding of a lower pitch minimum across measures in which the mother was rated as warm or attuned. Hypothesis 1, that the judges ratings of the mother's vocal warmth and of warmth and attunement in the emotion talk would be associated with the acoustic-prosodic profile for the vocal emotion of tenderness (Juslin & Laukka, 2003), was partially supported, particularly for the dimension of attunement.

Of the five vocal emotions identified in speech and music (Scherer, Johnstone & Klasmeyer, 2003), tenderness is the most relational and empathic in its expression, and the considerably stronger relationship between the attunement measure and the tenderness profile is consistent with this relational stance. In particular, warmth assessed when observing both speakers is more likely to reflect the mother's adaptiveness to the child's needs during the talk, an impression unable to be captured when examining only the mother's speech.

For example, it is possible that the mother may be displaying high positivity and warmth but that this expression is mis-attuned to the child's emotional needs during the interaction. A related concept is the "false bright" phenomenon, a term that refers to over-bright, exaggerated affect by one speaker that can be observed as a mis-attunement in attachment related contexts (Crittenden, 1992). Further, the highest number of matching parameters between the mother and child was seen for the attunement dimension, suggesting that this measure may also be capturing a synchronous element to each speaker's acoustic-prosodic features.

Overall, these results suggest that the quality of caregiver warmth/ attunement (tenderness) as it is expressed in the vocal channel should be preferentially evaluated in a context in which responsiveness to the emotional needs of the child can be directly observed; this is in contrast to rating the vocal qualities of the caregiver in single speaker samples. This idea shares overlap with the basic tenets of attachment theory, in which the child's emotion regulation is supported by empathic caregiver responses in contexts of potential disequilibrium arising from physical or psychological threat for the child (Bowlby, 1958). In evaluating the mother's vocal qualities in isolation of the child's in-the-moment needs, expressive mothers may not in fact be providing tender or empathic responses to the child's bids for support.

Operationalising caregiver warmth in this dyadic way seems particularly relevant to studies examining child social abilities as an outcome. Davidov and Grusec (2006), in their attempt to "untangle the links" between attachment-related concepts, found that parental responsiveness to distress during a laboratory interaction — but not parental warmth as defined by expressions of positive affect or admiration about the child — predicted higher child empathy and more prosocial behaviour in 6 to 8 year old children. In younger children, Wright, Sharp & Pickles (2018) found that both constructs that were assessed in a dyadic context — warmth such as smiling toward the child and maternal responsiveness to the child's cues of distress — contributed to a reduction in CU traits across time.

Supporting the importance of assessing dyadic behaviours in studies of CU traits, the mother's dismissiveness as a quality of caregiving behaviour was particularly deleterious in predicting a further reduction to the pitch range of children with CU traits, a parameter identified in Study 3 as particularly compromised by CU traits. In contrast, warmth in the emotion talk had no effect in moderating the pitch range of high CU children. In general, the pitch of children in dismissive conversations was characterised by a narrower range and flatter, less melodic quality when interacting with their dismissive or highly stressed mothers.

In the present study, neither warmth in the mother's speech nor on the Connectedness Scale was related to child CU traits or to child age. Hypothesis 2, that mothers of children with high CU traits would display less warmth, was not supported. This echoes an earlier finding that, in a laboratory setting, mothers of children with CU traits did not display lower levels of non-verbal warmth as expressed through eye contact (Dadds, Jambrak, Pasalich, Hawes & Brennan, 2011). However, warmth in the present study was negatively related to child conduct problems and to child lability/ negativity, and the acoustic-prosodic profile displayed by mothers of children with ODD in Chapter 6 is also clearly oppositional to the profiles for attunement and for tenderness (Juslin & Laukka, 2003). Therefore, externalising problems, rather than CU traits, appear to present the greater risk factor for reduced displays of warmth (tenderness) in the mother's voice when interacting with her child.

This study has identified a number of novel parameters not previously associated with the vocal emotion of tenderness. The mother-child dyadic context, and the large range of parameters examined in this high dimensional dataset, may explain this difference. For example, a significantly lower second formant (concentration of energy at approximately 2000Hz) was seen for both mother and child as the level of attunement increased, suggesting that synchronicity on this feature was present in more attuned conversations. This parameter is strongly associated with the phonemic content of speech, and therefore it remains possible that linguistic contributions account for this association in attuned conversations.

For example, phonemic matching can occur when the mother asks, "did you feel scared when that happened?", and the child responds, "yes it was scary when that happened". While this may partially explain the findings, Traunmuller (1989) found that listeners also associate the second formant with increases in vocal effort. Junqua (1993) found a similar association for female speakers although Liénard and Di Benedetto (1999) did not find such an association. It is also notable that the second formant was a key parameter disrupted by CU traits in Study 2, suggesting that if warmth and attunement are conveyed through values on this parameter this is not being matched in the child's speech. together, the findings indicate that the second formant warrants further scrutiny in studies of child CU traits and separately, the vocal emotion of tenderness.

In terms of mental health, the mother's anxiety was associated primarily with her pitch features, including pitch micro instability (jitter), a parameter associated with anger and fear in vocal emotion studies (Juslin & Scherer, 2005). Depression was associated with reductions in maternal warmth and attunement in the emotion talk, and also with a higher proportion of energy in the low/ middle end of the spectrum for the mother's energy, a pattern that was also partially seen for maternal stress. A possible reason for the heightened energy in these bands may relate to co-occurrence of both high stress and depression in the mother, or the unique parent-child interactional context in which mothers are managing the child's task compliance and behaviour. Results regarding energy parameters in relation to depression in adults do tend to be mixed (see Cummins et al, 2015 for a review). For example, some research has found higher energy in the upper bands of frequency in depressed adults (Ozdas et al, 2004) which the authors suggested may be related to heightened tension in the larynx.

In particular, depression was associated with a greater proportion of energy in the mother's voice in the bottom end of the spectrum, below 500Hz and 750Hz. In Study 3, children low on cognitive empathy also had more energy in this low end of the spectrum, and in Study 4 the mother's vocal warmth had little impact on this energy range in the speech of children low on this facet of empathy. The functional impact of this finding is unclear. Consonants, which are typically located above 1500Hz in English, are widely considered to carry most of the intelligibility yet much less of the power (Krause & Braida, 2004), while vowels contain most of the power and are located in the lower and mid ranges of the spectrum. Therefore, it is conceivable that the vocal expressions of depressed mothers may have conveyed less effective communication of linguistic information compared to non-depressed mothers. Overall, these associations raise questions about possible relationships between the mother's depression and the effect of these communicative features on child empathy development. In particular, the potential for reduced intelligibility in the speech of depressed mothers and children low in empathy are associations that would benefit from future investigation.

Overall, the mother's stress was associated with a combination of both heightened maternal pitch and energy features, and this profile was generally oppositional to that associated with the vocal emotion of tenderness. Both depression and stress also saw significant increases in energy for both mother-initiated and child-initiated overlaps; this further suggests heightened levels of arousal and problems for both speakers in effectively managing turn-taking, and such overlaps are more likely to be perceived as interruptive and turn-competitive (Hilton, 2016),

The mother's stress was also the primary mental health characteristic that was associated with acoustic-prosodic features of the child, particularly with increases in the child's pitch minimum. This finding of higher pitch floor for both mother and child was also observed in Study 3 for ODD, and suggests the possibility that synchronicity is occurring on this parameter. Hypothesis 3 — that mothers reporting high levels of depression and stress will display less warmth — was supported for depression by the judges rating scales on warmth and attunement. It was also partially supported by the mother's acoustic-prosodic profile for stress due to the higher pitch floor.

In terms of the child's temporal parameters, the results of this study indicate that parental warmth and attunement are related to increases in the proportion of "air time" for all children in emotion talk, but that these relational qualities were particularly notable for increases in the comparatively poor talk time of high empathy and high prosocial children up toward the mean. The findings indicate that high empathy children in poorly attuned conversations had the least opportunity in these interactions to verbally process their emotional experiences, and therefore appear to be at particular risk of missing out on the significant benefits of emotion reminiscing with their caregivers, such as improvements in emotion knowledge and self-regulation (Salmon & Reese, 2016).

7.8 Summary

In sum, this study provides support for the view that warmth and attunement are caregiving qualities that are conveyed in discernible patterns of acoustic-prosodic features. Along with dismissiveness, these vocal qualities are important modifiable factors that appear to influence the child's own vocal expression. In terms of potential applications, the results suggest that the addition of a psychoeducation component to parent support programs that explicitly addresses the premise that warmth/ tenderness is conveyed through vocal features, as well as the reciprocal nature of vocal arousal, is warranted.

Of note, the current study is unique in the field of vocal emotion research in identifying a dataset of acoustic-prosodic features associated with ecologically valid expressions of warmth and attunement in a caregiving context. Further studies testing these parameters in new samples are necessary to confirm their relevance to these relational constructs. It should be noted that adjustments were not made for multiple hypothesis testing in the correlation tables reported in this naturalistic study (Rothman, 1990), however the results are consistent with the first-order explanation relating to observed phenomena of tender interactions. Finally, the different findings for the acoustic-prosodic parameters associated with warmth in the mother's voice versus attunement support the continuing endeavours in the developmental field to establish consistent definitions that better discriminate between these two important concepts, particularly for studies relating to child empathy development.

CHAPTER 8: CONCLUSION

8.1 Summary of key findings

A number of essential questions were addressed by this thesis. Study 1 (Chapter 4) used dynamic time series methods to test the hypothesis that mutual and adaptive coordination of acoustic-prosodic parameters occurs in the speech of mothers and their children. All forty-four vocal parameters showed the capacity for cointegration, with rates between 84.13% and 47.37% of dyads across the total dataset. While a surprisingly prevalent phenomenon, this finding is consistent with established literature observing that mother-child synchrony is typical across communicative modalities in early development (Harrist & Waugh, 2002; Leclère et al, 2014).

The emotion coaching context of this thesis is also important, as Harrist and Waugh (2002), following Gottman (1997) observed that synchrony is more likely to occur in contexts where a caregiver is able to make an empathic connection to a child experiencing negative emotions. However, the findings of this thesis are also consistent with the body of literature revealing the presence of acoustic-prosodic entrainment in adult dyads, including those displaying rapport (Lubold & Pon-Barry, 2014), those engaged in a mutually cooperative task (e.g., Levitan et al, 2015), and those in close relationships (Harma, 2014). Hypothesis 1, that children and their mothers would display cointegration on acoustic-prosodic parameters, was supported.

However, while all acoustic-prosodic parameters showed the capacity for cointegration, its prevalence was also found to be dyad dependent. Study 2 (Chapter 5) found that these differences were associated with qualities of both the child and of the mother; as hypothesised, child callous-unemotional traits were associated with disruption to mother-child synchrony on a number of key emotion relevant vocal parameters. These parameters included pitch median, pitch maximum, intensity midpoint, the second formant, the proportion of energy below 500Hz, cepstral peak prominence, and the Hammarberg Index. Hypothesis 2, that children with callous-unemotional traits will show disruptions to acoustic-prosodic synchrony, was partially supported. This disruption is consistent with existing literature that finds positive relationships between mother-child synchrony and child prosocial behaviour and empathy (Feldman, 2007a; Feldman 2007b; Harrist & Waugh, 2002), and with the links between biobehavioural synchrony and prosocial behaviours shown in adult populations (Mogan et al, 2017).

The use of cointegration methodology in this thesis enabled the testing of Granger causality to examine the direction of acoustic-prosodic information flow between speakers. Due to a lack of power, conclusions regarding the influence of child or maternal characteristics, such as callous-unemotional traits or maternal depression, on the direction of this flow could not be drawn. However, the results showed that both the mother and child were capable of influencing the other on all parameters of vocal expression, although the general trend saw mothers Granger-cause their child's acoustic-prosodic expression values approximately twice as often as the child Granger-caused the mother's expression.

Study 3 (Chapter 6) found that high callous-unemotional children showed significant differences on two key emotion relevant parameters in their emotion talk, specifically a narrower pitch range for the child, and a substantially greater percentage of talk time; conversely, children with high prosocial traits showed wider pitch range and significantly more listening time. There was no evidence of differences between mothers of high CU children and those with low CU children. Hypothesis 3, that children with callous-unemotional traits would show less expressiveness in their affective prosody, was partially supported.

Study 3 also identified significant differences on acoustic-prosodic parameters for dyads with a child with ODD. The study found wide ranging evidence for heightened pitch and intensity features for both the mother and the child in dyads with child oppositional behaviours. As cointegration showed little disruption associated with ODD, for these mother-child dyads, the synchronous vocal system was one of heightened arousal.

Study 4 (Chapter 7) examined acoustic-prosodic features associated with characteristics of the mother. Study 4 found that of all the observer rated qualities of the interaction, the attunement item on the Connectedness Scale was most closely aligned with the prosodic profile for the vocal emotion of tenderness due to significantly reduced values across a number of pitch and intensity parameters. The attunement measure also showed the greatest number of matched vocal parameters between mothers and their children. These findings suggest that vocal qualities of caregiver attunement (tenderness) is primarily a relational construct that should be assessed in a dyadic context, and that acoustic-prosodic cues work together with linguistic features to optimise conveyance of this emotion.

Study 4 also found that child characteristics interacted with the qualities of mother-child emotion talk to influence a number of the same emotion relevant acoustic-prosodic features that were identified as significant in Study 3. For children with high callous-unemotional traits, the mother's warmth had limited effect on key parameters, with the exception of significantly increasing the already high proportion of speech time for these children. Warmth in the mother's voice was found to be particularly important in expanding the markedly smaller proportion of speaking time of children with low callous-unemotional traits. In contrast, the mother's dismissiveness had a particularly deleterious effect in further narrowing the high callous-unemotional child's pitch range, an important emotion relevant parameter that was shown to be compromised by CU traits in the previous study.

The hypothesis that maternal warmth would be more prominent in the emotion talk of mothers and their children with low levels of callous-unemotional traits compared to children with high levels of callous-unemotional traits was not supported. In contrast, reduced levels of warmth in the mother's voice and attunement in the interaction were observed both for children with conduct problems and with emotional lability / negativity, a finding that is generally consistent with the studies reviewed by Waller et al (2013). This result suggests that behavioural problems, rather than child empathic deficits per se, are disrupting the displays of warmth and attunement (tenderness) by caregivers.

Maternal mental health status was associated with differences on a number of the mother's emotion relevant vocal parameters. Maternal anxiety was associated primarily with the mother's pitch features and depression with her energy features, particularly a higher proportion of energy in the very low end of the spectrum where intelligibility may be compromised (Hazan & Markham, 2004; Krause & Braida, 2004). The mother's stress level was associated with a combination of both pitch and maternal energy features for the mother, and was the only maternal mental health characteristic that was associated with acoustic-prosodic values of the child, particularly a higher pitch floor during emotion talk.

8.2 Significance and implications

This thesis used a novel investigative paradigm that integrated clinical psychological assessment, speech signal feature extraction, and a dynamic time series method to study synchrony of vocal affect in the interactions of mothers and their children. In particular, this study is the first to our knowledge to apply the methodology of cointegration to speech processes. This approach differs from previous work in that it captures an adaptive relationship between each speaker's acoustic-prosodic features, and also allows for the testing of directionality in the dynamic flow of information between mother and child. As such, this is the first study to empirically demonstrate that the relationship between mothers and their children on parameters of vocal affect is a dynamic and adaptive one.

8.2.1 Acoustic-prosodic synchrony in mother-child interactions

This thesis is also the first study to examine a large number of acoustic-prosodic parameters across a substantial sample of mother-child dyads. In doing so, it greatly expands the number of vocal parameters that have been shown to synchronise between any two speakers, and extends upward evidence for acoustic-prosodic synchrony between mothers and their children beyond the period of very early childhood previously identified. As such, the breadth of the findings supports the view that the vocal channel is a facet of human communication that trends toward synchrony in close relationships.

In terms of the directionality of that communication, the Granger causality testing found evidence to suggest a bias in the direction of acoustic-prosodic information flow from mother to child, similar to Ko et al (2016) who used a different methodological approach. However the causality findings are particularly tentative due to the imitations in sample size (i.e., the length of the conversations) and the possibility of omitted variables; therefore, conclusions beyond the capacity for Granger causality by both mothers and their children cannot be drawn. The results do provide proof of concept for the application of causality testing to investigating dynamic processes in speech, and as argued by Stroe-Kunold et al (2012), is a methodology that can be applied to studies of interpersonal processes more generally. This might include examining speech processes in typically developing children, as well as in populations of particular clinical interest such as autism spectrum disorder (ASD).

8.2.2 Acoustic-prosodic synchrony, CU traits, and disruptive behaviours

Germane to the central research question, this thesis is the first to investigate and observe differences in acoustic-prosodic synchrony for children with callous-unemotional traits. The functional impact that this disruption might have on callous-unemotional children and their interlocutors is unclear. It is conceivable that deficits in vocal affect recognition previously observed in the high callous-unemotional cohort (Bagley et al, 2009) may represent a type of disrupted feedback cycle between synchronous acoustic-prosodic expression and recognition. In this way, disturbances to synchrony in the vocal channel may be reflecting – or maintaining – impaired processes of emotional arousal and affective empathy that are believed to interfere with the child's capacity to experience empathy.

In contrast, children with ODD showed limited disruption to synchrony on features of vocal affect unless coupled with child callous-unemotional traits or maternal depression. The synchronous vocal system for children with characteristics of ODD was one of markedly higher arousal compared to non-ODD dyads, indicating that the interaction was likely to have been more vocally demanding — and thus more physiologically effortful — for both dyad members. The findings of this thesis suggest that there is feedback occurring between both the child's and the mother's heightened arousal levels in these interactions.

Such findings are not inconsequential. Cavanagh et al (2017) found in a large sample factor analysis of children in middle childhood that ODD was unidimensional and colinear with emotion dysregulation, and argued that ODD should be conceptualised primarily as a disorder of emotion regulation rather than as a behaviour disorder. In such a context, meta-analytic findings by Suveg et al (2016) that behavioural synchrony in the presence of negative emotions has the potential to interfere with the child's capacity for self-regulation suggests that synchrony may be an important maintaining factor for ODD symptomology in this disorder. Equally, parenting a child with ODD is stressful (Bussing et al, 2003), and emotion contagion in the presence of negative emotions has been associated with increased risk of emotional distress and characteristics of personality disorder in adults (Murphy et al, 2018). Therefore, while it is possible that cointegration is contributing to the development of empathic understanding in these children, the phenomenon may be less positive for other facets of both child and maternal functioning, such as emotion regulation and internalising symptoms.

The current findings have implications for the important role of emotion regulation strategies for caregivers of children with oppositional behaviours. In particular, it is argued that the results of this thesis warrant that caregivers be made aware of the potential for these synchronous influences in vocal affect when they are communicating with their children. For example, integrating a psychoeducation component that explicates the presence of bidirectional influences in vocal expression into parent support programs could provide parents with a clear rationale to better manage their own levels of arousal during oppositional interactions. Importantly, such implications would appear to also extend to interactions with typically developing children due to the positive associations observed between the child empathy measures and the presence of acoustic-prosodic synchrony.

The results of this thesis also add to the accumulating literature indicating that maternal depression is a high priority for treatment due to its potential impact on the child's emotional and communicative development. This particularly relates to the finding that children without callous-unemotional traits interacting with highly depressed mothers still retained an approximately 50% probability of cointegrating with their mothers on median pitch, a key emotion relevant parameter. As reduced pitch expressiveness in depressed adults has been identified in other research (see Cummins et al, 2015a for a review), a substantial number of children interacting with depressed mothers may be at risk of synchronising on this compromised feature of their mother's vocal affect.

Equally, disruption to cointegration for other high callous-unemotional children interacting with highly depressed mothers may be protective for the child's own emotional experience, such as from feelings of sadness or distress, although it seems likely that there could be costs to child empathy associated with this. For example, depression on vocal parameters in adults shares overlap with the vocal emotion for sadness, such as a reduction in vocal activity (Balsters, Krahmer, Swerts & Vingerhoets, 2012). Therefore the high CU child interacting with a depressed mother may be less able to recognise the mother's sadness in a disrupted system. Overall, the results of this thesis add to the body of literature prioritising maternal mental health as an important modifiable risk factor for healthy processes of child development.

Of particular note, the GEM child empathy measure was associated with an increased probability of cointegration on a number of the same emotion relevant parameters that were disrupted by high callous-unemotional traits. The cognitive empathy scale is considered to be a measure of the child's capacity for perspective taking and understanding others mental states (Dadds, Hunter, Hawes et al 2008; Dadds, 2018), whereas the affective empathy scale has been found to be representative of an emotion contagion dimension (Dadds, 2018; Murphy 2017). Moreover, previous work by Dadds et al (2009) using a large sample indicates that the divergence between the cognitive and affective aspects of empathy that is frequently observed in psychopathic individuals is not apparent until after puberty. Therefore the GEM findings in this thesis are considered to serve primarily as cross-validation for the hypotheses relating to empathic deficits in child callous-unemotional traits and associated disruption to emotion contagion.

8.2.3 Child vocal affect expression and CU traits

In addition to the synchrony findings, this thesis is the first to study and observe differences in the acoustic-prosodic expressions of children with callous-unemotional traits, and in particular, the first to identify the novel parameter of a restricted pitch range for the callous-unemotional cohort. The size of these differences on the psychoacoustic pitch scale is sufficient that it is likely to be contributing to caregiver perceptions of restricted range of affect in these children. This finding is broadly consistent with an earlier study which identified limited variation in pitch and amplitude between neutral and affective words in adult psychopaths (Louth et al, 1998), and is in line with the view of an unemotional component in callous-unemotional traits (e.g., Blair, 2013).

The substantially greater speaking time of children with callous-unemotional traits also raises questions in relation to the role of listening versus speaking in child empathy. As noted by Heldner and Edlund (2010), turn taking is a highly practiced skill. Therefore, at least in early childhood, it is possible that poorly balanced turn taking may be an indicator of a delayed capacity to empathically balance the communicative needs of an interlocutor with one's own. Alternatively, it may be that the mothers of high callous-unemotional children experience more difficulty asserting their communicative needs in the emotion talk, which would be consistent with the model of bidirectional influences arising from the interaction of child characteristics and parent characteristics.

Allely et al (2013) and Marwick et al (2013) found clear relationships between reduced frequency of vocalisations by adult caregivers with their infants and the later diagnosis of oppositional and conduct disorders in middle childhood, and conversely, an increased risk of disruptive behaviour disorders associated with excessive amounts of infant vocalisation at 12 months. Teasing apart the relationships between impaired vocal turn taking and characteristics of child conduct problems such as callous-unemotional traits, which may extend from infancy through to at least middle childhood as seen in the current findings, seems an important area of further study for children with problems in social functioning.

8.2.4 Relational qualities in vocal affect and CU traits

In terms of the relational qualities of the interaction, the mothers of high callous-unemotional children were not observed to display less warmth or attunement in this laboratory task. However, conduct problems and emotional lability/ negativity were each associated with less warmth and attunement in the interaction, a finding which may also reflect mutual influences in the parent-child relationship over time (Waller et al, 2013). The acoustic-prosodic profiles for warmth and attunement (tenderness) in the interaction were in the opposite direction to the profiles displayed by mothers interacting with ODD children. Therefore, in dyads in which the child has ODD, it is possible that opportunities for the mother to display warmth or attunement may be hijacked by the high levels of synchronous arousal.

Mothers were not seen to display lower levels of warmth or attunement linked to their child's CU characteristics, therefore it is possible that the disruption to cointegration associated with CU traits may be maintaining difficulties for the high CU child in experiencing or recognising displays of tenderness. It is also notable that a subset of children with high callous-unemotional traits did retain the capacity for mother-child cointegration; therefore despite what may be the appearance of limited responsiveness by some high callous-unemotional children, the results of this thesis support the view (e.g., Waller et al, 2015) that there may still be benefit for the child in maintaining displays of warmth and attunement.

In addition, these affiliative qualities were associated with significant increases in the percentage of speaking time for all children. The established benefits of mother-child emotional reminiscing include increases in child emotion knowledge and self-regulation (Salmon & Reese, 2016; Salmon et al, 2016), therefore attunement as a caregiver quality may be helpful in amplifying such benefits for children who are particularly reticent in their speech.

Significantly, this thesis provides support for the view that warmth, attunement (tenderness) and to a lesser extent dismissiveness, are relational qualities that are conveyed in acoustic-prosodic features, and are important modifiable factors capable of influencing the vocal expression of both the child and the mother. These findings also have implications beyond mother-child interactions. For example, processes of psychological therapy also rely on empathic attunement via acoustic-prosodic features (Weiste & Peräkylä, 2014), and the prevalent nature of the cointegration findings – including on parameters significant for attunement (tenderness) – suggests a capacity for emotion transfer and soothing through the vocal channel in therapeutic settings.

Finally, this thesis builds on the small existing literature for the vocal emotion of tenderness, and due to the large set of acoustic-prosodic parameters and the dyadic context examined in this study, expands the range of parameters that have been previously associated with this essential caregiving quality. The differential findings in relation to the measures of warmth and attunement support the view that is important to consider the caregiver's responsiveness to the child emotional needs in the evaluation of caregiver warmth and attunement (tenderness) in the vocal channel.

8.3 Limitations

There are some important factors which limit the generalisability of the results in this thesis. Due to the sparse research relating to mother-child acoustic-prosodic synchrony, and particularly, to acoustic-prosodic expression and callous-unemotional traits, high dimensional data methods were used to explore a wide field of potential parameters and narrow those to ones of future research interest. While bias corrections were applied to the analyses, there is always a risk that significant findings reflect error or noise, and further validation studies using new samples are necessary. Future studies could consider testing for cointegration that may be arising from chance or a mathematical phenomenon through the addition of a pseudo-synchrony paradigm (e.g. Fujiwara & Daibo, 2016), for example, where the acoustic-prosodic time series variables for each speaker are randomly matched to another dyad member.

It is also important to note that the between-group comparisons did not account for any effects that may be due to variations in speaker physiology and that the recording of mother-child conversations used a microphone placed between the mothers and children. While occasional movements of the face away from the direction of the microphone are likely averaged out across the session and across similar dyads, it is conceivable that such movements may have led to spurious results on intensity parameters for the studies of cointegration.

However it is important to consider that the cointegration analysis intentionally overfits the model and incorporates tolerances when assessing the long-run pattern between variables. It is also a relevant consideration that intensity and pitch parameters frequently move together in speech and that cointegration on both types of features was a prevalent phenomenon across dyads, suggesting that any such movements were of insufficient strength to disrupt the identification of cointegration on intensity when using this approach. However where possible, future studies should use lapel microphones for greater fidelity of vocal measurement and to exclude the possibility of this particular confound.

Missing data, in this case missing cases at random (MCAR) could also have introduced potential bias in parameter estimation (Rubin 1987; Schafer 1997). MCAR is a particular case of missing at random in which the remaining data is considered to be a random sample of the complete data, due to the reasons relating to missingness. As outlined by Dong and Peng (2013), ignoring missing data under conditions of MCAR is less of a threat to inferences and should not introduce bias, however it can increase the standard errors of the sample estimates due to the reduced sample size.

The Granger causality results are particularly tentative in terms of drawing conclusions beyond identifying the capacity for mutual vocal influence in mother-child dyads. Where cointegration has been identified, the Granger-Engle Representation Theorem requires that there must be Granger causality in one or both directions; however Granger testing is particularly sensitive to sample size and to lag length (Stern & Enflo, 2013), therefore the failure to reject the null hypothesis of *no Granger causality* is likely to be the result of insufficient power in many cases. In future, the Granger causality studies should be repeated using conversations of a set minimum length to allow a sufficiently large number of speaker turns when forming the time series variables.

In addition, this thesis also used bivariate relationships in the time series analyses, as it was hypothesised that if synchrony occurred there would be evidence on the equivalent acoustic-prosodic feature for each speaker in the dyad, e.g., synchrony between each speaker's pitch median. However causal relationships that are not apparent in bivariate testing may be attributable to the influence of a third or omitted variable, which in this case may be the movement of another vocal parameter. In particular, it has been demonstrated that acoustic-prosodic features frequently move together (Moore, 2012), for example, pitch and intensity parameters can work in tandem to produce variations in vocal affect. Therefore a fruitful next step using cointegration methodology and Granger causality testing in the study of vocal affect would be to examine multi-cointegration between two or more acoustic-prosodic parameters between speakers.

Acoustic-prosodic parameters were extracted at the turn-by-turn level by two different software programs. Some parameters identified as significant at the session level, such as child pitch range, were not able to be directly tested in the synchrony analyses as they were not able to be extracted by the software at the turn-by-turn level. It is reasonable to expect that pitch range is also likely to display the capacity for synchrony given that pitch parameters in general displayed high rates of cointegration, however given that this parameter was not directly tested in this study, this is a hypothesis that would benefit from future testing as the software develops.

Recent vocal affect studies also suggest that there are acoustic-prosodic features which are important to emotion recognition that were not examined in this research. In particular, cepstral descriptors have been shown to increase the accuracy of emotion recognition above standard prosodic parameters, specifically Mel-Frequency Cepstral Coefficients (MFCC) and spectral flux (spectral changes in consecutive components of speech) (Eyben et al, 2016; Weninger, Eyben, Schuller, Mortillaro & Scherer, 2013). As clinical and developmental researchers gain increasing access to more sophisticated analysis tools, it is likely that there will be further opportunities for investigation of those additional parameters in clinical and developmental samples.

On this note it is worth mentioning that specialised software designed to investigate features of vocal emotion has been developed in recent years and will provide opportunities to map the multi-dimensional structure of vocal warmth in more nuanced ways. For example, openSMILE (Eyben, Weninger, Gross & Schuller, 2013), a C++ based software, has emerged as a leading tool for computer scientists researching vocal emotion and machine learning. openSMILE uses sophisticated algorithms developed with the goal of increasing replicability in the field of vocal emotion research (e.g., Eyben et al, 2016). At the time of feature extraction for this research however, openSMILE required a level of software engineering skill beyond most researchers outside the computer science field.

Another important limitation of the studies is that all conversations were conducted in English, and it is possible that other languages, particularly ones using intonation to denote linguistic differences such as Mandarin, will display synchrony on fewer, or a different range, of acoustic-prosodic parameters. This thesis also examined only the vocal channel however it has been established that facial and vocal processing together can work together to amplify emotional intelligibility (Rigoulot & Pell, 2012; 2014), and that the listener's visual system impacts on the auditory signals to the listener's brain (Luo et al, 2010). In future studies, the use of audiovisual recording would allow the application of dynamic time series methods to investigate the degree to which visual cues might mimic or amplify vocal synchrony in caregiver-child conversations.

A further consideration is that the different affective epochs (e.g., happy, sad/ angry, afraid) were not separately measured for their vocal behaviour. While all dyads successfully completed the task there was variability in the length of time spent discussing each emotion. It therefore remains possible that cointegration is a more predominant feature of either positively or negatively valenced emotion talk. Overlaps were also removed from the time series analysis, and these are likely to contain emotion relevant data that could be examined in future work. For example, it is possible that overlaps capture a significant component of shared vocal experience in terms of matching arousal or valence between speakers, and may be of further interest to studies of empathy.

Another important consideration is the potential contribution of undiagnosed autism as an explanatory factor for the results of this research. Differences have been documented in the level of non-verbal synchrony for children with autism (e.g., Trevarthen & Daniel, 2005) as well in aspects of their acoustic-prosodic properties more generally (e.g., Nakai et al, 2014). The screening process for the current research excluded children with a prior diagnosis of autism and the face to face assessment process included detailed descriptions of the child's early developmental milestones and behavioural problems as well as direct observation of parent-child interaction tasks by clinicians.

However there was no structured assessment tool of ASD criteria used to formally diagnose autistic features. Therefore it remains possible that a cohort of children with co-occurring CU traits and high functioning autism may account for at least some of the variance in the disruption to cointegration and the acoustic-prosodic expressions observed in this research. Future studies of the vocal features of children with CU traits should account for this possibility by including a formal measure of autism during the assessment process.

Finally, it is also worth noting that this research relied on parent self-report to measure the callous-unemotional construct, and the findings are likely to be strengthened in future by the use of multiple informants. Similarly, given the high heritability component of CU traits, it cannot be excluded that the presence of such traits in the mother may also be contributing to the disruptions in synchrony observed in those dyads. To address this possibility, future studies should consider including an assessment of CU traits in the caregiver. Moreover, while it is reasonable to assume that mothers and their children bring their characteristic patterns of interacting to the conversational task, for ecological validity this assumption would benefit from testing with new samples in naturalistic environments such as the family home.

Notwithstanding these limitations, this research in this nascent field provides the first evidence for cointegration of acoustic-prosodic features in dyadic speech, and identifies a subset of parameters to examine in future analyses for children with high callous-unemotional traits and for children showing problems in emotional and behavioural dysregulation. The focus of this research was to test first order questions regarding whether or not there was evidence for acoustic-prosodic cointegration in these dyads and if there were significant differences regarding the overall affective quality of vocal behaviour in these “thin-slice” interactions. As the speech signal is particularly complex to decode and is a focus of intensive ongoing research across a number of disciplines, it seems likely that progress in the automation of speech segmentation and signal analysis will allow larger datasets to be examined in quicker research timeframes for clinical populations in future.

8.4 Conclusion

In conclusion, this thesis found evidence for dynamic and mutual influences between mothers and their children on parameters of vocal affect, and that its prevalence was dyad dependent. As hypothesised, disruptions to acoustic-prosodic synchrony were associated with high callous-unemotional traits on a number of emotion relevant parameters, a finding consistent with the significant literature regarding biobehavioural synchrony and prosocial behaviour. This thesis therefore argues that the synchrony construct may be relevant to other channels of nonverbal communication in the high callous-unemotional population.

In contrast, the finding that children high in empathy did not show such disruption to acoustic-prosodic synchrony with their mothers highlights the vocal channel as a probable source of bidirectional emotional contagion in those dyads, a finding that has the potential to apply to other close relationships. The comparatively limited pitch range and listening time of children with callous-unemotional traits are findings that are consistent with the restricted affect and impaired empathy typically seen in the callous-unemotional cohort, and these differences are sufficiently distinguishable to contribute, perhaps unconsciously, to the caregiver impressions captured on the measure of callous-unemotional traits.

While individuals with callous-unemotional characteristics have been described as adept at learning to conceal any limitation in their emotional responses, the results of this thesis find that processes of acoustic-prosodic expression may be more difficult to mask in childhood when any compensatory mechanisms might still be developing. Therefore, this thesis argues that synchrony of vocal affect – and processes of biobehavioural synchrony more generally – are promising new mechanisms of study in the high callous-unemotional population that may help explain the long observed paradox: *"they know the words but not the music"*.

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APPENDICES

APPENDIX A: Descriptions of acoustic-prosodic parameters for Praat scripts (open access web source)

	Lennes scrip: Parameter descriptors extracted from https://lennes.github.io/spect/
F0 Midpoint (Hz)	The F0 value in Hertz (Hz) at the midpoint of each interpausal unit.
F1 Midpoint (Hz)	The first formant value at the midpoint of each interpausal unit.
F2 Midpoint (Hz)	The second formant value at the midpoint of each interpausal unit.
Intensity midpoint (dB)	The intensity value in decibels (dB) at the midpoint of each interpausal unit.
	ProsodyPro script: Parameter descriptions extracted from http://www.homepages.ucl.ac.uk/~uclyyix/ProsodyPro/
F0 Max (Hz)	The maximum F0 value in Hertz (Hz) within each interpausal unit.
F0 Min (Hz)	The minimum F0 value in Hertz (Hz) within each interpausal unit.
F0 Mean (Hz)	The mean F0 value in Hertz (Hz) within each interpausal unit.
F0 Final (Hz)	The F0 value near the interpausal unit offset, in Hertz (Hz). The offset is the temporal relation between a interpausal unit and its response, measured in milliseconds (Stivers et al, 2009).
F0 Excursion (ST)	The difference between maximum F0 and minimum F0 measured in semitones (ST).
Intensity mean	The mean intensity in decibels (dB) within each interpausal unit
Velocity	Velocity is a measure of the instantaneous rates of F0 change of the f0 contour in semitone/s, at fixed time intervals specified by the f0 sample rate.
Final velocity (ST)	F0 velocity near the interval offset in semitones/s (ST) within each interpausal unit.
Max velocity (ST)	Maximum F0 velocity in semitones/s (ST) within each interpausal unit.
Duration (ms)	Interval (interpausal unit) duration in milliseconds (ms)
Max f0 loc ratio	Relative location of the F0 peak as a proportion to the duration of the interpausal unit .
F0 max loc (ms)	Time of the F0 peak relative to the onset of the interpausal unit in milliseconds (ms) .
h1-h2 (dB)	Amplitude difference between 1st and 2nd harmonics
h1*-H2* (dB) / h1b-h2b (dB)	Formant-adjusted h1-h2
H1-A1 (dB)	Amplitude difference between 1st harmonic and 1st formant
H1-A3 (dB)	Amplitude difference between 1st harmonic and 3rd formant
CPP / cpp	Cepstral Peak Prominence (CPP) is a measure of the degree of regularity or periodicity in the voice signal, as a measure of peak amplitude normalised for overall amplitude. Perceptually, it is strongly negatively correlated with breathy ratings (the correlation of breathy rating and CPP is roughly –0.92, indicating that as breathiness increases, CPP decreases. It is the relative amplitude of the cepstral peak prominence to the expected amplitude, as derived via linear regression (to calculate CPP, a linear regression trend of the cepstrum in dB is calculated in a range of quefrencies around the CP, and the difference between CP and the regression line at the quefrency of the CP is defined as the CPP). The normalisation accounted for scaling issues of the cepstrum due to implementation factors (e.g., window type and length, fast Fourier transform size) and, to a lesser degree, the effects of the vocal tract and noise spectra on CP.

	ProsodyPro script: Parameter descriptions extracted from http://www.homepages.ucl.ac.uk/~uclyyix/ProsodyPro/
Center of gravity (Hz)	Center of gravity (CG) measures the tilt of the spectrum measured in Hertz. It is a measure for the average height of frequencies in a spectrum, e.g., for a sine wave with a frequency of 377 Hz, the centre of gravity is 377 Hz.
Hammarberg index (dB)	Difference in maximum energy between 0-2000 Hz and 2000-5000 Hz, measured in decibels.
Energy below 500Hz (dB)	Energy of voiced segments below 500Hz (proportion between energy below 500 Hz and total energy up to 4000 Hz). Intelligibility and novel word learning is compromised in children with stimulus speech under 500Hz.
Energy below 1000Hz (dB)	Energy of voiced segments below 1000Hz (proportion between energy below 1000 Hz and total energy up to 4000 Hz).
Formant dispersion 1_3 (Hz)	Average distance between adjacent formants up to the third formant (F3). A formant is a concentration of acoustic energy around a particular frequency in the speech wave. Formants occur at roughly 1000Hz intervals.
F dispersion 1_5 (Hz)	Average distance between adjacent formants up to fifth formant (F5). A formant is a concentration of acoustic energy around a particular frequency in the speech wave. Formants occur at roughly 1000Hz intervals.
Median pitch (Hz)	Median pitch (Hertz) in each interpausal unit
Jitter	The cycle-to-cycle rapid micro-variations of pitch. Specifically, it is a measure of frequency variability in comparison to F0 (calculated as the mean absolute difference between consecutive periods, divided by the mean period). Research shows that jitter values in normal voices range from 0.2 to 1 percent. Jitter is considered involuntary and is considered to be an indicator of stressor-provoked anxiety.
Shimmer	The cycle-to-cycle micro-variations of amplitude (loudness) in successive glottal cycles. It is calculated as the mean absolute difference between amplitudes of consecutive periods, divided by mean amplitude. It can serve as an indicator of underlying stress in human speech. The norms are 2.32% for children ranging in age from 8-12 years old.
Harmonicity (dB)	Harmonicity, also known as Harmonics-to-Noise Ratio (HNR), is a measure of the proportion of harmonic sound to noise in the voice measured in decibels (Ferrand, 2007). HNR value is the extent to which noise replaces the harmonic structure in the spectrogram, perceived as the "degree of hoarseness" of the signal. HNR quantifies the relative amount of additive noise. The lower the HNR, the more noise in the voice, e.g., laryngeal pathology may lead to poor adduction of the vocal folds and, therefore, increase the amount of random noise in the vocal note.
Energy profile (dB)	Fifteen signal energy values are computed from overlapping spectral bands of 500-Hz bandwidth: 0–500, 250–750, 500–1000, ... 3250–3750, 3500–4000. Higher amounts of high-frequency energy are associated with higher arousal. Lower frequency bands are associated with the emotions of tenderness and sadness.
	Prosogram script: Parameter descriptors extracted from https://sites.google.com/site/prosogram/home
Stylisation	A psychoacoustic algorithm analysis method based on Praat segmentation of the speech signal. Allows computation of statistical data of the prosodic properties of vocalic nucleus, as well as of the sequences of nuclei, based on principles of human hearing. For each input file the Prosogram generates a file containing the prosodic profile of the speech signal.
Vocalic nucleus	The voiced part around the local intensity peak, delimited by the points located at -3 dB (left) and -9 dB (right) from the peak. The value for the left boundary (-3 dB) eliminates most microprosody perturbations at syllable onset as well as microprosodic phenomena for voiced consonants at syllable boundaries; the value for the right boundary (-9 dB) preserves late pitch variations in stressed vowels.
rowLabel	(a) When speaker information is provided in Praat tier, the first column gives the speaker label in that tier. This allows to select data from a given speaker (b) Otherwise, column 1 gives the start time of the nucleus.
nucl_t1	Start time of nucleus
nucl_t2	End time of nucleus
nucl_dur	duration of nucleus
f0_min	f0 min (Hz) within nucleus, before stylisation
f0_max	f0 max (Hz) within nucleus, before stylisation
f0_median	f0 median (Hz) within nucleus, before stylisation
f0_mean	f0 mean (Hz) within nucleus, before stylisation
f0_meanST	f0 mean (ST) within nucleus, before stylisation
f0_start	f0 value (Hz) at start of nucleus, after stylisation
f0_end	f0 value (Hz) at end of nucleus, after stylisation

	Prosogram script: Parameter descriptors extracted from https://sites.google.com/site/prosogram/home
lopitch	f0 min (Hz) within nucleus, after stylisation
hipitch	f0 max (Hz) within nucleus, after stylisation
intersyllab	intersyllabic interval (ST) between end of previous nucleus and start of current one
up	Sum of upward pitch intervals (ST) of tonal segments in nucleus
down	Sum of downward pitch intervals (ST) of tonal segments in nucleus
trajectory	Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up)
prnp_start	Pitch-range normalised pitch value of start of nucleus
prnp_end	Pitch-range normalised pitch value of end of nucleus
prnp_intra	Pitch-range normalised pitch value of intra-nucleus variation
vowel_dur	Vowel duration (only if phon tier available)
syll_dur	Syllable duration (only if syll tier available) (Not available in automatic segmentation mode.)
rime_dur	Rime duration (only if phon and syll tier available) (Not available in automatic segmentation mode.)
gap_left	Time between end of previous nucleus and start of current one
int_peak	Peak intensity (in dB) in nucleus
speaker_id	Identification number of speaker
Speech Time	Total speech time (in seconds) (internucleus time + intranucleus time + pause time)
Phon Time	Phonation time (in seconds) without pauses (internucleus time + intranucleus time)
Prop Phon	Proportion (%) of estimated phonation time (internucleus time + intranucleus time) to speech time
Prop Pause	Proportion (%) of estimated pause time (when internucleus time >= 0.3) to speech time
Speech Rate	Estimated speech rate (in syllables) = nrof_nuclei/phonation_time
Mean Of ST	Mean of pitch values, where values are min and max pitch in ST for each syllable
Stdev Of ST	Standard deviation of pitch values, where values are min and max pitch in ST for each syllable
PitchRange	Estimated pitch range (in ST) (2%-98% percentiles of data in nuclei without discontinuities)
Gliss	Proportion (%) of syllables with large pitch movement (abs distance) >= 4ST)
Rises	Proportion (%) of syllables with pitch rise (>= 4ST)
Falls	Proportion (%) of syllables with pitch fall (<= -4ST)
NuclDur	Sum of durations for nuclei for this speaker
InterNuclDur	Sum of durations between successive nuclei for this speaker

	Prosogram script: Parameter descriptors extracted from https://sites.google.com/site/prosogram/home
TrajIntra	Pitch trajectory (sum of absolute intervals) within syllabic nuclei, divided by duration (in ST/s)
TrajInter	Pitch trajectory (sum of absolute intervals) between syllabic nuclei (except pauses or speaker interpausal units), divided by duration (in ST/s)
TrajPhon	Sum of TrajIntra and TrajInter, divided by phonation time (in ST/s)
TrajIntraZ	as for TrajIntra, but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)
TrajInterZ	as for TrajInter, but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)
TrajPhonZ	as for TrajPhon, but for pitch trajectory in standard deviation units on ST scale (z-score) (in sd/s)

APPENDIX B: Session level acoustic-prosodic parameters tested in linear regression equations

1	Parent-child emotion talk length (J)
2	Mother total speaking time (K)
3	Child total speaking time (L)
4	Total time of pauses (P)
5	Total number of pauses (Q)
6	Mother-child total overlap time (AB)
7	Child-mother total overlap time (AC)
8	Average speech unit time for mother (AF)
9	Average speech unit time for child (AG)
10	Average pause unit time in emotion talk (AH)
11	Percentage of time mother speaks (AK)
12	Percentage of time child speaks (AL)
13	Mother total talk time with mo overlaps added (AT)
14	Child total talk time with child initiated overlaps added (AU)
15	Mo initiated overlaps as a % of all overlaps (BD)
16	Ch initiated overlaps as a % of all overlaps (BE)
17	Mo initiated overlaps as a % of all overlap time (BH)
18	Ch initiated overlaps as a % of all overlap time (BI)
19	Total number of overlaps in this talk (BJ)
20	Mo initiated overlaps as a % of total time (BO)
21	Ch initiated overlaps as a % of total time (BP)
22	Mo initiated overlaps average time (BQ)
23	Ch initiated overlaps average time (BR)
24	Ch talk time incl overl but no pauses in % total (CR)
25	Ch initiated overl segments as a % of all overl segments (CT)
26	Ch initiated overl as a % of all overl time (CX)

27	Ch initiated overl as a % of all talk time (DD)
28	Total mo speech segments (DK)
29	Total ch speech segments (DL)
30	Mo segments with overl & gaps collapsed (DV)
31	Ch segments with overl & gaps collapsed (DW)
32	Mo percentage of all speech units & gaps collapsed (DY)
33	Mo & ch total segments & gaps collpased (DZ)
34	Mo total segments with ch overlaps & gaps collapsed (EA)
35	Ch total segments with mo overlaps & gaps collapsed (EB)
36	Mo inititated overl as a % of all segments & gaps collapsed (ED)
37	Ch initiated overl as a % of all segments & gaps collapsed (EE)
38	Difference Ch total speaking time SH - FH
39	Difference v0.2 Mo total speaking time SH - FH
40	Difference Mo Avge Talk Time
41	Difference Ch Avge Talk Time
42	Difference Ch-Mo Overlap SH-FH
43	Difference Mother overlap avge time second half vs first half of talk
44	Difference Mother % segments SH-FH
45	differencehalveshalvesMoOverlapsPercentTime
46	differencehalveshalvesMoOverlapsPercentunits
47	differencehalvesBQMoInitiatedOverlapsAvgeTime
48	differencehalvesBRChInitiatedOverlapsAvgeTime
49	PitchRange (in ST) based on 2 stylization values per nucleus (2%-98% percentiles of data in nuclei without discontinuities) - mother
50	PitchRange (in ST) based on 2 stylization values per nucleus (2%-98% percentiles of data in nuclei without discontinuities) - child
51	PitchBottom (in Hz) based on 2 stylization values per nucleus - mother
52	PitchBottom (in Hz) based on 2 stylization values per nucleus - child
53	Mean (in Hz) of raw pitch values (based on 2 raw F0 values per nucleus) - mother
54	Mean (in Hz) of raw pitch values (based on 2 raw F0 values per nucleus) - child
55	Median pitch (n Hz) of raw pitch values per syllable - mother

56	Median pitch (in Hz) of raw pitch values per syllable - child
57	Top 98 percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - mother
58	Top 98 percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - child
59	NuclDur (sum of durations for nuclei for this speaker - mother
60	NuclDur (sum of durations for nuclei for this speaker - child
61	Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - mother
62	Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - child
63	InterNuclDur (sum of durations between successive nuclei for this speaker - mother
64	InterNuclDur (sum of durations between successive nuclei for this speaker - child
65	PitchTop (estimated pitch top (in Hz) based on 2 stylization values per nucleus - mother
66	PitchTop (estimated pitch top (in Hz) based on 2 stylization values per nucleus - child
67	MeanOfST (mean of pitch values, where values are min and max pitch in ST for each syllable - mother
68	MeanOfST (mean of pitch values, where values are min and max pitch in ST for each syllable - child
69	StdevOfST (stdev of pitch values, where values are min and max pitch in ST for each syllable - mother
70	StdevOfST (stdev of pitch values, where values are min and max pitch in ST for each syllable - child
71	Gliss (proportion (%) of syllables with large pitch movement (abs(distance) >(4ST) - mother
72	Gliss (proportion (%) of syllables with large pitch movement (abs(distance) >(4ST) - child
73	Rises (proportion (%) of syllables with pitch rise (>(4ST) - mother
74	Rises (proportion (%) of syllables with pitch rise (>(4ST) - child
75	Falls (proportion (%) of syllables with pitch fall (<(-4ST) - mother
76	Falls (proportion (%) of syllables with pitch fall (<(-4ST) - child
77	SpeechRate (estimated speech rate (in syll/s) (nrofnuclei/phonationtime - mother
78	SpeechRate (estimated speech rate (in syll/s) (nrofnuclei/phonationtime - child
79	TrajInterZ (pitch trajectory (sum of absolute intervals) between syllabic nuclei (except pauses or speaker units), divided by duration (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - mother
80	TrajInterZ (pitch trajectory (sum of absolute intervals) between syllabic nuclei (except pauses or speaker units), divided by duration (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - child
81	TrajIntraZ (pitch trajectory (sum of absolute intervals) within syllabic nuclei, divided by duration (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - mother

82	TrajIntraZ (pitch trajectory (sum of absolute intervals) within syllabic nuclei, divided by duration (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - child
83	TrajPhonZ (sum of TrajIntra and TrajInter, divided by phonation time (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - mother
84	TrajPhonZ (sum of TrajIntra and TrajInter, divided by phonation time (in ST/s) in standard deviation units on ST scale (z-score) (in sd/s) - child
85	Number of speaker segments - mother
86	Number of speaker segments - child
87	Number of speaker units - child speaks over mother
88	Number of speaker units - mother speaks over child
89	Average pitch min (Hz) across nuclei before stylization - mother
90	Average pitch min (Hz) across nuclei before stylization - child
91	Average pitch max (Hz) across nuclei before stylization - mother
92	Average pitch max (Hz) across nuclei before stylization - child
93	Pitch median (Hz) across nuclei before stylization - mother
94	Pitch median (Hz) across nuclei before stylization - child
95	Pitch mean (Hz) across nuclei before stylization - mother
96	Pitch mean (Hz) across nuclei before stylization - child
97	Average pitch min (Hz) across nuclei after stylization - mother
98	Average pitch min (Hz) across nuclei after stylization - child
99	Average pitch max (Hz) across nuclei after stylization - mother
100	Average pitch max (Hz) across nuclei after stylization - child
101	Average intensity peak (dB) across nuclei - mother
102	Average intensity peak (dB) across nuclei - child
103	Average intensity peak (dB) across nuclei - child speaks over mother
104	Average intensity peak (dB) across nuclei - mother speaks over child
105	Average pitch midpoint of unit - mother
106	Average F1 midpoint of unit - mother
107	Average F2 midpoint of unit - mother
108	Average intensity midpoint of unit - mother

109	Average unit duration - mother
110	Average pitch midpoint of unit - child
111	Average F1 midpoint of unit - child
112	Average F2 midpoint of unit - child
113	Average intensity midpoint of unit - child
114	Average unit duration - child
115	Average intensity midpoint of unit - child overlaps mother
116	Average intensity midpoint of unit - mother overlaps child
117	Average unit duration - child overlaps mother
118	Average unit duration - mother overlaps child
119	Average unit duration - conversational pauses
120	Intrasyllabic interval (ST) within nucleus - mother
121	Intrasyllabic interval (ST) within nucleus - child
122	Intrasyllabic interval (ST) within nucleus - child speaks over mother
123	Intrasyllabic interval (ST) within nucleus - mother speaks over child
124	Intersyllabic interval (ST) between end of previous nucleus and start of current one - mother
125	Intersyllabic interval (ST) between end of previous nucleus and start of current one - child
126	Intersyllabic interval (ST) between end of previous nucleus and start of current one - child speaks over mother
127	Intersyllabic interval (ST) between end of previous nucleus and start of current one - mother speaks over child
128	Sum of upward pitch intervals (ST) of tonal segments in nucleus - mother
129	Sum of upward pitch intervals (ST) of tonal segments in nucleus - child
130	Sum of upward pitch intervals (ST) of tonal segments in nucleus - child speaks over mother
131	Sum of upward pitch intervals (ST) of tonal segments in nucleus - mother speaks over child
132	Sum of downward pitch intervals (ST) of tonal segments in nucleus - mother
133	Sum of downward pitch intervals (ST) of tonal segments in nucleus - child
134	Sum of downward pitch intervals (ST) of tonal segments in nucleus - child speaks over mother
135	Sum of downward pitch intervals (ST) of tonal segments in nucleus - mother speaks over child
136	Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up) - mother
137	Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up) - child

138	Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up) - child speaks over mother
139	Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up) - mother speaks over child
140	Pitch-range normalised pitch value of start of nucleus - mother
141	Pitch-range normalised pitch value of start of nucleus - child
142	Pitch-range normalised pitch value of start of nucleus - child speaks over mother
143	Pitch-range normalised pitch value of start of nucleus - mother speaks over child
144	Duration of nucleus - mother
145	Duration of nucleus - child
146	Duration of nucleus - child speaks over mother
147	Duration of nucleus - mother speaks over child
148	Sp1AVGEmaxf0 (ProsPro)
149	Sp1AVGEminf0 (ProsPro)
150	Sp1AVGEexcursionsize (ProsPro)
151	Sp1AVGEmeanf0 (ProsPro)
152	Sp1AVGEfinalf0 (ProsPro)
153	Sp1AVGEmeanintensity (ProsPro)
154	Sp1AVGEduration (ProsPro)
155	Sp1AVGEmaxvelocity (ProsPro)
156	Sp1AVGEfinalvelocity (ProsPro)
157	Sp1AVGEmaxf0locms (ProsPro)
158	Sp1AVGEmaxf0locratio (ProsPro)
159	Sp2AVGEmaxf0 (ProsPro)
160	Sp2AVGEminf0 (ProsPro)
161	Sp2AVGEexcursionsize (ProsPro)
162	Sp2AVGEmeanf0 (ProsPro)
163	Sp2AVGEfinalf0 (ProsPro)
164	Sp2AVGEmeanintensity (ProsPro)
165	Sp2AVGEduration (ProsPro)
166	Sp2AVGEmaxvelocity (ProsPro)

167	Sp2AVGEfinalvelocity (ProsPro)
168	Sp2AVGEmaxf0locms (ProsPro)
169	Sp2AVGEmaxf0locratio (ProsPro)
170	Sp1AVGEh1h2
171	Sp1AVGEh1h2asterix
172	Sp1AVGEH1A1
173	Sp1AVGEH1A3
174	Sp1AVGEcpp
175	Sp1AVGEcenterofgravity
176	Sp1AVGEHammarbergindex
177	Sp1AVGEenergybelow500Hz
178	Sp1AVGEenergybelow1000Hz
179	Sp1AVGEFdispersion13
180	Sp1AVGEFdispersion15
181	Sp1AVGEmedianpitch
182	Sp1AVGEjitter
183	Sp1AVGEshimmer
184	Sp1AVGEharmonicity
185	Sp1AVGEEnergyProfile250Hz
186	Sp1AVGE500
187	Sp1AVGE750
188	Sp1AVGE1000
189	Sp1AVGE1250
190	Sp1AVGE1500
191	Sp1AVGE1750
192	Sp1AVGE2000
193	Sp1AVGE2250
194	Sp1AVGE2500
195	Sp1AVGE2750

196	Sp1AVGE3000
197	Sp1AVGE3250
198	Sp1AVGE3500
199	Sp1AVGE3750
200	Sp2AVGEh1h2
201	Sp2AVGEh1h2asterix
202	Sp2AVGEH1A1
203	Sp2AVGEH1A3
204	Sp2AVGEcpp
205	Sp2AVGEcenterofgravity
206	Sp2AVGEHammarbergindex
207	Sp2AVGEenergybelow500Hz
208	Sp2AVGEenergybelow1000Hz
209	Sp2AVGEFdispersion13
210	Sp2AVGEFdispersion15
211	Sp2AVGEmedianpitch
212	Sp2AVGEjitter
213	Sp2AVGEshimmer
214	Sp2AVGEharmonicity
215	Sp2AVGEEnergyProfile250Hz
216	Sp2AVGE500
217	Sp2AVGE750
218	Sp2AVGE1000
219	Sp2AVGE1250
220	Sp2AVGE1500
221	Sp2AVGE1750
222	Sp2AVGE2000
223	Sp2AVGE2250
224	Sp2AVGE2500

225	Sp2AVGE2750
226	Sp2AVGE3000
227	Sp2AVGE3250
228	Sp2AVGE3500
229	Sp2AVGE3750
230	Sp12AVGEh1h2
231	Sp12AVGEh1h2asterix
232	Sp12AVGEH1A1
233	Sp12AVGEH1A3
234	Sp12AVGEcpp
235	Sp12AVGEcenterofgravity
236	Sp12AVGEHammarbergindex
237	Sp12AVGEenergybelow500Hz
238	Sp12AVGEenergybelow1000Hz
239	Sp12AVGEFdispersion13
240	Sp12AVGEFdispersion15
241	Sp12AVGEmedianpitch
242	Sp12AVGEjitter
243	Sp12AVGEshimmer
244	Sp12AVGEharmonicity
245	Sp12AVGEEnergyProfile250Hz
246	Sp12AVGE500
247	Sp12AVGE750
248	Sp12AVGE1000
249	Sp12AVGE1250
250	Sp12AVGE1500
251	Sp12AVGE1750
252	Sp12AVGE2000
253	Sp12AVGE2250

254	Sp12AVGE2500
255	Sp12AVGE2750
256	Sp12AVGE3000
257	Sp12AVGE3250
258	Sp12AVGE3500
259	Sp12AVGE3750
260	Sp12AVGEmaxf0 (ProsPro)
261	Sp12AVGEminf0 (ProsPro)
262	Sp12AVGEexcursionsize (ProsPro)
263	Sp12AVGEmeanf0 (ProsPro)
264	Sp12AVGEfinalf0 (ProsPro)
265	Sp12AVGEmeanintensity (ProsPro)
266	Sp12AVGEduration (ProsPro)
267	Sp12AVGEmaxvelocity (ProsPro)
268	Sp12AVGEfinalvelocity (ProsPro)
269	Sp12AVGEmaxf0locms (ProsPro)
270	Sp12AVGEmaxf0locratio (ProsPro)
271	Sp21AVGEmaxf0 (ProsPro)
272	Sp21AVGEminf0 (ProsPro)
273	Sp21AVGEexcursionsize (ProsPro)
274	Sp21AVGEmeanf0 (ProsPro)
275	Sp21AVGEfinalf0 (ProsPro)
276	Sp21AVGEmeanintensity (ProsPro)
277	Sp21AVGEduration (ProsPro)
278	Sp21AVGEmaxvelocity (ProsPro)
279	Sp21AVGEfinalvelocity (ProsPro)
280	Sp21AVGEmaxf0locms (ProsPro)
281	Sp21AVGEmaxf0locratio (ProsPro)
282	Sp21AVGEh1h2

283	Sp21AVGEh1h2asterix
284	Sp21AVGEH1A1
285	Sp21AVGEH1A3
286	Sp21AVGEcpp
287	Sp21AVGEcenterofgravity
288	Sp21AVGEHammarbergindex
289	Sp21AVGEenergybelow500Hz
290	Sp21AVGEenergybelow1000Hz
291	Sp21AVGEFdispersion13
292	Sp21AVGEFdispersion15
293	Sp21AVGEmedianpitch
294	Sp21AVGEjitter
295	Sp21AVGEshimmer
296	Sp21AVGEharmonicity
297	Sp21AVGEEnergyProfile250Hz
298	Sp21AVGE500
299	Sp21AVGE750
300	Sp21AVGE1000
301	Sp21AVGE1250
302	Sp21AVGE1500
303	Sp21AVGE1750
304	Sp21AVGE2000
305	Sp21AVGE2250
306	Sp21AVGE2500
307	Sp21AVGE2750
308	Sp21AVGE3000
309	Sp21AVGE3250
310	Sp21AVGE3500
311	Sp21AVGE3750

Notes. Speaker 1 refers to the mother and Speaker 2 to the child; 12 refers to the overlap unit initiated by the child while the mother was talking and 21 refers to the overlap unit initiated by the mother while the child was talking. Units reflect speech segments that are terminated by a pause. Adjoining units of speech by the same speaker constituted a speech turn. F-H refers to the first half of the emotion talk and S-H refers to second half of the emotion talk.

APPENDIX C: Correlations between child measures

	Child measure	1	2	3	4	5	6	7	8	9	10	11
1	ICU Total	1										
2	ICU Callous	.888**	1									
3	ICU Unemotional	.521**	.321**	1								
4	GEM Aff Em	-.519**	-.553**	-.087	1							
5	GEM Cog Em	-.789**	-.740**	-.281*	.518**	1						
6	ERC Lability	.694**	.644**	.169	-.454**	-.576**	1					
7	ERC EmotReg	-.719**	-.626**	-.463**	.293*	.582**	-.590**	1				
8	SDQ Conduct	.532**	.522**	-.004	-.415**	-.446**	.737**	-.455**	1			
9	SDQ Emotions	.293*	.206	.153	.085	-.111	.411**	-.463**	.298**	1		
10	SDQ Prosocial	-.652**	-.579**	-.225	.478**	.600**	-.517**	.692**	-.414**	-.307**	1	
11	EVT	-.214	-.149	-.206	-.045	.035	-.109	.117	-.130	-.029	.029	1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

APPENDIX D: Time series acoustic-prosodic parameters tested in logistic regression equations*

	Parameter	Parameter descriptor
1	medpitch	Median pitch (Hertz) in each speech turn
2	F0mean	The mean F0 value in Hertz (Hz) within each turn
3	F0midpt	The F0 value in Hertz (Hz) at the midpoint of each turn
4	F0min	The minimum F0 value in Hertz (Hz) within each turn
5	F0max	The maximum F0 value in Hertz (Hz) within each turn.
6	F1midpt	The first formant value at the midpoint of each turn. A formant is a concentration of acoustic energy around a particular frequency in the speech signal (Praat). Formants correspond to resonances (vibrations) made in a particular part of the vocal tract and occur at roughly 1000Hz intervals. The first formant is
7	F2midpt	The second formant value at the midpoint of each turn. Formants reflect a concentration of energy at a certain pitch. The second formant is associated with the air above and in front of the tongue (the hump of the tongue to the tip of the lips).
8	excursion	The difference between maximum F0 and minimum F0 measured in semitones (ST)
9	maxf0locratio	Relative location of the F0 peak as a proportion to the duration of the turn (Xu)
10	velocityfinal	F0 velocity near the interval offset in semitones/s (ST) within each turn
11	velocitymax	Maximum F0 velocity in semitones/s (ST) within each turn.
12	F0final	The F0 value near the turn offset, in Hertz (Hz). The offset is the temporal relation between a turn and its response, measured in milliseconds (Stivers et al, 2009)
13	f0maxlocms	Time of the F0 peak relative to the onset of the turn in milliseconds (ms) (Xu
14	jitter	The cycle-to-cycle rapid micro-variations of pitch. Specifically, it is a measure of frequency variability in comparison to F0 (calculated as the mean absolute difference between consecutive periods, divided by the mean period). Jitter is considered involuntary and is considered to be an indicator of stressor-provoked
15	shimmer	The cycle-to-cycle micro-variations of amplitude (loudness) in successive glottal cycles. It is calculated as the mean absolute difference between amplitudes of consecutive periods, divided by mean amplitude. It car serve as an indicator of underlying stress in human speech.
16	cpp	Cepstral Peak Prominence (CPP) is a measure of the degree of regularity or periodicity in the voice signal. Perceptually, it is strongly negatively correlated with breathy ratings (the correlation of breathy rating and CPP is roughly –0.92, indicating that as breathiness increases, CPP decreases
17	centerofgrav	Center of gravity (CG) measures the tilt of the spectrum (Surendran & Levow, 2008) measured in Hertz. A measure for the average height of frequencies in a spectrum, e.g., for a sine wave with a frequency of 377 Hz, the centre of gravity is 377 Hz
18	harmonicity	Harmonics-to-Noise Ratio (HNR) is a measure of the proportion of harmonic sound to noise in the voice measured in decibels (Ferrand, 2007). HNR quantifies the relative amount of additive noise (Awen & Frankel, 1994). The lower the HNR, the more noise in the voice, e.g., laryngeal pathology may lead to
19	h1h2	Amplitude difference between 1st and 2nd harmonics
20	h1bh2b	Formant-adjusted h1-h2
21	H1A1	Amplitude difference between 1st harmonic and 1st formant
22	H1A3	Amplitude difference between 1st harmonic and 3rd formant

** Parameters extracted using ProsodyPro with descriptors taken from Xu (2013)*
http://www.homepages.ucl.ac.uk/~uclyyix/ProsodyPro/

	Parameter	Parameter descriptor
23	Hammarberg	Difference in maximum energy between 0-2000 Hz and 2000-5000 Hz, measured in decibels.
24	Fdisp1_3	Average distance between adjacent formants up to the third formant (F3). A formant is a concentration of acoustic energy around a particular frequency in the speech wave.
25	Fdisp1_5	Average distance between adjacent formants up to fifth formant (F5). A formant is a concentration of acoustic energy around a particular frequency in the speech wave. Formants occur at roughly 1000Hz intervals.
26	intensmean	The mean intensity in decibels (dB) within each turn
27	intensmidpt	The intensity value in decibels (dB) at the midpoint of each turn.
28	energyprof250	Energy present in voiced segments at 250Hz
29	energybel500	Energy of voiced segments below 500Hz (proportion between energy below 500 Hz and total energy (up to 4000 Hz). Intelligibility and novel word learning is compromised in children with stimulus speech under 500Hz.
30	energybel1000	Energy of voiced segments below 1000Hz (proportion between energy below 1000 Hz and total energy (up to 4000 Hz).
31	E500	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 0–500
32	E750	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 250-750
33	E1000	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 500-1000
34	E1250	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 1250-1750
35	E1500	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 1000-1500
36	E1750	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 1250-1750
37	E2000	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 1500-2000
38	E2250	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 1750-2250
39	E2500	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 2000–2500
40	E2750	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 2250-2750
41	E3000	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 2500-3000
42	E3250	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 27500-3250
43	E3500	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 3000-3500
44	E3750	Fifteen signal energy values were computed from overlapping spectral bands of 500-Hz bandwidth: 3250-3750

**Parameters extracted using ProsodyPro with descriptors taken from Xu (2013)*
http://www.homepages.ucl.ac.uk/~uclyyix/ProsodyPro/

APPENDIX E: Cutoffs used for additional child and maternal clinical factors in linear and logistic regression equations

Variable	Median	Mean	Max	Min	Cutoff value	Reference
ICU Callous	7	7.1	18	2	>= 8	ICU subscale all ages & sex cutoff Kimonis et al, 2014)
ICU Unemotional	4	4.17	11	0	>= 8	ICU subscale all ages & sex cutoff Kimonis et al, 2014)
ICU Uncaring	6	6.56	17	0	>= 8	ICU subscale all ages & sex cutoff Kimonis et al, 2014)
ICU Careless	8	7.78	17	3	>= 8	ICU subscale all ages & sex cutoff Kimonis et al, 2014)
SDQ Emotions	2	3.13	10	0	>= 4	SDQ Clinical norms (Goodman, 1997; SDQ website)
SDQ Conduct	4	3.82	9	0	>= 3	SDQ Clinical norms (Goodman, 1997; SDQ website)
SDQ Prosocial	6	6.06	10	0	>= 7	SDQ Clinical norms (Goodman, 1997; SDQ website)
Child age (months)	68	72.11	107	48	>= 60	5 years
Child gender	0	0.33	1	0	>= 1	Dichotomised variable
Mother mental health history	0	0.25	1	0	>= 1	Dichotomised variable

APPENDIX F: Additional statistical data for the logistic regression models that met significance for main and interaction effects between child characteristics and child and maternal factors (Chapter 5)

Additional statistical data for Table 5.1: ICU Total significant main and interaction effects for cointegration with both lower order relatives

No.	Parameter	Predictor X1	Predictor X2	*p* X1	*p* X2	*p* D00	*p* D01	*p* D10	*p* D11	Null Dev.	Null Dev. df	Res. Dev.	Res. Dev. df	const_se	c_X1_se	c_X2_se	c_D00_se	c_D01_se	c_D10_se	c_D11_se
1	coint medpitch	ICUTotal		0.003						55.475	63	42.583	62	1.492	0.043					
2	coint medpitch	ICUTotal	DASSDep	0.043	1.738					83.612	61	36.338	59	0.048	0.067	3.545				
3	coint medpitch	Maternal MH Hx	ICUTotal	0.004	1.639					55.374	61	37.357	59	0.885	0.044	3.785				
4	coint 0.01 F0max	Childage	ICUTotal	0.032	0.016		0.035	0.046		59.598	58	47.450	54	2.279	0.036	0.055		1.484	1.115	
5	coint 0.01 energyprof250	ERCLability	ICUTotal	0.024	0.003		0.024			86.459	63	74.185	60	0.759	0.056	0.045		1.052		
6	coint 0.01 energyprof250	SDQConduct	ICUTotal	0.017	0.003		0.009			87.492	64	72.982	61	0.772	0.189	0.037		1.310		
7	coint 0.01 Fdisp1 5	SDQEmotions	ICUTotal	0.001	0.003		0.001	0.010		64.144	62	43.429	58	1.206	0.341	0.070		1.693	1.660	
8	coint 0.01 h1bh2b	ICUTotal	DASSDep	0.026	0.008	0.007		0.041		66.743	62	46.623	58	2.928	0.057	0.144	2.129		1.624	
9	coint 0.01 maxf0locratio	ICUTotal	CS13Dismissive	0.001	0.030			0.004		70.169	57	52.296	54	1.071	0.057	0.420			1.270	

Note. All predictors and Chi *p* significant < .05 with ICU Total and the second predictor as the lower order relatives in these models. Where β X1 and β X2 only are reported these represent main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term. *p* = p value; Dev. = deviance; df = degrees of freedom; se = standard error of coefficients.

Additional statistical data for Table 5.2: ICU Total significant main and interaction effects for cointegration with CU only as the lower order relative

No.	Parameter	Predictor X1	Predictor X2	*p* X1	*p* X2	*p* D00	*p* D01	*p* D10	*p* D11	Null Dev.	Null Dev. df	Res. Dev.	Res. Dev. df	const_se	c_X1_se	c_X2_se	c_D00_se	c_D01_se	c_D10_se	c_D11_se
1	coint F2midpt	ICUTotal	CS9Warmth	0.008			0.023			58.024	71	48.494	69	2.068	0.054			1.310		
2	coint F2midpt	ICUTotal	DASSDep	0.007		0.018				58.024	71	47.894	69	2.042	0.053		1.294			
3	coint F2midpt	ICUTotal	DASSStress	0.004		0.003				58.024	71	42.827	69	2.076	0.054		1.385			
4	coint 0.01 energyprof250	ICUTotal	CS13Dismissive	0.012			0.021		0.609	87.492	64	76.963	62	0.030				0.675		2.511
5	coint energybel500	ICUTotal	DASSDep	0.025	0.041				0.926	29.925	63	20.693	61	0.094		2.731				2.616
6	coint energybel500	ICUTotal	DASSStress	0.024	0.023				0.926	29.925	63	18.190	61	0.095		2.831				2.632
7	coint Hammarberg	ICUTotal	DASSDep							62.182	64	50.683	62							
8	coint Hammarberg	ICUTotal	CS13Dismissive	0.040			0.047		*0.826*	62.182	64	53.373	62	0.030				1.109		3.026
9	coint Hammarberg	ICUTotal	CS9Warmth	0.008		0.016			*0.826*	62.182	64	52.292	62	0.052			1.233			3.267
10	coint E1750	ICUTotal	CS13Dismissive	0.011	0.006				0.841	59.106	64	48.194	62	0.050		1.278				3.294
11	coint E2500	ICUTotal	CogEm100	0.029		0.040			0.912	39.825	63	32.089	61	0.126			1.847			-1.650
12	coint 0.01 cpp	ICUTotal	CS13Dismissive	0.009			0.011		0.754	72.549	64	56.746	62	0.032				1.126		3.122
13	coint 0.01 medpitch	ICUTotal	PFMSSWarmth	0.003			0.047		0.632	83.591	63	72.868	61	0.032				0.694		3.213
14	coint 0.01 intensmidpt	ERCEmotReg	ICUTotal		0.008			0.009		78.704	71	68.706	69	1.577		0.044			1.031	
15	coint 0.01 F0max	ERCEmotReg	ICUTotal		0.017			0.015		59.598	58	50.898	56	1.983		0.056			1.260	
16	coint F2midpt	ERCEmotReg	ICUTotal		0.005			0.014		58.024	71	47.151	69	2.151		0.056			1.393	
17	coint medpitch	ICUCallous	ICUUnemotional	0.006			0.030		0.853	55.475	63	44.001	61	0.138				1.097		3.678

Note. All predictors and Chi *p* significant < .05 but ICU Total is the only lower order relative in these interaction models. Where β X1 and β X2 only are reported these represent main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term. *p* = p value*;* Dev. = deviance; df = degrees of freedom; se = standard error of coefficients.

Additional statistical data for Table 5.3: GEM empathy significant main effects and significant interaction effects for cointegration with both lower order relatives

No.	Parameter	Predictor X1	Predictor X2	*p* X1	*p* X2	*p* D00	*p* D01	*p* D10	*p* D11	Null Dev.	Null Dev. df	Res. Dev.	Res. Dev. df	const_se	c_X1_se	c_X2_se	c_D00_se	c_D01_se	c_D10_se	c_D11_se
1	coint medpitch	CogEm100		0.002						50.397	58	35.321	57	7.567	0.076					
2	coint F0max	CogEm100		0.016						41.654	53	34.286	52	7.348	0.073					
3	coint 0.01 energyprof250	CogEm100		0.007						81.503	59	72.515	58	4.553	0.043					
4	coint F2midpt	AffEm100		0.008						56.469	66	48.511	65	2.758	0.029					
5	coint F0max	GEM100		0.005						42.198	55	31.953	54	1.432	0.015					
6	coint E2000	GEM100		0.015						43.474	60	36.974	59	1.298	0.013					
7	coint F0mean	GEM100		0.015						55.044	54	48.153	53	1.262	0.012					
8	coint F0max	AffEm100		0.021						41.654	53	35.580	52	3.039	0.032					
9	coint F0max	AffEm100	DASSDep	0.031	0.017					37.193	51	19.879	49	4.935	0.055	0.081				
10	coint 0.01 medpitch	GEM100	AffEm100	0.013	0.048					78.903	58	68.050	56	3.749	0.033	0.069				

Note. All predictors and Chi *p* significant < .05 with GEM empathy and the second predictor as the lower order relatives in these models. Where β X1 and β X2 only are reported these represent main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term. *p* = p value*;* Dev. = deviance; df = degrees of freedom; se = standard error of coefficients.

Additional statistical data for Table 5.4: GEM significant interaction effects for cointegration with GEM only as the lower order relative

No.	Parameter	Predictor X1	Predictor X2	*p* X1	*p* X2	*p* D00	*p* D01	*p* D10	*p* D11	Null Dev.	Null Dev. df	Res. Dev.	Res. Dev. df	const_se	c_X1_se	c_X2_se	c_D00_se	c_D01_se	c_D10_se	c_D11_se
1	coint F0max	SDQConduct	CogEm100		0.007				0.024	41.654	53	27.792	51	12.549		0.129				1.822
2	coint F2midpt	AffEm100	DASSStress	0.002				0.015		56.469	66	41.966	64	3.743	0.041				1.179	
3	coint E2000	GEM100	DASSAnx	0.005				0.043		43.474	60	32.398	58	1.634	0.019				1.512	
4	coint E1750	AffEm100	CS13Dismissive	0.005				0.036		50.725	59	39.459	57	4.050	0.046				1.314	
5	coint E1750	AffEm100	CS8Intune	0.006					0.044	50.725	59	39.895	57	4.067	0.046					1.325
6	coint E1750	AffEm100	CS9Warmth	0.006					0.050	50.725	59	40.132	57	4.100	0.046					1.338
7	coint E1750	AffEm100	DASSAnx	0.006				0.047		50.725	59	39.951	57	4.134	0.047				1.343	
8	coint E1750	AffEm100	DASSDep	0.004				0.027		50.725	59	38.726	57	4.188	0.047				1.388	
9	coint E1750	AffEm100	ParentWarmthExpres	0.005				0.017		50.725	59	38.006	57	3.934	0.044				1.265	
10	coint E1750	CogEm100	DASSDep	0.027				0.013		50.725	59	42.353	57	7.900	0.081				1.365	

Note. All predictors and Chi *p* significant < .05 but GEM empathy is the only lower order relative in these interaction models. Where β X1 and β X2 only are reported these represent main or separate partial effects; where the model also includes an interaction coefficient (β D00, β D01, β D10, β D11) then β X1 and β X2 represent the lower order relatives to the interaction term. *p* = p value*;* Dev. = deviance; df = degrees of freedom; se = standard error of coefficients.

Additional statistical data for Table 5.5: ODD significant interaction effects for cointegration with models for lower order relatives

No.	Parameter	Predictor X1	Predictor X2	*p* X1	*p* X2	*p* D00	*p* D01	*p* D10	*p* D11	Null Dev.	Null Dev. df	Res. Dev.	Res. Dev. df	const_se	c_X1_se	c_X2_se	c_D00_se	c_D01_se	c_D10_se	c_D11_se
1	coint 0.01 F2midpt	DiagnosisODD	DASSStress	0.009	0.008	0.012			0.025	82.483	70	69.253	66	1.536	1.409	0.075	1.516			1.188
2	coint 0.01 cpp	DiagnosisODD	ERCEmotReg	0.004					0.004	77.048	68	62.067	66	0.741	0.856					0.750
3	coint 0.01 cpp	DiagnosisODD	CS13Dismissive	0.008				0.011		77.048	68	63.800	66	0.741	0.836				0.839	
4	coint 0.01 jitter	DiagnosisODD	AffEm100	0.036				0.009		82.565	65	73.155	63	0.449	0.867				0.851	

Note. All predictors and Chi *p* met significance, but with the exception of the second formant (F2midpt), ODD is the only lower order relative in these interaction models. *p* = p value*;* Dev. = deviance; df = degrees of freedom; se = standard error of coefficients

APPENDIX G: Granger causality results and child callous-unemotional (CU) traits

ICU and the probability of the mother Ganger-causing the child's values

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	Granger_x_on_y_energybel500	-6.785	0.130	ICUTotal							0.242	31.845	0.001	0.36%	0.36%	70.65%	70.65%	7.59%
2	Granger_x_on_y_E2750_0.1	-5.281	0.114	ICUTotal							0.196	51.338	0.001	1.40%	1.40%	80.89%	80.89%	12.66%
3	Granger_x_on_y_E3500_0.1	-4.839	0.108	ICUTotal							0.181	57.993	0.001	2.06%	2.06%	82.63%	82.63%	15.19%
4	Granger_x_on_y_medpitch_0.1	-1.160	0.069	ICUTotal	-1.514	CS13Dismissive					0.183	64.633	0.005	11.40%	0.03%	80.41%	0.95%	17.72%
5	Granger_x_on_y_E2750_0.1	-8.677	0.044	Childage	0.115	ICUTotal					0.272	48.873	0.006	0.39%	54.91%	5.02%	94.22%	12.66%
6	Granger_x_on_y_velocityfinal_0.1	8.392	-0.211	Childage	0.117	ICUTotal		-3.431			0.290	41.019	0.012	33.48%	84.97%	0.00%	0.07%	8.86%
7	Granger_x_on_y_h1bh2b_0.1	-2.185	0.205	ERCLability	-0.182	ICUTotal					0.208	30.658	0.033	1.75%	0.00%	97.75%	0.49%	5.06%
8	Granger_x_on_y_E1250_0.1	-1.081	0.740	SDQConduct	-0.206	ICUTotal					0.253	40.749	0.018	5.07%	0.00%	97.66%	0.14%	10.13%
9	Granger_x_on_y_E2750_0.1	-8.375	0.629	SDQEmotions	0.087	ICUTotal		3.213			0.320	48.079	0.001	0.05%	48.65%	21.33%	95.36%	12.66%
10	Granger_x_on_y_centerofgrav_0.1	-2.779	0.223	SDQTotalDiff	-0.125	ICUTotal					0.163	52.088	0.021	3.04%	0.01%	98.42%	10.52%	12.66%
11	Granger_x_on_y_h1bh2b_0.1	-5.405	0.470	SDQTotalDiff	-0.273	ICUTotal					0.349	26.341	0.033	0.10%	0.00%	99.99%	0.97%	5.06%
12	Granger_x_on_y_Fdisp1_5	-6.663	0.120	ICUTotal		DASSStress	3.478				0.190	43.699	0.045	10.85%	0.37%	60.12%	60.12%	10.13%

Notes: β X1 and β X2 are main or separate partial effects; where the model includes interaction coefficients (β D00, β D01, β D10, β D11) then β X1 and β X2 refers to the lower order relatives. β D00 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 below the clinical cutoff; β D0 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 above the clinical cutoff; β D10 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 below the clinical cutoff; β D11 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 above the clinical cutoff. LR^2 = Likelihood Ratio test. AIC = Akaike Information Criterion. SGoF = Sequential Goodness of Fit multi-test correction. EGA = Extreme Group Analysis.

ICU and the probability of the child Ganger-causing the mother's values

No.	Parameter	Constant	β X1	Predictor X1	β X2	Predictor X2	β D00	β D01	β D10	β D11	LR^2	AIC	Chi *p* SGoF	EGA 00 Prob	EGA 01 Prob	EGA 10 Prob	EGA 11 Prob	Mean (Y)
1	Granger_y_on_x_H1A3	-6.662	0.110	ICUTotal							0.180	24.662	0.045	0.34%	0.34%	45.08%	45.08%	5.06%
2	Granger_y_on_x_h1h2_0.1	-6.278	0.123	ICUTotal							0.221	36.566	0.005	0.56%	0.56%	72.20%	72.20%	8.86%
3	Granger_y_on_x_intensmidpt_0.1	-0.530	-0.163	ICUTotal	0.245	DASSDep			2.905		0.224	50.120	0.007	11.98%	99.91%	0.07%	25.32%	11.39%
4	Granger_y_on_x_E2750	0.267	0.239	ICUTotal	-3.709	PFMSSWarmth		5.055	-6.941		0.242	41.704	0.018	21.60%	2.53%	97.65%	96.27%	7.59%
5	Granger_y_on_x_shimmer_0.1	8.158	0.103	ICUTotal	-4.309	PFMSSWarmth	-4.423		-6.256		0.282	52.283	0.011	58.81%	2.10%	97.57%	79.07%	12.66%
6	Granger_y_on_x_shimmer_0.1	0.914	0.107	ICUTotal	-2.127	PFMSSWarmth			-2.703		0.175	56.577	0.034	43.71%	1.09%	91.52%	69.58%	12.66%
7	Granger_y_on_x_F0max_0.1	1.523	-0.307	ICUTotal		ParentWarmthExpress				6.008	0.291	32.038	0.044	22.48%	22.48%	0.00%	0.00%	7.59%
8	Granger_y_on_x_intensmidpt_0.1	0.545		ERCEmotReg	-0.174	ICUTotal		4.000			0.194	50.386	0.007	26.53%	0.33%	26.53%	0.01%	11.39%
9	Granger_y_on_x_E2750	-8.222		Mo MH Hx	0.138	ICUTotal	4.446				0.222	38.552	0.012	7.35%	48.00%	0.09%	48.00%	7.59%

Notes: β X1 and β X2 — in the absence of interaction coefficients in the model (β D00, β D01, β D10, β D11) — are main or separate partial effects; where the model includes interaction coefficients then β X1 and β X2 refers to the lower order relatives. β D00 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 below the clinical cutoff; β D0 refers to the coefficient for the interaction between X1 and X2 for values of X1 below the clinical cutoff and for X2 above the clinical cutoff; β D10 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 below the clinical cutoff; β D11 refers to the coefficient for the interaction between X1 and X2 for values of X1 above the clinical cutoff and for X2 above the clinical cutoff. LR^2 = Likelihood Ratio test. AIC = Akaike Information Criterion. SGoF = Sequential Goodness of Fit multi-test correction. EGA = Extreme Group Analysis.

APPENDIX H: Acoustic-prosodic features in the emotion talk of high prosocial and regulated children

6.7 Results: Acoustic-prosodic features in the emotion talk of prosocial children

6.7.1 Prosocial behaviour and significant associations in the child's speech

Comparative study was made of the acoustic-prosodic features associated with prosocial behaviour due to the strong positive associations between mother-child synchrony and prosocial outcomes established in the literature (e.g., Rennung & Göritz, 2016) Child prosocial behaviour was related to fewer child speech turns, a slower child speech rate, and a lower percentage of child speaking time overall (Table 6.1). Prosocial behaviour was also associated with a lower child pitch floor and this relationship remained significant after controlling for child age (-.234, $p < .05$). Significant relationships show a wider child pitch range (ST), a lower pitch floor, a slower speech rate, lower intensity at the midpoint of child turns, less child jitter and shimmer. There were no significant associations with child age on these features.

6.7.2 Prosocial behaviour and the discriminant function of the child's speech

Regarding the discriminant function in the child's acoustic-prosodic expression, The overall Chi-square test was significant (Wilks λ = .596, Chi-square = 38.264, df = 10, Canonical correlation = .635, $p < .001$) and the single function extracted accounted for 40.3% of variance between groups, leaving 59.7% of the variance unexplained.

The structure matrix (Table 6.23) indicated that the parameters with the strongest correlations with the function were child pitch features, particularly more gliss (large pitch movements within syllables) and less falls (percentage of syllables with falls less than 4ST), and fewer child speech turns, indicating that function in the child's speech that best discriminates child prosocial behaviour might be conceptualised as an expressive but smoother pitch profile with less child speaking time.

Table 6.23

Structure matrix from the discriminant analysis for prosocial behaviour and the child's parameters

	Function
	1
Gliss (%) of syllables with large pitch movement (abs(distance) >= 4ST) - child[a]	0.346
Sum of downward pitch intervals (ST) of tonal segments in nucleus - child	-0.361
Number of speaker turns - child	-0.334
Sum of absolute pitch interval (ST) in nucleus (rises and falls add up) - child[a]	0.32
Falls (%) of syllables with pitch fall (<= -4ST) - child[a]	0.317
Total time of pauses (P)[a]	-0.305
Duration of nucleus - child[a]	0.291

Note. Variables ordered by absolute size of correlation within function; [a] This variable not used in the analysis to produce the function.

Table 6.24 shows the group centroids and Table 6.25 the cross-validation results with 74.7% of cases accurately classified. The function showed reasonable specificity (79.5%) but comparatively poor sensitivity (68.6%). The risk of mis-identifying the high prosocial group using only vocal parameters was considered acceptable for this exploratory analysis.

Table 6.24

Functions at group centroids for prosocial and the child's parameters

Prosocial	Function
	1
Low prosocial	-0.725
High prosocial	0.911

Note. Unstandardised canonical discriminant functions evaluated at group

Table 6.25

Hit ratio for cross-validation for prosocial behaviour and the child's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low prosocial	44	35 (79.5)	9 (20.5)
High prosocial	35	11 (31.4)	24 (68.6)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.7.3 Prosocial behaviour and significant associations in the mother's speech

In contrast to the child's speech which showed a number of significant relationships between child pitch parameters and prosocial behaviour, the only significant association shown for the mother's speech was a lower pitch floor (Table 6.7).

6.7.4 Prosocial behaviour and the discriminant function of the mother's speech

A discriminant function was identified in the mother's speech and the overall Chi-square test was significant (Wilks λ = .518, Chi-square = 30.864, df = 6, Canonical correlation = .584, $p < .001$), however the single function was comparatively weak, explaining 34.1% of the discrimination between groups (i.e., where $r^2 = (.584)^2 = .341$). Table 6.26 shows the structure matrix which indicates that the strongest parameters loading on the latent variable were the mother's falls (percentage of syllables with pitch drops less than 4ST) and gliss (large pitch movements within syllables) and fewer mother-initiated overlaps, indicating that the function that discriminated child prosocial behaviour in the mother's speech might be conceptualised as smoother and upward leaning in pitch, and better self-regulated (i.e., fewer overlaps).

Table 6.26

Structure matrix from the discriminant analysis for prosocial behaviour and the mother's parameters

	Function
	1
Falls (%) of syllables with pitch fall (<= -4ST) - mother	0.453
Gliss (%) of syllables with large pitch movement (>= 4ST) - mother[a]	0.404
Mother-initiated overlaps as a % of all overlaps	-0.365
Standard deviation of ST – minimum & maximum pitch per syllable - mother[a]	0.287

Note. ST refers to semitones; [a] This variable not used in the analysis to produce the function.

Table 6.27 shows the group centroids and Table 6.28 the cross-validation findings. The function was successful at predicting 67.1% of the original cases and showed reasonable specificity (72.7%) and less sensitivity (60.0%). As with the child's vocal parameters, the function is more likely to result in a high rate of false negatives (40%) and also false positives (27.3%). Further studies should include a number of substitute parameters, such as those relating to overlaps.

Table 6.17

Functions at group centroids for prosocial behaviour and the mother's parameters

Prosocial	Function
	1
Low Prosocial	-0.633
High prosocial	0.796

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 628

Hit ratio for cross-validation for prosocial behaviour and the mother's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low prosocial	44	32 (72.1)	12 (27.3)
High prosocial	35	14 (40)	21 (60)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.8 Results: Acoustic-prosodic features in the emotion talk of children with high emotion regulation

6.8.1 Emotion regulation and significant associations in the child's speech

Comparative study was also made of emotional regulation primarily due to its inverse relationship to child ODD, and also due to the regulatory functions that have been associated with mother-child synchrony (Davis et al, 2017). In general, a trend of associations in the opposite direction was seen compared to characteristics of ODD (Table 6.1). Notably, significant parameters in the child's speech associated with these characteristics include a wider child pitch range (ST), a lower pitch floor, a slower speech rate, lower intensity at the midpoint of child turns, less child jitter and shimmer, and a smoother pitch trajectory both within and between child syllables for child emotion regulation. There were no significant associations at the session level with child age on these features. Notably, cognitive empathy was also negatively associated with pitch floor for the child. This relationship remained significant after controlling for child age (-.289, p = .017) but not after controlling for child emotion regulation (-.210, p = .085).

6.8.2 Emotion regulation and the discriminant function of the child's speech

The overall Chi-square test was significant (Wilks λ = .528, Chi-square = 45.967, df = 10, Canonical correlation = .687, p < .001), and the single function extracted accounted for 47.1% of variance between groups. Table 6.29 identifies the acoustic-prosodic features of the child that were most strongly correlated with the discriminant function. Child pitch rises (>=4ST) was the only parameter above the accepted cutoff of 0.30 in the structure matrix, indicating that the function discriminating emotion regulation in the child's speech might be conceptualised as expansive upward pitch. A number of temporal parameters loaded above 0.20, including fewer child turns (of indeterminate length) but less overall pause time in the emotion talk and a slower speech rate, suggesting better self-regulation during the talk. Table 6.30 shows the group centroids. For future consideration the parameters which formed the latent variable that discriminated emotion-regulation are also reported (Table 6.31), and identified a number of parameters associated with voice quality.

Table 6.29

Structure matrix from the discriminant analysis for emotion regulation and the child's parameters

	Function
	1
Rises (%) of syllables with pitch rise (>= 4ST) - child	0.344
Number of speaker turns - child[a]	-0.288
Total time of pauses[a]	-0.284
Inter-Nuclei Duration - sum of durations between successive nuclei - child	-0.230
Speech rate (in syll/s) = nrof nuclei/phonation time - child[a]	-0.221
Child h1 h2 aster (formant adjusted amplitude difference between 1st & 2nd harmonics)	-0.221

Note. 1 value > .30; values > .20 reported; [a] This variable not used in the analysis to produce the function.

Table 6.30

Functions at group centroids for emotion regulation and the child's parameters

High Low ER	Function
	1
Low ER	-1.161
High ER	0.75

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.31

Standardised canonical discriminant function coefficients for emotion regulation and the child's parameters

	Function
	1
Child cepstral peak prominence	-1.975
Child shimmer	1.603
Speech turn time for child	1.282
Child harmonicity	1.185
Inter-Nuclei duration - sum of durations between successive nuclei - child	-0.812
Percentage of time child speaks in emotion talk	-0.779
Rises (%) of syllables with pitch rise (>= 4ST) - child	0.769
TrajPhonZ (Time-normalized pitch trajectory in ST all pitch variations (z-score) child	-0.751
Child h1 h2 asterix (formant adjusted amplitude difference 1st & 2nd harmonics)	-0.715
Child excursion size	0.645

Note. ST refers to semitones.

Cross-validation data showed that 81.0% of the original cases were correctly classified (Table 6.32), indicating that the function was stronger for the high emotion regulation group (85.4%) compared to the low group of children (74.2%), but with a reasonably high rate of false positives (25.8%).

Table 6.32

Hit ratio for cross-validation for emotion regulation and the child's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low ER	31	23 (74.2)	8 (25.8)
High ER	48	7 (14.6)	41 (85.4)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.8.3 Emotion regulation and significant associations in the mother's speech

Child emotion regulation was also negatively associated with a wide range of the mother's acoustic-prosodic parameters, including the mother's pitch median and mean, pitch trajectory, pitch and intensity values at the midpoint of her turns, and energy at her first formant (Table 6.7). In addition, shorter maternal syllables, less shimmer, a narrower formant dispersion (formants 1 to 3), a lower center of gravity and less cepstral peak prominence were all associated with higher levels of child emotion regulation. There were no significant relationships with child age for these features. Child emotion regulation was also associated with a wider pitch range at the level of the mother's syllables, with a greater percentage of speech turns by the mother in the emotion talk, and with a faster speech rate for the mother. A lower pitch floor for the mother was also associated with higher child emotion regulation, a relationship which remained after controlling for child age (-.282, $p < .05$).

6.8.4 Emotion regulation and the discriminant function of the mother's speech

The overall Chi-square test was significant (Wilks λ = .892, Chi-square = 8.706, df = 2, Canonical correlation = .629, p = .013), and the single function extracted accounted for 39.5% of variance between groups. Table 6.33 shows that the mother's pitch features were highly correlated with the function, including falls (pitch movements less than 4ST), pitch range within syllables (in semitones), and gliss (large up and down pitch movements), indicating that the function in the mother's speech discriminating emotion regulation between the groups might be conceptualised as a considerably more expansive pitch profile.

Table 6.33

Structure matrix from the discriminant analysis for emotion regulation and the mother's parameters

	Function
	1
Falls (%) of syllables with pitch fall (<= -4ST) - mother	0.699
Standard deviation of ST (minimum & maximum pitch each syllable) mother	0.673
Gliss (%) of syllables with large pitch movement (abs(distance) >= 4ST) mother[a]	0.620
Pitch range (in ST) based on 2 stylization values per nucleus - mother[a]	0.504
Rises (%) of syllables with pitch rise (>= 4ST) - mother[a]	0.420
Top 98 percentile in pitch range (2 raw F0 values per nucleus) - mother[a]	0.407

Note. ST refers to semitones; F0 refers to fundamental frequency; [a] This variable not used in the analysis to produce the function.

Table 6.34 shows the group centroids and Table 6.35 indicates that the latent function accurately reclassified 64.4% of the original cases, and was substantially better at predicting high emotion regulation group membership (79.2%) than low regulation (41.9%). There was an unacceptably high number of false positives for the low regulation group (58.1%) based on this group of acoustic-prosodic parameters.

Table 6.34

Functions at group centroids for emotion regulation and the mother's parameters

High Low ER	Function
	1
Low ER	-0.428
High ER	0.276

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.32

Hit ratio for cross-validation for emotion regulation and the mother's parameters

		Predicted group membership	
Actual group	No. of cases	Low	High
Low ER	31	13 (41.9)	18 (58.1)
High ER	48	10 (20.8)	38 (79.2)

Note. Percentages in parentheses; in cross validation (leave one out) each case is classified by the functions derived from all cases other than that case.

6.9 Acoustic-prosodic features in the emotion talk of high empathy children

6.9.1 High child empathy and significant associations in the child's speech

Comparative study was made of the acoustic-prosodic features associated with high empathy due to the demonstrated relevance of mother-child synchrony to empathy development (Feldman, 2007a; 2007b). As seen In Table 6.1, an overall inverse pattern of associations with acoustic-prosodic parameters was seen in the emotion talk of children high in empathy compared to those for CU traits. Child empathy was positively associated with a wider child pitch range in semitones, shorter child speech turns, and negatively with the percentage of time the child speaks, particularly in the first half of the emotion talk.

Child affective empathy was negatively associated with mean intensity in the child's speech. Cognitive empathy in particular displayed significant negative relationships with energy across the child's spectrum from 0Hz through to 3000Hz. Cognitive empathy was also negatively associated with pitch floor for the child, a relationship which remained significant after controlling for child age (-.289, p = .017) but not after controlling for child emotion regulation (-.210, p = .085).

6.9.2 High child empathy and the discriminant function of the child's speech

Regarding child cognitive empathy and the child's speech, the overall Chi-square test was significant (Wilks λ = .674, Chi-square = 29.631, df = 4, Canonical correlation = .571, p = .000). The child's first formant, pitch-range at start of the syllables (normalised pitch value of start of nucleus), the child's shimmer (micro-perturbations in amplitude), the child's pitch falls (percentage of syllables with pitch fall less than 4ST), the child's pitch bottom (based on 2 raw F0 values per nucleus), and the sum of absolute pitch interval in semitones (rises and falls in syllables added up) were correlated with the latent discriminant variable for child cognitive empathy, with 74.7% of cases correctly classified.

For affective empathy, the overall Chi-square test was significant (Wilks $\lambda = .849$, Chi-square = 12.372, df = 3, Canonical correlation = .389, $p = .006$). Key child parameters associated with the latent variable for affective empathy were standard deviation of pitch (semitones), pause time, the first formant, and pitch range (semitones). The function was weaker at re-classifying cases compared to the cognitive empathy measure.

Table 6.36

Structure matrix from the discriminant analysis for cognitive empathy and the child's parameters

	Function
	1
F1 midpoint of turn - child	-.469
Gliss (%) of syllables with large pitch movement (abs(distance) >= 4ST) - child	.367
Pitch-range normalised pitch value of start of nucleus - child	.365
Sp2_AVGE_shimmer[a]	-.349
Falls (%) of syllables with pitch fall (<= -4ST) - child[a]	.341
Bottom 2nd percentile in pitch range of speaker (based on 2 raw F0 values per nucleus) - child[a]	-.315
Sum of absolute pitch interval (ST) of tonal segments in nucleus (rises and falls add up) - child[a]	.307
Duration of nucleus - child[a]	.293
Pitch bottom - pitch bottom (in Hz) based on 2 stylization values per nucleus - child[a]	-.273
Sp2_AVGE_jitter[a]	-.268

Note. ST refers to semitones; F0 refers to fundamental frequency; [a] This variable not used in the analysis to produce the function.

Table 6.37

Classification Results[a,c] from the discriminant analysis for cognitive empathy and the child's parameters

T1CogEm100			Predicted Group Membership		
			.00	1.00	Total
Original	Count	.00	23	11	34
		1.00	9	36	45
	%	.00	67.6	32.4	100.0
		1.00	20.0	80.0	100.0
Cross-validated[b]	Count	.00	22	12	34
		1.00	9	36	45
	%	.00	64.7	35.3	100.0
		1.00	20.0	80.0	100.0

a. 74.7% of original grouped cases correctly classified.
b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
c. 73.4% of cross-validated grouped cases correctly classified.

Table 6.38

Functions at group centroids for cognitive empathy and the child's parameters

High Low Cog Empathy	Function
	1
Low Cog empathy	-.791
High Cog empathy	.597

Note. Unstandardised canonical discriminant functions evaluated at group means.

Table 6.39

Structure matrix from the discriminant analysis for affective empathy and the child's parameters

	Function
	1
Standard deviation Of ST - stdev of pitch values using min and max pitch for each syllable - child	.599
Total time of pauses (P)	.591
Average F1 midpoint of turn - child	-.542
Pitch range (in ST) based on 2 stylization values per nucleus (2%-98% percentiles of data in nuclei without discontinuities) - child[a]	.430
TrajIntraZ - pitch trajectory (sum of absolute intervals) within syllabic nuclei, divided by duration (in ST/s) in standard deviation units on ST	-.366
Sp2_AVGE_center_of_gravity[a]	-.308
Number of speaker turns - child[a]	.293
Top 98 percentile in pitch range (F0 values per nucleus) - child[a]	.291

Note. ST refers to semitones; F0 refers to fundamental frequency; [a] This variable not used in the analysis to produce the function.

Table 6.40

Classification Results[a,c] from the discriminant analysis for affective empathy and the child's parameters

T1AffEm100			Predicted Group Membership		
			.00	1.00	Total
Original	Count	.00	21	15	36
		1.00	11	32	43
	%	.00	58.3	41.7	100.0
		1.00	25.6	74.4	100.0
Cross-validated[b]	Count	.00	20	16	36
		1.00	11	32	43
	%	.00	55.6	44.4	100.0
		1.00	25.6	74.4	100.0

a. 67.1% of original grouped cases correctly classified.
b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
c. 65.8% of cross-validated grouped cases correctly classified.

Table 6.41

Functions at group centroids for affective empathy and the child's parameters

High Low Aff Empathy	Function
	1
Low Aff empathy	-.455
High Aff empathy	.381

Note. Unstandardised canonical discriminant functions evaluated at group means.

6.9.3 High child empathy and significant associations in the mother's speech

In terms of the mother's speech, negative relationships were seen between child empathy values and the mother's pitch minimum, maximum, median and mean, her pitch excursion size, and the mean intensity in her speech turns (Table 6.7). Child affective and cognitive empathy were also associated with less energy in the mother's spectrum from 500Hz to 2000Hz, and for cognitive empathy through to 3500Hz. Negative relationships were also seen between child empathy and large pitch movements (up and down) for the mother, particularly for pitch rises greater than or equal to 4 semitones, in the mother's emotion talk. There was no significant relationship for the child's speech for these pitch measures.

6.9.4 High child empathy and the discriminant function of the mother's speech

Regarding child cognitive empathy and the mother's speech, the overall Chi-square test was significant (Wilks λ = .622, Chi-square = 34.852, df = 7, Canonical correlation = .641, p = .000). The mother's cepstral peak prominence, formant dispersion (formants 1 to 3), mother-initiated overlaps, harmonicity, center of gravity, and length of speech turns combined to form a latent variable. The mother's shimmer was also correlated with the latent variable. The discriminant function was better at predicting high cognitive empathy group membership (75.6%) than low cognitive empathy (67.6%). Wilks' Lambda showed that no maternal acoustic-prosodic variables qualified for the discriminant analysis for child affective empathy.

6.9.5 Cognitive empathy and the mother's acoustic-prosodic features

Table 6.42

Structure matrix from the discriminant analysis for cognitive empathy and the mother's parameters

	Function
	1
Sp1_AVGE_harmonicity	.338
Sp1_AVGE_shimmer[a]	-.337
Mo initiated overlaps as a % of all overlaps (BD)	-.270
Average F1 midpoint of turn - mother[a]	-.268

[a] This variable not used in the analysis to produce the function.

Table 6.43

Classification Results[a,c] from the discriminant analysis for cognitive empathy and the mother's parameters

T1CogEm100			Predicted Group Membership		
			.00	1.00	Total
Original	Count	.00	24	10	34
		1.00	8	37	45
	%	.00	70.6	29.4	100.0
		1.00	17.8	82.2	100.0
Cross-validated[b]	Count	.00	23	11	34
		1.00	11	34	45
	%	.00	67.6	32.4	100.0
		1.00	24.4	75.6	100.0

a. 77.2% of original grouped cases correctly classified. b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

Table 6.44

Functions at group centroids for cognitive empathy and the mother's parameter.

High Low Cog Empathy	Function
	1
Low Cog empathy	-.885
High Cog empathy	.668

Note. Unstandardised canonical discriminant functions evaluated at group means.

APPENDIX I: Additional statistical data for the linear regression models for child characteristics and relational qualities of the emotion talk (Chapter 7)

Additional statistical data for Table 7.7: Main and interaction effects of child characteristics and warmth in the mother's speech on key parameters

Eqn	Parameter	Predictor X1	Predictor X2	*df* 1	*df* 2	*F p* value	*p X*1	*p* X2	*p* D00	*p* D01	*p D*10	*p* D11	min(y)	mean(y)	max(y)
1	Sp2 RangeST	PFMSS_Warmth(1to3)	ICUCallous	2	74	0.000	0.043	0.000					7.300	17.902	26.000
2	Sp2 BottomHz	DiagnosisODD	ParentWarmthExpress	3	76	0.000	0.000	0.003			0.014		0.000	172.901	327.000
3	Sp2 AVGE jitter	DiagnosisODD	PFMSSWarmth	3	76	0.006	0.002	0.010			0.024		0.000	0.040	0.080
4	Sp2 AVGE Energy Profile 250Hz	DiagnosisODD	PFMSSWarmth	2	77	0.000		0.004				0.000	-17.746	15.471	25.616
5	AVGE 2 INTmid	PFMSS_Warmth(1to3)	CogEm100	75.100	13.430	1.322	0.113	2.112					33.490	3.000	67.000
6	Sp2 AVGE 500	PFMSS_Warmth(1to3)	CogEm100	27.207	15.592	1.534	0.132	2.452					-16.273	3.000	67.000
7	Sp2 AVGE 750	PFMSS_Warmth(1to3)	CogEm100	26.461	15.559	1.531	0.131	2.447					-18.696	3.000	67.000
8	Sp2 BottomHz	Vocal_Warmth(1to7)	ERCLability	327.000	34.121	5.950	0.735	NA	16.392	NA	NA		0.000	3.000	74.000

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$

Additional statistical data for Table 7.8: Main and interaction effects of child characteristics and warmth in the emotion talk on key parameters

Eqn	**Parameter**	**Predictor X1**	**Predictor X2**	***df* 1**	***df* 2**	***F p* value**	***p X*1**	***p* X2**	***p* D00**	***p* D01**	***p D*10**	***p* D11**	**min(y)**	**mean(y)**	**max(y)**
1	Sp2 RangeST	CS9Warmth(1to5)	ICUTotal	2	74	0.000		0.000			0.034		7.300	17.902	26.000
2	Ch percent talk time	CS9Warmth(1to5)	ICUTotal	2	73	0.004	0.009	0.015					7.250	24.006	47.390
3	Sp2 TrajPhonZ	CS9Warmth(1to5)	ICUTotal	2	77	0.004	0.011		0.004				2.900	4.675	11.400
4	Sp2 StDevST	CS9Warmth(1to5)	ICUTotal	2	74	0.000		0.028	0.004				1.800	4.028	7.000
5	Ch percent talk time	CS9Warmth(1to5)	SDQProsocial	47.390	3.615	0.755	0.371						7.250	2.000	75.000

Note. Models reported are those where the *p* values for each main effect, interaction, and the full model all met significance at $p < .05$

Additional statistical data for Table 7.9: Main and interaction effects of child characteristics and attunement in the mother's speech on key parameters

Eqn	Parameter	Predictor X1	Predictor X2	*df* 1	*df* 2	*F p* value	*p X*1	*p* X2	*p* D00	*p* D01	*p D*10	*p* D11	min(y)	mean(y)	max(y)
1	Ch percent talk time	CS8 In tune(1to5)	ICUTotal	4	71	0.006	0.002	0.023	0.008	0.041			7.250	24.006	47.390
2	Sp2 InterNuclDur	CS8 In tune(1to5)	ICUTotal	3	76	0.003	0.001				0.001	0.020	0.030	25.777	93.020
3	Ch avge talk time	DiagnosisODD	CS8 In tune	4	74	0.015	0.042	0.001		0.016	0.016		0.730	1.171	2.310
4	Sp2 TopHz	DiagnosisODD	CS8 In tune	4	74	0.001	0.000	0.004		0.000	0.022		0.000	498.605	811.000
5	Ch percent talk time	CS8 In tune(1to5)	AffEm100	4	65	0.002	0.005	0.013			0.006	0.035	7.250	24.006	47.390
6	Ch percent talk time	CS8 In tune(1to5)	SDQProsocial	4	73	0.001	0.001	0.003	0.033	0.001			7.250	24.006	47.390
7	Sp2 TopHz	CS8 In tune(1to5)	SDQProsocial	5	72	0.000	0.005	0.004		0.000	0.000	0.000	0.000	498.605	811.000
8	Prstart 2	CS8 In tune(1to5)	ERCLability	2	74	0.000	0.023	0.001					28.050	45.326	74.040
9	Ch avge talk time	CS8 In tune(1to5)	SDQEmotions	4	73	0.003	0.001	0.041			0.001	0.032	0.730	1.171	2.310

Note. Models reported are those where the p values for each main effect, interaction, and the full model all met significance at $p < .05$

Additional statistical data for Table 7.10: Main and interaction effects of child characteristics and dismissiveness in the mother's speech on key parameters

Eqn	Parameter	Predictor X1	Predictor X2	*df* 1	*df* 2	*F p* value	*p X*1	*p* X2	*p* D00	*p* D01	*p D*10	*p* D11	min(y)	mean(y)	max(y)
1	Sp2 RangeST	CS13Dismissive(1to5)	ICUTotal	3	72	0.000	0.005	0.000	0.048				7.300	17.902	26.000
2	Sp2 RangeST	DiagnosisODD	CS13Dismissive	2	76	0.001	0.027	0.027					7.300	17.902	26.000
3	InterSy 2	CS13Dismissive(1to5)	ICUTotal	3	72	0.004	0.015	0.005	0.020				-0.570	0.395	3.740

Note. Models reported are those where the p values for each main effect, interaction, and the full model all met significance at $p < .05$