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DOCTOR OF PHILOSOPHY

Translation of empirical findings from the social timing of interactions, to assess and therapeutically address Social Reciprocity Difficulties in Autistic Spectrum Disorder (ASD) and to help delineate its diagnostic boundary

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Translation of empirical findings from the social timing of interactions, to assess and therapeutically address Social Reciprocity Difficulties in Autistic Spectrum Disorder (ASD) and to help delineate its diagnostic boundary

Judit Elias-Masiques

Thesis submitted to the School of Human and Behavioural Sciences, Bangor University, in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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Kami Koldewyn (second supervisor)
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Declaration and Consent

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards. I confirm that I am submitting this work with the agreement of my supervisors.

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Summary

Social Timing refers to temporal synchronising in social interactions, which plays a vital role in the developmental dynamics of parent-infant interactions. Autism Spectrum Disorder (ASD) is a neurodevelopmental condition marked by apparent difficulties in temporal synchrony, that extend across modalities and impact interactions, as well as postulated diminished joint and shared attention, affecting social engagement and coordination. The current thesis investigates shared attention and temporal synchrony in naturalistic interactions using a novel micro-coding methodology: the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA). SCAEMA evaluates Matching Synchrony (through gaze synchrony), Sequential Synchrony (of vocal response latency), and Bidirectional Synchrony (a time series through cross-correlation analysis).

The first empirical chapter (Chapter 3) applies SCAEMA in typically developing (TD) infants, considering both age-related changes and the impact of Mutual Shared Attention (MSA). The second empirical chapter (Chapter 4) investigates MSA and temporal synchrony through SCAEMA in non-verbal ASD-diagnosed and non-ASD children, controlling for Developmental Delay/Learning Disability (DD/LD). The third empirical chapter (Chapter 5) introduces Musical Interaction Therapy (MIT), an early parent-mediated intervention that uses live music to scaffold the timing of the interaction, alongside redirecting parental synchrony. This chapter investigates the impact of MIT on MSA and temporal synchrony assessed through SCAEMA.

Overall, the results from the thesis revealed that Matching Synchrony of gaze in TD infants experienced an age-related decline at 10 months and was influenced by MSA, with higher percentages of gaze synchrony observed during shared attention episodes. Bidirectional Synchrony was present across all ages, emphasizing its early emergence in infant communication. ASD children exhibited significantly less Matching Synchrony of gaze, MSA and Bidirectional Synchrony compared to non-ASD children, irrespective DD/LD status. While statistically significant improvements in Matching Synchrony of gaze and MSA were observed after six months of MIT, challenges arose in attributing these changes solely to therapeutic interventions due to the absence of control groups and baselines. Sequential Synchrony, or vocal response latency did not correlate with chronological age nor MSA, possibly suggesting nuanced developmental trajectories. Additionally, non-verbal ASD children’s vocal response latencies showed no significant differences from those with no ASD diagnosis, irrelevant of their DD/LD statuses. Six months of MIT did not appear to impact vocal response latencies nor Bidirectional Synchrony. This thesis introduces valuable insights into interpersonal synchrony in TD and ASD making valuable contribution to the field of temporal synchrony.

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"Alone we can do so little; together we can do so much."

- Helen Keller

Chapter 1

General Introduction

1.1. Social Timing and Temporal Synchrony

Social timing, temporally synchronising with a partner in social interaction (Wimpory, 2015), is crucial to the development of parent-infant interactions (Leclere et al., 2014). It stems from and creates a feeling of shared motivation and lessens the cognitive demands of the exchange (Cross et al., 2020; Dideriksen et al., 2020), ultimately affecting language, cognition, and social developments. For example, Cirelli et al. (2014a, 2014b) found that infants were significantly more likely to engage in altruistic behaviour and help an experimenter following synchronous versus asynchronous movement (bouncing) with that person.

Interpersonal temporal synchrony, also referred to as primary intersubjectivity by some authors such as Delafield-Butt et al. (2020), results from the coordination of both content (from the meaning of words to non-verbal aspects such as emotional states) and process (regarding the timing of the beginning and endings of the interaction phases) (Delaherche, 2012). Interpersonal synchrony is brought about through a process of mutual focus, turn-taking, and responsiveness to the emotions and intentions of the other (Delafield-Butt et al., 2020). Previous research (Feldman, 2007b) delineates three types of temporal synchronies: Matching Synchrony, Sequential Synchrony and Bidirectional Synchrony.

Matching Synchrony refers to the coherence of content across different sensory modalities and can be unimodal, multimodal and intermodal. In synchronous social interactions, the dyad engages in a matched verbal or non-verbal dialogue (Tronick & Cohn, 1989). This dialogue necessitates a level of attunement in which two individuals share the same focus of attention (Harrist, 2002). In young infants, Matching Synchrony can take the unimodal form of copying their parent's affective state (i.e. smiling) or non-verbal behaviour (i.e. vocalising). Between the third and fourth month of life, infants become able to integrate different modalities (i.e. matching parent's gestures with a vocalisation) and deepen in complexity (i.e. singing together a nursery rhyme that requires motions) (Trevarthen & Aitken, 2001). Matching Synchrony can also be called synchrony at "lag 0", as the co-occurrence of content is simultaneous.

Sequential Synchrony relates to the timing order of the interaction. It has a lead-lag aspect, where a partner of the dyad is leading the exchange and the other follows, synchronising with a second’s latency. This can also be unimodal, crossmodal or multimodal. Sequential Synchrony becomes the foundation of turn-taking, with the infant first learning to follow the parents. This will later scaffold the cognitive skills to more complex social interactions (Stivers et al., 2009). An example of early unimodal Sequential Synchrony is a child vocalising after the parent has made a vocalisation; a complex multimodal example would be an infant repeatedly laughing and clapping after a parent sings a verse of "If you are happy and you know it, clap your hands".

Developmentally, Bidirectional Synchrony follows Sequential Synchrony (Evans & Porter, 2009). Feldman (2007b), describes “Bidirectional Mutual Synchrony” as resulting in a non-random patterned stochastic interaction with lead-lag aspect that leads to reciprocal adaptation; while the author favours the term “Mutual Synchrony” after the first full description, this project will employ Bidirectional Synchrony as to keep distinct from the term “Mutual Shared Attention”, later described. While in the previous type of synchrony, one partner followed the other, in Bidirectional Synchrony, both partners become leader and follower at the same time, taking turns and constructing an organised mutual dependence between their behaviours and rhythms (Rochat et al., 1999).

1.2. The Development of Temporal Synchrony

Temporal synchrony appears before birth. Foetuses respond to their mother's voice as early as 32 - 34 weeks by their heart rates becoming adjusted to it (Kisilevsky & Hains, 2011). Several studies point towards foetuses or preterm infants being able to detect auditory, vestibular or somatosensory stimulation patterns and rhythms and manifesting corresponding changes with their heart rate or breathing (Provasi et al., 2014). Eckerman et al. (1995) and Malloch (1999) both found newborns (including preterm) synchronise limb movements to salient moments of adult communication by syllabic rhythms of speech. Ramus et al. (2000) found infants can discriminate and react to speech rhythms of other cultures. Trevarthen and Aiken (2001) found that infants move their limbs to a turn-taking beat of 0.9 seconds at 1.5 months, which decrease to 0.7 seconds at 2.5 months and 0.5 seconds at 3.5 months old. Cuadros (2019) found significant correlation levels of body synchrony between 14-month-old infants and unknown adults: infants' movements mirror those of the adults with a latency of 0.9 seconds.

By 2-3 months, parent-infant interaction is defined by temporally sequential matching through repetitive rhythmic cycles of individual modalities such as indicators of arousal, posture, gaze, emotional expressions, hand movement and touch (as reviewed by

Wimpory, 2015). Around this age, the infant experiences visual input of the parent faces, including both eyes, with a high frequency (Fausey et al., 2016; Jayaraman et al., 2015), which leads to shared gaze becoming one of the primary modalities of the interaction (Feldman, 2007a; Senju & Johnson, 2009). Lewkowicz and Hansen-Tift (2012) and Pons et al. (2015) found that, when infants look at an interactive partner's face, they focus their gaze majorly on their eyes at 4-months-old, which starts to shift at 6-month-old. At 8-months-old, the main focus becomes the mouth, with this prevalence disappearing around 12-months-old when infants become more familiar with their native speech. Hillairet et al. (2017) concluded that audio-visual perceived synchrony plays an essential role in 10-month-olds and becomes less important as children's verbal language skills emerge.

Vocalisations take a co-leading role at 4-months-old (Beebe & Gertsman, 1980; Malloch 1999), with gaze decreasing in importance from 4-month-old as infants develop the ability to share their attention to objects (Landry et al., 1996). Gratier and Devouche (2011) found that 3-month-old infants can copy and repeat the prosodic contours of the parent's vocalisations. In a literature review, Nguyen et al. (2022) reported that typically developing infants take, on average, 1 second to respond vocally, ranging from 0.60 seconds to 3.04 seconds. This is supported by previous research (Gratier et al, 2015) that established that pauses between mother/infant utterances that are connected by form or content, rarely exceed 3 seconds, while longer pauses generally demarcate episodes of mutual engagement (Stern et al.,1977; Stern & Gibbon, 1979), where the infant or mother disengages from the current form or topic of the dyad’s interaction. Similarly, Balog and Roberts (2004) found that in children ranging 12-months-old and 19-months-old, silences in their (either non-verbal or verbal) vocalisation responses occur within 4.25 seconds of the parent utterance nearly 90% of the time.

In her cross-sectional study, Gratier et al. (2015) reported a slowdown in the latency of vocal responses from 8-weeks-old to 21-weeks-old infants. Hilbrink et al. (2015) found that, while up to 9 months preverbal infants' vocal response latencies were similar to those of adults, these increased in duration until infants were 18 months of age. These larger latencies can be explained by infants acquiring more complex language skills, which they attempt to incorporate in their turns (Nguyen et al., 2022). Casillas et al. (2016) pointed out that slowdowns and speed-ups in the latency of vocal response might be relative to the specific context (i.e. the complexity/familiarity of words used).

The emergence of turn-taking appears very early in infancy and develops during the first year: Jasnow and Feldstein (1986) found that 9-months-old infants have already developed switching pauses that constitute the boundaries between conversational turns and ultimately enable more conventional vocal turn-taking. This is supported by earlier research that had found infants display smooth turn-taking even before 3-month-old (Bateson, 1975). More recently, Gratier et al. (2015) found a turn-taking format in vocal interactions of infants aged between 2 and 5 months. Evans and Porter (2009) found a significant developmental shift from 6 months to 12 months old, in which mother–infant interactions become increasingly more symmetrical and bidirectional; it must be noted, however, that this study did not investigate younger ages. Lewkowicz (2000) found that infants develop from unimodal to multimodal synchrony between 4 and 8 months of age. Feldman (2007b) found crossmodal and multimodal bidirectional mutual synchrony in 9-month-old infants.

1.3. Temporal Synchrony in Autism Spectrum Disorder

1.3.1 Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a highly heritable (Colvert et al., 2015) neurodevelopmental disorder characterized by enduring challenges in social communication and interaction, coupled with restricted and repetitive patterns of behaviours, activities, or interests, including sensory behaviours. These characteristics manifest from early childhood and are significant enough to restrict and hinder everyday functioning (American Psychiatric Association, 2022).

ASD has an estimated prevalence of 1–2% of the UK population (1 per 100 children and 2 per 100 adults) (NHS Digital(a), 2021). However, a recent study posed that the prevalence for ASD could be much higher, with 59–72% of autistic people undiagnosed (0.77%–2.12% of the English population) (O'Nions et al., 2023). English primary care data for 2020–2021 indicated that the percentage of patients with a learning disability who had a diagnosis of ASD was significantly higher (24.8%) than in patients without a learning disability (0.7%) (NHS Digital(b), 2021).

ASD is characterised by impairments in communication and social interaction (World Health Organization, 2023; American Psychiatric Association, 2013). Research has been pointing towards elements of temporal synchrony being diminished in individuals of ASD across various domains. Recent studies propose this atypical synchrony as a potential biomarker for both diagnosis and intervention target in ASD (McNaughton & Redcay, 2020). ASD timing difficulties include a genetic component through timing genes (Briuglia et al., 2021; Bowton et al., 2014; Wimpory et al., 2002). Circadian-associated clock genes, such as *RORA* (Nguyen et al., 2010; Guissart et al., 2018) and *PER1* (Nicholas et al., 2008; Nicholas et al., 2007; Neale et al., 2012; Yang et al., 2016), have been identified as potential contributors to ASD temporal deficits. Bloch et al. (2019) pose that atypicalities in intrapersonal synchrony present in ASD (such as temporal processing of sensory input and motor coordination) may contribute to interpersonal synchrony difficulties in these individuals. Temporal synchrony is a crucial developmental skill in parent-infant interactions (Leclère et al., 2014), and a life-long impairment could limit a child's participation in and benefit from early preverbal interactive experiences: social timing could, therefore, be fundamental to the aetiology of autism (Wimpory et al., 2002).

1.3.2. Social Motor Synchrony in ASD

Synchrony impairments in autism span several modalities. Social motor synchrony, the tempo and coordination of movement, posture and orientation during a social interaction (Xavier et al., 2018), has been one of the most studied. While social motor synchrony increases with age in both autistic and typically developing (TD) individuals (Xavier et al., 2018), a variety of motor impairments are clear among ASD individuals (Kaur et al., 2018; Fitzpatrick et al., 2016)

Children with high-functioning ASD (HFA) exhibit lower interactional movement synchrony during natural conversations with both familiar and unfamiliar partners (Zampella et al., 2020), and children with high and those with low-functioning autism display weaker interpersonal motor synchrony (i.e. clapping, marching, drumming) in social tasks (Kaur et al., 2018). Children with ASD show reduced synchrony and smaller sway amplitude compared to TD when swaying face to face with an adult (Su et al., 2021). Children and adults with ASD show lower gross and fine motor skills and movement rates (Bhat et al., 2011), correlating with IQ but not autism severity (Kaur et al., 2018). Both high and low-functioning children with ASD present greater praxis errors and increased movement variability compared to age-matched typically developing children (Kaur et al., 2018). High-functioning autistic adults show reduced social motor synchrony when interacting with a partner, regardless of the partner's diagnosis (Georgescu et al., 2020). Several studies have found a correlation between greater ASD symptom severity and social motor synchrony impairments (Su et al., 2020; McNaughton & Redcay, 2020; Kaur et al., 2018).

Children with ASD experience poor temporal integration of information, including the understanding of other's motor actions (Cattaneo et al., 2007; Di Cesare et al., 2017; Su et al., 2020). This results in slower motor planning (Gowen & Hamilton, 2013), preparation and initiation (Rinehart et al., 2006). Motor synchrony performance in ASD adolescents relates to attention and social responsiveness assessed through clinical measures (Fitzpatrick et al., 2018). Since interpersonal synchrony relies on the alignment of behaviours and states, these atypical processing phenomena could interfere with the motor aspect of these behaviours (Daniel et al., 2022). Therefore, they are highly likely to play a vital part in social motor synchrony impairment (Fitzpatrick et al., 2016; Bloch et al., 2022) Autistic children are posturally hyporeactive to visually perceived motion (Gepner et al., 1995), which correlates to the severity of their motor impairments and visuopostural tunning (Gepner & Mestre, 2002). There is evidence that that ASD deficiencies in posturing anticipation could lie in timing parameters (Schmitz et al., 2003), while posture maintenance has been linked with shortcomings in the integration of visual, vestibular, and somatosensory input (Molloy et al., 2003).

1.3.3 Tactile Experience and Orientation in ASD

ASD individuals display an abnormal detection of tactile stimuli (Blakemore et al., 2006) and a lack of tactile habituation (Tannan et al., 2008). This atypical tactile experience may influence the child's capacity to orient socially: in early infancy, maternal touch is vital in developing attachment through orientation (Duhn, 2010). Infants later diagnosed with ASD experienced less maternal touch stimulation (Baranek, 1999); and poor attachment has been associated with failure to socially orient in TD (Reece et al., 2016) and low-weight infants (Weiss et al., 2000).

Atypical tactile perception around the face and mouth could disrupt tactile stimulation of the orienting reflex towards the mother in infants, which is crucial to face-to-face orientation and could result in the infant experiencing diminished positive social attention (Sokolov, 1963). Both atypical tactile perception in face and mouth and failure to orient have been observed in individuals with ASD (Silva et al., 2015). Moreover, the severity of tactile sensory abnormalities has been correlated to the severity of ASD symptoms (Silva et al., 2015).

1.3.4 Vocal Synchrony and Turn Taking in ASD

Both verbal and non-verbal vocal communication synchrony difficulties, including turn-taking aspect of communication, have also been extensively reported in ASD: ASD individuals have shown early-emerging deficits in temporal auditory processing (Boucher, 2001) as well as atypical high-level complexity time processing (Casassus et al., 2019), which result in difficulties when discriminating timing in sequential auditory stimuli (Kwakye et al., 2011) and reproducing the duration of auditory stimuli (Szelag et al., 2004). For example, high-functioning ASD children commit more errors when reproducing short (less than 2 seconds) and long (more than 45 seconds) stimulus durations than TD peers (Maister & Plaisted-Grant, 2011).

Autistic children show lower thresholds, longer latencies and greater right-left asymmetry in acoustic stapedial reflex in response to loud sounds (Lukose et al., 2013), with lower thresholds correlating with higher ASD severity. (Ohmura et al., 2019). The stapedial reflex threshold significantly correlates with loudness tolerance in both TD and autistic children (Ohmura et al., 2019). Additionally, ASD individuals show delayed latency of evoked potentials in response to tones of various pitch (Roberts et al., 2010). Infants with autism do not preferentially attend to their mother’s speech or child-directed speech, as opposed to non-speech sounds, in contrast to TD infants, who show a clear preference for speech sounds (Dawson et al., 1998; Klin, 1991; Paul et al., 2007; Curtin & Vouloumanos, 2013). This lack of orientation towards child-directed speech in ASD is linked to poor sound discrimination (Kuhl et al., 2005).

Non-verbal vocal synchrony (regarding non-verbal vocalisations and the timing of silences/pauses) is impaired, even in high-functioning ASD children who display more atypicality in the length of their silences between verbal conversational turns, which correlate with the severity of ASD symptoms of when comparing diagnosed 9-16 years old to TD (Zampella et al., 2020) and difficulty in initiating turn-taking in 7-12 years old diagnosed children as opposed to TD (Choi & Lee, 2013).

While autistic individuals show conversational atypicalities (Nguyen et al., 2022), there is contrasting evidence regarding vocal response latencies during turn-taking in ASD.

Plank et al. (2023) observed that mixed dyads, consisting of both an individual with HFA and a non-autistic adult, experienced prolonged periods of silence compared to dyads involving only non-autistic individuals. Heeman et al. (2010) found significantly longer latencies (27.3% longer) in high-functioning verbal ASD children; and Ochi et al. (2019) found substantially longer turn-taking gaps with a greater proportion of vocal response latency, less variability and less synchronous changes in adults with HFA. However, Warlaumont et al. (2010) did not find significant differences in vocal response latency between non-verbal autistic and typically developing children aged between 1.3 and 4 years old. These findings suggest that, although verbal individuals with HFA face particular challenges in the temporal aspects of non-verbal communication, vocal response latency may not distinguish non-verbal individuals with ASD from typically developing children, potentially due to younger age or lower functioning status. Moreover, children in the Broader Autism Spectrum (that is, siblings of diagnosed children with subclinical features of ASD) showed a lower vocalisation production at 15 months old than TD, but no statistical differences at other ages (12, 18 or 24 months old)(Kellerman et al., 2019). It is to note, however that this last study's participants were not diagnosed with autism, and this could be a potential reason for the lack of statistical differences.

HFA children exhibit less verbal vocal synchrony (including content of verbalisation) during natural conversations with familiar and unfamiliar partners (Zampella et al., 2020). Diminished language skills in children with ASD and early language delays are evident as early as 12 months (Swanson et al., 2017). ASD infants show distinct brain-behavior associations between amygdala, thalamus and caudate nucleus volume and receptive/expressive language skills than do children with language delay who lack an ASD diagnosis (Swanson et al., 2017).

Research has highlighted the pivotal role the language component plays in the detection of synchrony in ASD: HFA individuals show more difficulties in matching audiovisual stimuli by its synchrony when the stimuli are related to speech but not objects (i.e. a bouncing ball), and these difficulties correlate with ASD severity (Smith et al., 2017). Toddlers with ASD show awareness and orient towards speech less often than TD and developmentally delayed (DD) toddlers; however, there are no group differences when the auditory stimuli are instrumental music, animal calls or mechanical noises (Adamson et al., 2021).

1.3.5 Gaze Synchrony and Affect Matching in ASD

Gaze synchrony (also known as eye contact), which occurs when two people look at each other's eyes simultaneously, has been extensively described in ASD. Poor eye contact, combined with a lack of communicative gestures and giving or a lack of imaginative play at 18 months, predicts ASD diagnosis at 36 months old (Chawarska et al., 2014). A lower frequency of eye contact, detectable by the first birthday, has also been shown in children with broader autism phenotype (Ozonoff et al., 2014), who show statistically less gaze towards their partners at 15-month-old and overall a lower trend than TD controls from 12 to 24 month old (Kellerman et al., 2019).

A review of home movies found that children later diagnosed as autistic showed lower eye contact quantity and quality during the first two years of life (Saint-Georges et al., 2010). This diminished gaze synchrony negatively impacts the ASD children's ability to participate in anticipation/build-up interactional games (Trevarthen & Daniel, 2005). ASD children show lower gaze synchrony in face-to-face naturalistic interactions and goal-oriented activities when compared with TD and DD children; this lower synchrony correlates with ASD severity (Wang et al., 2018).

Individuals with ASD show less focus on the eyes and increased looking to the mouth (Klin et al., 2002), and toddlers with autism spend less time looking at the speaker's face and monitoring lip movements than DD and TD children (Chawarska et al., 2012). Enlarged delays between gaze-gesture nonverbal signals (looking at the stimulus and pointing) in HFA adults have been associated with greater intrapersonal variability, indicating a weaker temporal coherence of nonverbal cues within individuals (Bloch et al., 2022). These delays appear to play a role in both sides of a dyadic exchange: Bloch et al. (2024) observed that both non-autistic adults and those with HFA exhibited prolonged response times when observing a virtual character displaying behaviours indicative of ASD, with individuals with HFA demonstrating even longer response times. This phenomenon could be facilitated by non-autistic observers employing a more consistent eyes-focused strategy, leading to efficient and rapid responses, whereas observers with ASD demonstrated highly variable decoding strategies.

Autistic individuals struggle when looking at faces. Attending to human faces in social interactions requires rapid and complex visual information perception and integration that are impaired in individuals with ASD (Thye et al., 2018; Charrier et al., 2017). Children later diagnosed with ASD have shown intact gaze-following at 7 and 13 months old (Bedford et al., 2012) as well as intact face attention in the first year of life (Elsabbagh et al., 2013; Yirmiya et al., 2006). This social attention is, however, decreasing and falls behind typical development in the second year (Jones & Klin, 2013; Ozonoff et al., 2010; Gliga et al., 2014).

Research has found ASD individuals have deficits in face processing (Teunisse & Gelder, 1994), diminished face discrimination (Rutherford et al., 2007a) with abnormal cortical activation (Schultz et al., 2000; Pierce, 2001), poorer facial identity recognition (Kirchner et al., 2011), facial memory (Wilson et al., 2010) and, lastly, impairments in facial emotion recognition (Hobson, 1986; Baron-Cohen, 1991; Harms et al., 2010).

Adults with ASD struggle to discriminate whether faces and voices have congruent emotions (O'Connor, 2007) and to differentiate emotions when given audiovisual cues (Xavier et al., 2015; Charbonneau et al., 2013). An ERP study detected an altered temporal phase response to fearful audiovisual stimuli (Magnée et al., 2008). Children on the spectrum have difficulties to show positive affect as opposed to TD peers (Kellerman et al., 2019; Saint-Georges et al., 2010; Ozonoff et al., 2014)

1.3.6 Mutual Shared Attention in ASD

Joint attention involves an interactional dyad coordinating mutual engagement with the same focus (Tomasello, 1995) and plays a vital role in both social, cognitive and language development (Gillespie-Lynch et al., 2015). Joint attention has been shown to be impaired in autistic children (Kasari et al., 2006). Shared attention involves this mutual coordination in sharing focus, but with both individuals being aware of their common attentional state (Edwards et al., 2015). This shared awareness is not required for joint attention (Emery, 2000) (Stephenson et al., 2021).

Shared attention has been, therefore referred, as a more elaborate, reciprocal, joint attention episode (Tomasello & Carpenter, 2007; Moll & Tomasello, 2007). It is thought to be expressed only in humans (Saxe, 2006), and may play a critical role in language acquisition (Baldwin, 1995), theory of the mind such as inferring intention (Mundy & Newell, 2007), and pretend play (Rutherford et al., 2007). Shared attention can signal both primary intersubjectivity (whereby the attention focus is on the other partner of the dyad) and secondary intersubjectivity (whereby both partners of the dyad focus on the same object) (Trevarthen & Aitken, 2001; Rochat et al., 2008).

The ability to share the focus of attention is an important prerequisite for synchrony (Harrist, 2002). Gaze synchrony has been suggested as a means to capture shared and joint attention (Tschacher et al., 2021). Research has found that the ability to synchronise with a group predicts less inattentional and hyperactive behaviour in school age children (Khalil et al., 2013).

Attention Deficit and Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by inattention and/or hyperactivity-impulsivity, which interferes with everyday functioning (American Psychologist Association, 2022). Intentional interpersonal synchrony is reduced in adults with ADHD (Gvirts Problovski et al., 2021) and children with ADHD struggle in synchronizing to a beat (Puyjarinet et al., 2017). Dyadic synchrony between mother and child during structured tasks correlates with global functioning in preschool in children displaying elevated symptoms of hyperactivity/inattention (Healey 2010)

ASD is characterised by reduced attention to social information (Chevallier et al., 2015; Frazier et al., 2017), for example, visual and auditory cues from a social interaction partner who which to synchronise (Kinsbourne & Helt, 2011). Behind this reduced interest in engaging social stimuli, some research has found evidence of a diminished response in the brain's motivation and reward circuitry (Chevallier et al., 2012; Clements et al., 2018). This lack of attention to social stimuli in ASD toddlers, links to difficulties in imitation (Vivanti et al., 2014).

A review of home movies (Saint-Georges et al., 2010) found that children diagnosed as autistic show lower rates of shared attention during the first two years of life. Toddlers with ASD show decreased attention to a social scene compared to their DD and TD peers when explicit dyadic cues such as eye contact or speech are introduced; this lower social attention correlates with increased symptom severity and lower nonverbal functioning (Chawarska et al., 2012). Autistic children struggle in anticipation/build-up interactional games that require well-timed coregulation and a coherent engagement of shared attention (Trevarthen & Daniel, 2005).

1.3.7 Music in ASD

Music perception appears to be spared in ASD: with intact processing of global features and enhanced processing of detailed features (Altgassen et al., 2005; DePape et al., 2012; Mottron et al., 2006). Children with ASD perform similarly to TD children on melodic pitch and rhythm perception and melodic memory (Jamey et al., 2019), melodic global-local perception (Foster et al., 2016), pitch direction discrimination (Germain et al., 2019) and music structure processing (Bhatara et al., 2013).

High-functioning children (Heaton et al., 2008; Heaton, 2005) and adults (Bonnel et al., 2003; Mottron et al., 2000) as well as low-functioning children and adolescents (Heaton et al., 2008; Stanutz et al., 2014) show enhanced pitch processing through judgments of pitch difference, direction, identification and long-term memory in both single tone and melodic context. Studies have also found a greater incidence of absolute pitch (the ability to recognise or recreate any musical note without a reference tone (Deutsch, 2013)) in HFA children (Bouvet et al., 2016; Masataka, 2017) and adolescents (DePape et al., 2012).

1.4. Targeting Synchrony in ASD Therapy

1.4.1. Previous research

Since music can provide an external rhythmic framework that facilitates synchrony (Tarr et al., 2014), music could be a motivating non-verbal tool to help develop social and communication skills in individuals with ASD (Jamey et al., 2019). Autistic children who experience greater early synchrony during dyadic interaction with their parents show greater communication outcomes sixteen years later (Siller & Sigman, 2008; Siller & Sigman, 2002). Making (Dunbar et al., 2012; Weinstein et al., 2016) or dancing to (Tarr et al., 2016) synchronised music has an essential influence on social bonding in typically developing individuals, with effects on pro-social behaviour in small children (Kirschner & Tomasello, 2010). A review of human social behaviour studies suggests an important function for synchronised music and antiphonal speech (i.e., singing alternate musical phrases) in the context of social bonding (Oesch, 2019).

A gradually expanding body of empirical evidence suggests that targeting temporal synchrony plays a mediating role in diverse therapeutic interventions for young children with autism, both with and without learning disabilities (Dvir et al., 2020; Forti et al., 2020; Griffioen et al., 2020; Pickles et al., 2015; Srinivasan et al., 2015). ASD difficulties in synchrony take precedence in the early stages of development, in both low and high functioning subjects (Murat Baldwin et al., 2022; Bloch et al., 2019; McNaughton & Redcay, 2020). Early intervention can substantially impact joint attention, social communication, and adaptive functioning (Fuller & Kaiser, 2020; Nahmias et al., 2019; Reichow, 2012; Schertz et al., 2012).

The efficacy of parent-mediated interventions, which centre on toddlers engaging with a communicative partner in their natural environment (Ratliff-Black & Therrien, 2021), has been extensively reviewed and indicates generally promising effects for social communication outcomes (Schertz et al., 2012; Meadan et al., 2009; Patterson et al., 2012). A fundamental principle of this approach is that the formulation of the child's social and communication systems as a two-way process, optimally achieved when the caregiver tailors their input to the child's developmental stage during reciprocal interactions that align with the toddler's interests (Rowe & Snow, 2020).

1.4.2 Musical Interaction Therapy

Betsi Cadwaladr University Health Board of the National Health Service (BCUHB NHS) provided Musical Interaction Therapy (MIT) through an Integrated Care Fund Grant. MIT is an early intervention, parent-mediated therapy that involves triadic working: A musician works to scaffold the interaction of the autistic child with a familiar adult (i.e. parent) to facilitate enhanced communication within and beyond the therapy.

The musician's role resembles the one of a live pianist's accompaniment in early cinemas, making the music frame and support the vitality flow (the perceived sensation of a purposeful sequence of actions that integrates movement, force, direction vector, and intention into a cohesive whole (Daniel et al., 2022)) and the emotional tone of the interaction. In other words, the musician adjusts the rhythm, pitch, and tune of the music to reflect the child's actions. For example, if the child is running excitedly, the music may become fast-paced and lively. If the child lies down, the music will slow accordingly. Additionally, familiar melodies are introduced to guide the interaction. For instance, the child might sit on the mother's lap, and the mother might say, "Let's do 'Row Your Boat'," prompting the music to change accordingly and helping the child adapt more quickly to the change in activity. In their annexes, Daniel et al. (2022) provide some examples of MIT sessions.

Usually, during the initial sessions, MIT also involves a psychologist who strengthens the interaction by supporting the adult's actions, movements and verbalisations to mirror the child's. In this area, MIT shares concepts with her sister therapy Paediatric Autism

Communication Therapy (PACT), in that adults are taught to synchronise the child's focus of interest rather than try to redirect it. From 2017 to 2021, both PACT and MIT were offered to children referred for communication difficulties in the west BCUHB North Wales area. Those children with lower functioning were referred to MIT. A MIT case study (Wimpory et al., 1995) found enhancements in a severely autistic child's use of social acknowledgement, eye contact, and initiation of interactive involvement that were sustained at a two-year follow-up.

1.5. Analysing Synchrony and motivation for the current research

The majority of research, when interrogating temporal synchrony, focuses in analysing just one its expressed modalities (i.e. gaze or movement) (Cuadros et al., 2019; Lotzin et al., 2015; Cirelli et al., 2014a; Cirelli et al., 2014b). Some other studies analyse several modalities but in an individual manner (Zeegers et al., 2019; Apter-Levi et al., 2014; Weisman et al., 2013). Several studies have attempted to code synchrony of naturalistic dyadic interaction in children with autism, and some consider the different modalities synchrony can be expressed, even analysing crossmodally (i.e. responding to a vocalisation through gaze) (Kellerman et al., 2019; Zampella et al., 2020; Schertz et al., 2018).

However, the nature of dyadic interactions is multi-faceted, and synchrony is usually expressed in a multimodal integration. While an integrated multimodal methodology as has been proposed in studies of TD (Pratt et al., 2017; Atzil et al., 2014), feeding disorder (Feldman et al., 2004) or premature infants (Feldman, 2003; Feldman & Eidelman, 2007; Silberstein et al., 2009); to my knowledge, no study involving ASD participants has analysed synchrony with an integrated multimodal approach.

There also exists a need to analyse synchrony in children undergoing therapy during naturalistic play. Traditional methods of studying synchrony often involve sophisticated stationary recording equipment in controlled environments, which, while producing reliable sound data, can introduce negative challenges for participants, particularly those with Autism Spectrum Disorder (ASD). Children with ASD, in particular those that are low functioning, may experience discomfort and restricted movement in such settings, potentially impacting their natural behaviours and the authenticity of the interactions being studied. Developing a measure that involves the use of a single mobile point of video/audio recording would minimize intrusion and avoid the need for physically restraining low-functioning children or creating experimental conditions that could introduce confounding factors.

1.6. Thesis Overview

The current chapter (**Chapter 1**) has provided a definition of synchrony, highlining its importance in social communication, its emergence in typical development and its impairment in ASD through the existing research literature.

Chapter 2 is a general methods sections, where the development of the coding measure SCAEMA is described, as well as the justification for this choice of methodology and analysis.

Chapter 3 is an empirical chapter in which the following research questions are asked:

1. Does temporal synchrony, as measured by SCAEMA, correlate with age in infancy?
2. Does temporal synchrony, as measured by SCAEMA, correlate with Mutual Shared Attention in infancy?

Chapter 4 is an empirical chapter in which the following research question is asked:

1. Can SCAEMA detect differences in temporal synchrony in ASD (after controlling for Developmental Delay/Learning Disability)?

Chapter 5 is an empirical chapter in which the following research question is asked:

1. Does Musical Interaction Therapy (MIT) impact on Mutual Shared Attention and temporal synchrony as measured by SCAEMA?

Chapter 6 is a general discussion, where the key findings of the previous chapters are summarised and interpreted.

Chapter 2

Developing SCAEMA

2.1. Determining SCAEMA's modalities

Work for this thesis builds on early piloting by Dr Wimpory's lab and Anne Muth (Muth, 2018) and ultimately revises and redevelops a micro-coding tool that allows quantification of interpersonal aspects of naturalistic communication through high-resolution computerised temporal analyses: The Synchrony of Communication in Autism: Evaluation by Micro-Analysis, or SCAEMA. SCAEMA is coded through Mangold Interact™ software on a 24 frames per second resolution (0.0416 seconds). Based on Tronick's Monadic Phases (Tronick et al., 1980), SCAEMA evaluates a dyad's social interaction modalities: body orientation towards partner, gaze at partner, positive affect through smiles and laughter, vocalisations, touch and body language (presence of communicative gestures); and produces quantifiable unimodal outputs of synchrony, aggregating all these modalities to allow for an integrated multimodal measure of Bidirectional Synchrony that takes into account the crossmodal reality of dyadic natural interaction.

SCAEMA allows for coding of naturalistic interaction where the camera moves around the dyad to capture their faces, as opposed to other measures which have been designed to code with a still camera, necessitating the filmed individuals to be sitting down/secured in a specific position. SCAEMA was developed to analyse synchrony in Musical Interaction Therapy (MIT), where both the child and a caregiver interact naturally. MIT involves a high degree of movement and spontaneous engagement, making it essential to use a flexible and non-intrusive recording method to capture the authentic synchrony between the child and the caregiver without disrupting the natural flow of the therapy.

While Monadic Phases evaluates several subcodes for each indicator, SCAEMA only evaluates its presence or absence. The first pilots of the measure tried to incorporate sub-codes into each index (i.e. gaze at partner's eyes, lips or body) similar to Monadic Phases codes. However, inter-observer reliability proved those were not applicable for video data of therapy videos where the dyad moves around the room as the camera follows, attempting to capture both faces simultaneously whilst not becoming intrusive and having a detrimental effect on the therapy. This led to the final binary variable configuration of SCAEMA.

SCAEMA's Mangold Interact™ output is exported to Excel™ where the modalities are aggregated into the multimodal time series. This results in two ordinal time series (one for parent and one for child) reflecting the engagement in the interaction of each individual.

2.2. Time Series Analysis

2.2.1. The Cross-Correlation Function

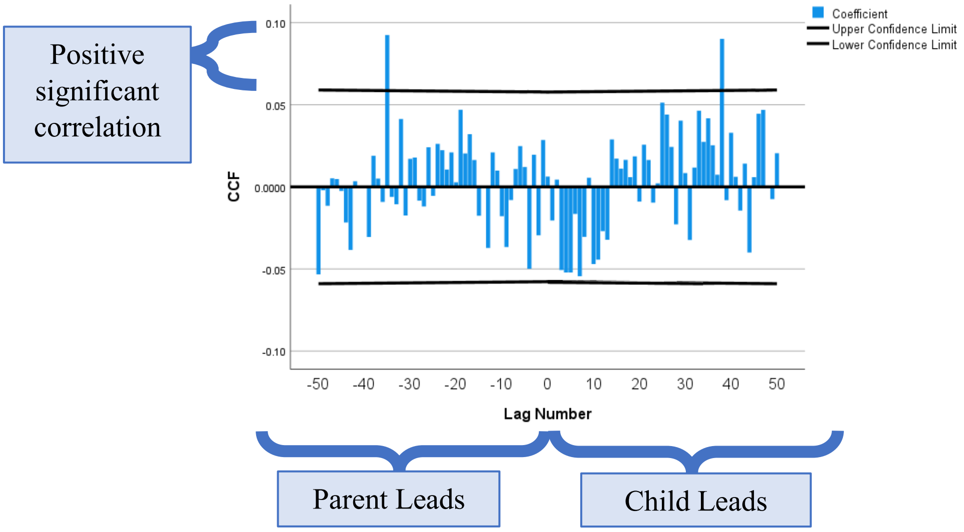
To explore how the resultant multimodal time series relays clinically observed synchrony SCAEMA employs the cross-correlation function (CCF). CCF calculates the correlation between two time series at all the time points that form both time series. CCF requires that the time points are spread in the same interval and are either continuous or ordinal variables (Kreiss & Lahiri, 2012; Boker & Rotondo, 2001). Highly detailed lag timing and the ability to detect leader-follower patterns make CCF analysis the optimally suitable statistical approach for determining multimodal Bidirectional Synchrony with SCAEMA.

CCF output produces a bar graph that indicates significant cross-correlations as peaks that can be positive (the multimodal time series are matched, whereby when one increases or decreases, the other follows by doing the same) or negative (they are mismatched, whereby when one increases or decreases, the other follows by doing the opposite). These peaks are distributed along the x-axis, indicating the lead-lag relation of the peak. Positive lags signal the parent following the direction of change in the child's time series, whilst negative lags imply the child following the direction of change in the parent's. The Y axis represents how strong the correlation is, ranging from -1 to 1 (Figure 1).

CCF moves one time series back and forth to calculate the correlation with the other time series. CCF can, therefore, identify the directionality between the two time series through the direction of the moved time series, indicating leader-following relationships. The number of lags translates to seconds, depending on the resolution employed in the analysis. For example, for a resolution of 0.1 seconds (s), lag 1 = 0.1 s, lag 10 = 1 s, and lag 21 = 2.1 s.

Figure 1

Sample of CCF Output Graph



Note. Cross Correlation Function (CCF) output graph with a 0.1 second resolution. The parent time-series is shifted in increments of 0.1 seconds (1 lag), and the correlation between the parent and child time-series is calculated at each step. The resulting correlation coefficients are represented by the blue peaks on the graph. <u>Positive lag numbers</u>: Indicate the parent time-series is moved forward in time, suggesting that the child time-series leads the interaction, and the parent responds to it. <u>Negative lag numbers</u>: Indicate the parent time-series is moved backward in time, suggesting that the parent time-series leads the interaction, and the child responds to it. A significant correlation coefficient (or peak) exceeds the upper confidence limit. In this graph, significant correlations are observed at lag -34 and lag 37, indicating: at lag -34 (parent leads): the child's time-series follows the parent's time-series with a delay of 3.4 seconds. At lag 37 (child leads): the parent's time-series follows the child's time-series with a delay of 3.7 seconds. The significant peaks in both the leading regions for the parent and child indicate the presence of bidirectional synchrony, with turn-taking interactions between the two time-series.

CCF also depends on the assumption that the time series are stationary (The Odum Institute, 2017). For the data to be stationary, it must deviate around a fixed mean, and the pattern of auto- and cross-covariance remain the same and independent of historical time; in other words, the time series cannot autocorrelate with itself. Otherwise, if the parent and infant's coded behaviours are individually cyclic, the cross-correlation will be tainted by the autocorrelation of each line with its cyclicity (Cromwell et al., 1994). Gottman & Ringlan (1981) used Tronick et al.'s (1977) study data to demonstrate how cross-correlations of individually cyclical data would be non-zero even in a case of no interaction. The parent's and child's cycles would either be successively aligned (giving false positive correlations) or misaligned (showing false negative correlations) due to the individual cyclicities.

An Autoregressive Integrated Moving Average (ARIMA) model is usually employed to detect and parcel out the autocorrelation within a time series before analysing CCF. ARIMA is a statistical model used to estimate the temporal dynamics of an individual times series and is the most widely used parametric model in time series analysis (Luceño & Peña, 2007). For a time series variable to be suitable to be analysed through an ARIMA model, it needs to be continuous: the time series intervals between coding should be of the same frequency and without any non-coded gaps (Luceño & Peña, 2007).

2.2.2. Previous Research

Two authors have used the CCF to investigate synchrony in social interaction: Feldman (2003) and Lotzin et al. (2015), whose methodologies are summarised below:

Feldman (2003) used the Monadic Phases Manual (Tronick et al., 1980) and coded two minutes of interaction at a 1-second resolution (the first filmed minute was discarded). Her coding system used the dyad's gaze direction, vocalisation, facial expressions, body orientation and level of perceived arousal to create a set of mutually exclusive codes. The autocorrelated component of each time series was detected and separated using ARIMA and CCFs were computed. The degree of synchrony was calculated by selecting the largest positive cross-correlation.

Lead-lag relations were reported only when the degree of synchrony was significant and took the form of three binary variables: parent synchrony with infant (positive lag significant cross-correlation), infant synchrony with parent (negative lag significant cross-correlation) and Bidirectional Synchrony (both positive and negative lag significant cross-correlations). Bidirectional Synchrony indicated that both child and parent were responsive to each other's behaviour. Time-lag-to-synchrony, only reported when the degree of synchrony was significant, expressed the time-lag to the first significant positive peak (whether lag positive or lag negative) and ranged from 1 to 7 seconds. Feldman assessed how sex pairing affected synchrony in dyads of 5-month-old typically developing (TD) male and female children and their mothers and fathers. She found statistically significant correlation degrees of synchrony that ranged from .06 to .20 across the study conditions. Bidirectional Synchrony was found in 17%-29% of the dyads, and time lags to synchrony ranged from 1.24 seconds to 3.44 seconds.

Lotzin et al. (2015) coded mother and infant gaze (at a partner's face, at an object and away) for 3 minutes of each the initial free-play phase and the reunion-play phase of the Still Face Paradigm (Tronick et al., 1978) with a resolution of 0.04 seconds. Gaze scores were converted to whole seconds. Mother and infant gaze time series were inspected for stationarity (consistency of mean and variance across time) by using ARIMA and linear regression analysis (gaze behaviour was regressed over time). Autocorrelation was partialled out of each time series to control for the cyclicity within an individual's behaviour. CCF was performed, and the largest positive cross-correlation at any lag was selected to reflect the interaction's synchrony. The lead lag was assessed by the lag position on which the significant peaks were found. A positive lag indicated that the mother was responding to the child. If the lag was negative, this suggested that the child was responding to the mother. If there were significant cross-correlations at both positive and negative lags, this signalled Bidirectional Synchrony.

Lotzin et al. investigated synchrony in mother-infant dyads involving 4 to 9-month-olds whose mothers had mood disorders. The degree of synchrony during the first free-play interaction ranged between .00 and .30, (the mean was .11, with 75% of the sample ranging between .03 to .14). During the second free-play interaction, the degree of synchrony ranged between .00 to .45; (the mean was .15, with 57% of the sample ranging between .03 to .14 and 41% of the sample ranging between .14 to .45). During the initial free-time period 46.6% of significant positive synchrony was only in the child-led area (indicating the mother was following the child); 28.6% was in the mother-led area (indicating that the child was following the mother) and 25% was in areas led by both mother and child (indicating Bidirectional Synchrony).

During the reunion play period, 71.4% of significant positive synchrony was only in the child-led area (indicating that the mother was following the child); 20% was in the mother-led area (indicating that the child was following the mother) and 8.6% were in both led areas (indicating Bidirectional Synchrony). Lotzin et al. investigated the interaction between degrees of synchrony scores and several variables such as infant sex, infant age, maternal anxiety symptoms and maternal depressive symptoms. Only maternal depressive symptoms were significantly correlated with mother-infant synchrony. Feldman's and Lotzin et al.'s studies emphasise the importance of inspecting the time series' stationarity to detect and separate the autocorrelation each series can have at differing lags.

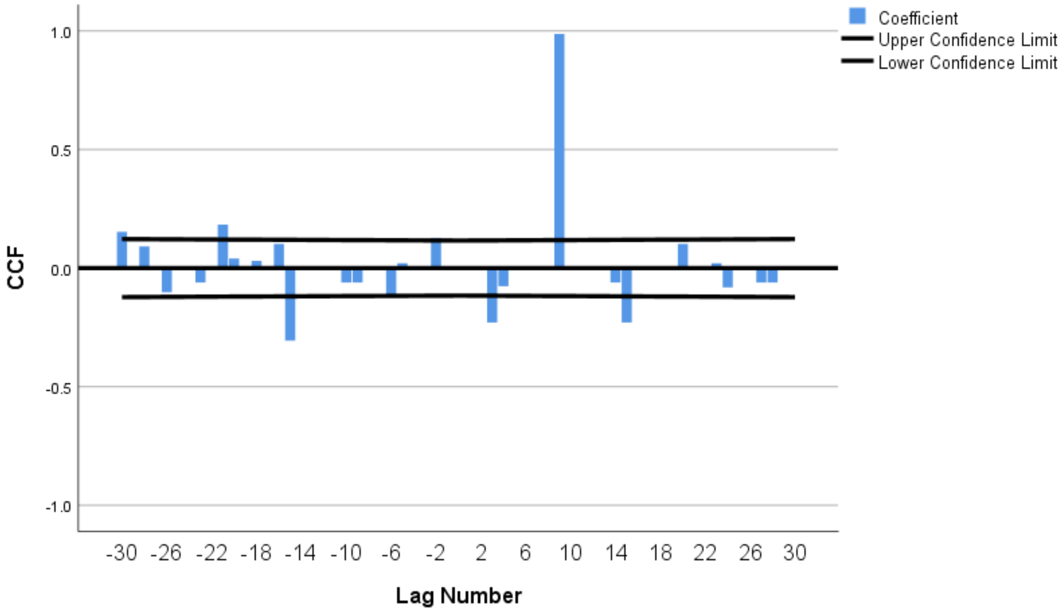
2.3. SCAEMA Pilot Analyses

2.3.1 Understanding the Cross-Correlation Function

A Fabricated Time Series was employed to explore how the CCF works. Time series values were fabricated so that the direction of change in one time series consistently followed the other, with a constant set amount of delay. The CCF yielded an evident large positive significant correlation in the expected lag but also gave other small but significant positive and negative correlations due to random effects (Figure 2). Further manipulation of the fabricated time series allowed investigation of how the CCF graph resulted in different scenarios, such as one partner of the dyad following the other at various lags, each partner taking turns following the other, etc.

Figure 2

Fabricated Time Series: Parent follows Child with 1s lag in a Resolution of 0.1s



Note. Cross Correlation Function output graph of a fabricated time series where the parent is following the child with 1 second of delay (in a 0.1s resolution), this is corroborated by the displayed significant CCF peak at lag number 10.

This pilot exercise supports Feldman’s (2003) assertation that Bidirectional Synchrony is indicated by the presence of positive significant CCF peaks in both child and parent-led areas, translating as a lead-lag interaction pattern, whereby the parent leads consistently for a few seconds and the child leads consistently for a few seconds, forming a turn-taking interaction. Significant peaks of different lags in the same lead area indicate that the time taken for one partner’s time series to change in response to their partner’s varies across the interaction. However, small significant peaks due to randomness seem unavoidable. The fabricated timeline pilot points towards random peaks being smaller than true ones, supporting Feldman’s (2003) and Lotzin et. al.’s (2015) methodology of selecting the largest peak as a representation of the degree of synchrony. However, one of the caveats of this larger lag selection method is that, in naturalistic interactions, the time-to-lag responses are not as consistent as in the fabricated timeline, resulting in several small correlation peaks rather than a clear big one.

2.3.2 Challenging the resolution

SCAEMA provides time series outputs at every 24 frames per second, which can be converted to a resolution of 0.05 seconds when exported. A pilot-case video was selected showing a two minutes video of non-verbal twin toddlers (approximately 18 months old) in spontaneous proto-conversation comprising interactive babbling of the same syllable with lively intonation (Jayrandall, 2011). This video-clip has been used in professional and in service training; the clinical and public consensus is that this clearly portrays Bidirectional Synchrony, which is typically well-established by this age (Feldman, 2003) and is readily observable in the turn-taking nature of the interaction.

This interaction is an excellent example of what Jasnow and Feldstein (2003) described as the “co-active mode”: turn-taking without a switching pause, which causes the dyad to step slightly on each other’s turns. There are a few instances where the twins use the switching pause, which is also consistent with their developmental age (Jasnow & Feldstein, 2003). The twins timeseries were run at 0.05, 0.1, 0.5 and 1 second resolution to interrogate how the synchrony of the time series responded to different resolutions. To avoid losing the fine-resolution data, the punctuations were aggregated to enhance capture of the summed variety of communicative modalities employed by the dyad at the selected time points (Table 1).

Table 1

Time series Output from 0.05s to 0.1s and 0.5 Resolutions

	RESOLUTIONS		
Onset Time	0.05 seconds	0.1 seconds	0.5 seconds
0	8	16	96
0.05	8	-	-
0.10	8	16	-
0.15	8	-	-
0.20	8	16	-
0.25	8	-	-
0.30	9	17	-
0.35	9	-	-
0.40	10	18	-
0.45	10	-	-
0.50	10	20	96
0.55	10	-	-
0.60	10	20	-
0.65	8	-	-
0.70	8	16	-
0.75	7	-	-
0.80	7	14	-
0.85	7	-	-
0.90	7	14	-
0.95	8	-	-
1.00	8	16	80

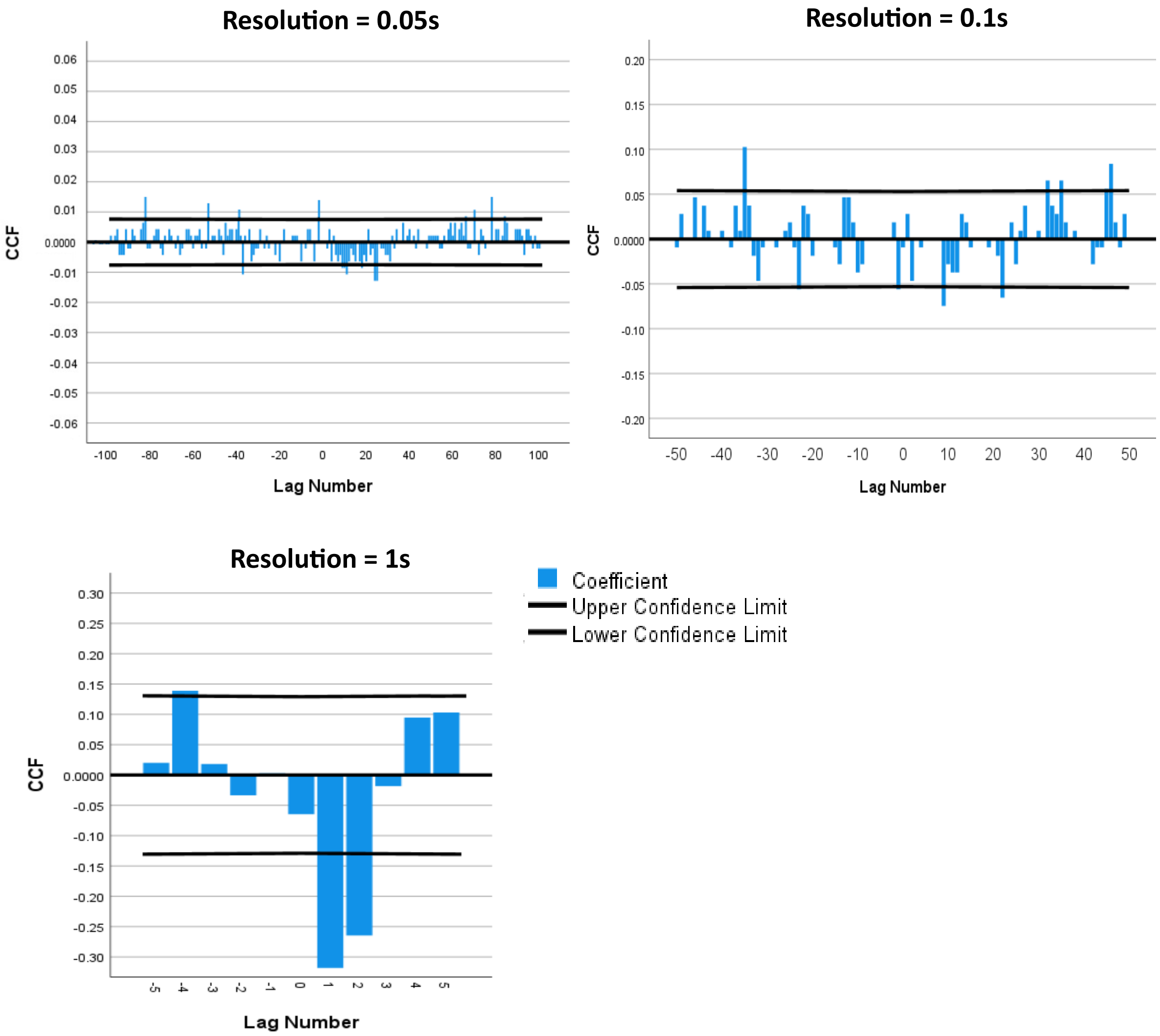
As the resolution augmented, the CCF lags took different values, for example, at resolution 0.1 each lag was 0.1s, therefore lag 10 was 1 second. At resolution 0.05s, lag 10 was 0.5 seconds. At resolution 0.5s, lag 10 was 5 seconds. The number of examined lags was adjusted, so that the CCF would always analyse up to 5 seconds lag. A response of more than 5 seconds was recognised as too delayed for the young children under a year who were part of the pilot, and for the children with severe communication difficulties for whom SCAEMA was being designed (Balog & Roberts, 2004). This meant that when the resolution of 0.1s is the maximum, lags are +/-50, whereas in a resolution of 0.05s, the maximum lags are +/-100.

While the first three resolutions (0.05, 0.1s and 0.5s) relayed Bidirectional Synchrony; when the resolution was widened to 1 second, the output for the twins failed to show the two significant positive peaks in each of the lead-lag areas that would signal the presence of Bidirectional Synchrony (Figure 3).

While this initially pointed towards the smallest resolution being the best choice, the smaller the resolution the lower the CCF values, which populated the CCF graph with several small significant peaks, making false positives easier to appear. For this reason, this project set the cross-correlations to run at 0.1 second lag, which was judged to be the best resolution to preserve the finest temporal data while enabling higher CCF values.

Figure 3

Left and Right Twin's Bidirectional Synchrony at 0.05s, 0.1s and 1s



Note. The Cross Correlation Function (CCF) output graphs display the bidirectional synchrony between the left and right twin's time-series at different resolutions: 0.05 seconds, 0.1 seconds, and 1 second. In the 0.05 resolution graph, the parent time-series is shifted in increments of 0.05 seconds for each lag (which results in 100 lags to cover 5 seconds of delay analysed). In the 0.1 resolution graph, the parent time-series is shifted in increments of 0.1 seconds for each lag (which results in 50 lags to cover 5 seconds of delay analysed). In the 1 resolution graph, the parent time-series is shifted in increments of 1 seconds for each lag (which results in 10 lags to cover 5 seconds of delay analysed). The significant peaks in both the leading regions at finer resolutions (0.05s and 0.1s) confirm the presence of bidirectional synchrony, with turn-taking interactions between the twins' time-series. However, this synchrony is not evident when the resolution is widened to 1 second, suggesting the importance of fine resolution in detecting these interactions.

2.3.3 Piloting the CCF

Based on work by Feldman (2003) and Lotzin et al. (2015), three output variables are derived from the CCF:

1. The Presence of Bidirectional Synchrony, indicated by at least one significant positive correlation at both lead-lag areas on the CCF. This is a binary variable indicating presence (1) or absence (0) of Bidirectional Synchrony.
2. The Degree of Synchrony, indicated by the correlation value of the highest significant positive correlation. This is a quantitative variable ranging from 0 to 1.
3. The Time-lag-to-Synchrony, indicated by the lag position of the highest significant positive correlation. This is an ordinal variable ranging from 0 to 50.

Following Feldman’s methodology, CCF assesses the Bidirectional Synchrony through the presence of statistically significant correlation peaks in both lead-lag areas. In case of several peaks of the same value, the shorter lags are selected. CCF also relays the amount of synchrony and main lag delay (indicated by the highest significant cross-correlation value and its lag position respectively). A concerning thought is that, despite having corrected the time series for stationarity and eliminating the autocorrelated component through ARIMA modelling, the significant cross-correlation encountered could still be noise resulting from the long data strings formed by the time series. To contest this hypothesis, a more in-depth exploratory analysis to investigate these outputs was run on 2-minute segment videos of twelve full term typically developing infants aged from 3 to 19 months. Infants were filmed interacting with their parents. As a control condition, a randomised time series substituted the parent time series in all dyads.

All the real dyads showed presence of Bidirectional Synchrony, while none of the random dyads produced Bidirectional Synchrony. In the real dyads, the degree of synchrony for the child leading ranged from 0.06 to 0.10 and averaged 0.07; while the Time-lag-to-Synchrony ranged from 5 to 0.3 seconds of delay and averaged at 2.76 seconds. For child following, the degree of synchrony averaged 0.12 (range 0.06 to 0.68) at a Time-lag-to-Synchrony of 2.48 seconds (ranging from 0.3 seconds to 4.3 seconds) (Table 2). These values coincided with those found by Feldman (2003). Worryingly, the randomised time series condition produced significant peaks at one of the lead lag areas in 9 out of 12 children (three on the "child follows" area and two on the "child leads" area). These peaks would translate into the degree of synchrony and Time-lag-to-Synchrony measures.

Table 2

SCAEMA Pilot in 12 TD infants using Feldman's (2003) three output variables

	Presence of	**Child**	**Child Follows**	**Child**	**Child Leads**
Real Dyads	YES	2.2	0.68	5	0.07
	YES	3.8	0.063	4.5	0.079
	YES	0.9	0.075	0.7	0.098
	YES	1.7	0.07	1	0.065
	YES	2.7	0.062	4	0.08
	YES	4.3	0.072	3.6	0.066
	YES	3.8	0.062	0.3	0.08
	YES	0.3	0.08	3.8	0.062
	YES	2.7	0.079	3.8	0.072
	YES	0.8	0.071	4.2	0.06
	YES	3.4	0.07	1.8	0.069
	YES	3.1	0.06	0.4	0.08
Randomly Generated Mother – Real Child	NO	.	.	.	.
	NO	.	.	.	.
	NO	.	.	1.8	0.063
	NO	.	.	2.2	0.062
	NO	3.1	0.071	.	.
	NO	.	.	2.6	0.084
	NO	0.3	0.072	.	.
	NO	0.5	0.063	.	.
	NO	.	.	1	0.077

	NO	0.5	0.072	.	.
	NO	.	.	.	.
	NO	2.9	0.064	.	.

The results of these pilot explorations indicate that SCAEMA could correctly determine the presence of clinically observed Bidirectional Synchrony. However, the largest peak observed in the cross-correlations does not seem to relay what is clinically observed, nor does show significant differences in true vs randomised control conditions. Therefore, the variables Degree of Synchrony and Time-lag-to-Synchrony are not trustworthy enough to include in SCAEMA.

2.4. Matching Synchrony, Sequential Synchrony and Mutual Shared Attention

Within SCAEMA, two individual modalities are further interrogated to assess Matching and Sequential Synchrony separately. When choosing the modalities for individual analysis, out of SCAEMA's six individual modalities, touch was discarded because both child and mother time series would be equal. In previously analysed data in TD children, Body Language and Body Orientation had shown to have often a constant time series (one time series that always had the same value: usually the mother always oriented to the child and the child never performing any body language), this made the variables unsuitable for analysis.

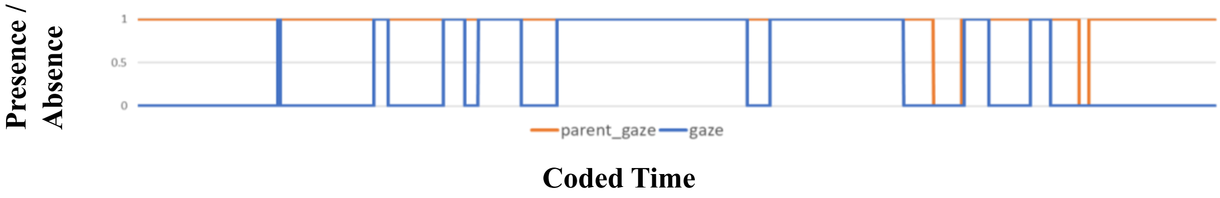
Gaze, vocalisation, and positive affect remained. The first two were chosen for a more in-depth analysis because their time series showed more consistent patterns across the dyads. Positive affect had a more variable pattern that would require a more complex analysis than this project's scope allowed. It could be an interesting follow-up to investigate how its synchrony is displayed in different kinds of dyads.

2.4.1. Matching Synchrony: Gaze Synchrony

Gaze usually follows a pattern of long engagements, followed by short periods of non-engagement in the case of the parent, and medium/long periods of non-engagement in the TD infant (Figure 4). This pattern facilitates the analysis of Matching Synchrony, the immediate synchrony, without delays, between the two time series, indicating the percentage of time parent and child are looking at each other simultaneously.

Figure 4

Sample of Parent/Child Gaze Timeseries



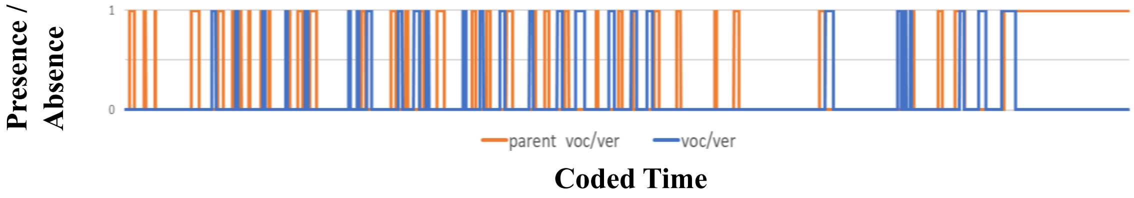
Note. Sample of part of a timeseries showcasing the coding of presence/absence of gaze to partner of the dyad across the coded time (in milliseconds).

2.4.2. Sequential Synchrony: Vocalisation Synchrony

Vocalisation follows a very different pattern, with many short spurts of engagement (vocalisations) followed by longer segments of non-engagement (silence) (Figure 5). This makes vocalisation an ideal modality to investigate Sequential Synchrony. In contrast to the other modality patterns that can easily co-occur without necessitating Sequential Synchrony, it is harder to hear a partner's vocalisations if a space is not made within the flow of one's own vocalising.

Figure 5

Sample of Parent/Child Vocalisations Timeseries



Note. Sample of part of a timeseries showcasing the coding of presence/absence of vocalisations across the coded time (in milliseconds).

Sequential Synchrony is indicated by the average seconds for child to respond vocally to parent vocalisations (within a maximum time delay of 3 seconds). The three seconds maximum limit was selected after reviewing current literature that posited that typically developing infants range up to 3.04 (Nguyen et al., 2022) seconds to respond vocally and that pauses between mother/infant utterances connected by form or content rarely exceed 3 seconds (Gratier et al., 2015).

2.5. Mutual Shared Attention

Due to the impact of joint and shared attention in social situations and its significance in ASD, in this thesis, the Mutual Shared Attention measure of the Dyadic Communication Measure for Autism is a preliminary requirement for SCAEMA. This measure, employed by Green et al. (2010) in their randomised controlled trial of parent-mediated communication-focused treatment for children with autism, assesses shared attention, including joint attention in less able children. Episodes of mutual shared attention occur when a dyad shares each other's attention to a focal object, action or event; or sharing emotion related to the object or event. Mutual shared attention may be signalled by body orientation, posture, eye-gaze, gesture or verbalisation and may be initiated by either person (Aldred et al., 2014).

2.6. SCAEMA Output variables

The use of SCAEMA can gauge several output variables that elucidate the temporal synchrony:

1. **Matching Synchrony** of gaze: Percentage of time parent and child are looking at each other.
2. **Sequential Synchrony** of vocal response latency: Average of the time of delay (in seconds) for child to vocally respond to parent vocalisations (within a maximum time delay of 3 seconds)
3. Multimodal **Bidirectional Synchrony**: indicated by at least one significant positive correlation at both lead-lag areas on the CCF. A binary variable indicating presence (1) or absence (0) of Bidirectional Synchrony.

2.7. SCAEMA Coding Manual

A SCAEMA coding manual was created during this thesis and employed in training the secondary coders for reliability. It can be read in Appendix A.

Chapter 3

Does temporal synchrony, as measured by SCAEMA, correlate with age and Mutual Shared Attention in infancy?

Acknowledgements

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3.1. Abstract

This study investigates how different aspects of temporal synchrony develop in typically developing infants and if they correlate with Mutual Shared Attention (MSA). Naturalistic interactions of twelve infants (aged 3 to 21 months) and their primary caregivers were analysed using a novel micro-coding methodology: the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA). The study encompassed measures of Matching Synchrony (of gaze), Sequential Synchrony (of vocal response latency), and Bidirectional Synchrony (multimodal time series).

Our findings revealed age-related shifts in synchrony: gaze synchrony predominated in younger infants and gradually declined after 10 months, consistent with published research. However, contrary to previously published findings, vocal response latency did not correlate with chronological age, possibly suggesting nuanced developmental trajectories. Bidirectional Synchrony was present across all ages, emphasizing its early emergence in infant communication. MSA influenced gaze synchrony, with higher percentages observed during shared attention episodes. Yet, there was no significant impact of MSA, on Sequential or Bidirectional Synchrony, possibly highlighting the complex nature of these developmental processes.

While the study introduces valuable insights into multimodal interpersonal synchrony, limitations, including a small sample size, call for cautious interpretation. Future research, employing larger samples could enhance understanding of Bidirectional Synchrony across age and shared attention contexts.

3.2. Introduction

Background

Social timing refers to temporal synchronising in social interactions (Wimpory, 2015), which plays a vital role in the developmental dynamics of parent-infant interactions (Leclere et al., 2014). This fosters a sense of shared motivation, reducing cognitive demands and influencing language, cognition, and social development (Cross et al., 2020; Dideriksen et al., 2020). Interpersonal synchrony encompasses Matching Synchrony, Sequential Synchrony, and Bidirectional Synchrony (Feldman, 2007b).

Matching Synchrony involves the simultaneous coherence of content across sensory modalities, i.e., the simultaneous co-occurrence of a particular behaviour of affective state. In synchronous social interactions, individuals engage in a matched dialogue, requiring attunement and a shared focus of attention (Harrist, 2002). Sequential Synchrony involves the timing order of interactions, with a lead-lag aspect, and forms the foundation of turn-taking, a crucial skill for complex social interactions (Stivers et al., 2009). Bidirectional Synchrony follows Sequential Synchrony in development (Evans and Porter, 2009), resulting in a non-random, patterned stochastic interaction with a lead-lag aspect. Unlike Sequential Synchrony, both partners in Bidirectional Synchrony become leaders and followers simultaneously, constructing an organized bidirectional dependence between behaviours and rhythms (Feldman, 2007b; Rochat et al, 1999).

Temporal synchrony emerges before birth: foetuses can detect auditory, vestibular, or somatosensory stimulation patterns and rhythms, resulting in corresponding changes in their own heart rate or breathing (Kisilevsky & Hains, 2011; Provasi, 2014). Newborns, including preterm infants, have been observed synchronizing limb movements to syllabic rhythms of speech (Eckerman, 1995; Malloch, 1999) and turn-taking beats (Trevarthen & Aiken, 2001).

In her review, Wimpory (2015) stated that between 2-3 months, parent-infant interaction is characterized by temporally sequential matching through repetitive rhythmic cycles within individual modalities, including indicators of arousal, posture, gaze, emotional expressions, hand movement, and touch. The importance of visual input from parent faces, particularly the eyes, becomes prominent around this age (Fausey et al., 2016; Jayaraman et al., 2015, Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015), leading to shared gaze becoming a primary modality of interaction (Feldman, 2007b; Senju & Johnson, 2009).

The importance of gaze gradually decreases from 4 month of age as vocalisations gain a co-leading role (Beebe & Gertsman, 1980; Malloch, 1999). Audio-visual perceived synchrony plays a crucial interactive role for 10-month-olds and becomes less important as children's verbal language skills emerge (Hillairet et al., 2017)

Infants experience a slowdown in the latency of vocal responses of an adult's vocalisation during the first two years of life (Gratier et al., 2015; Hilbrink et al., 2015). These prolonged latencies may be attributed to infants acquiring more complex language skills and attempting to incorporate them into their turns (Nguyen et al., 2022). Casillas et al.

(2016) emphasized that slowdowns and speed-ups in the latency of vocal response could be relative to the specific context, such as the complexity or familiarity of the words used.

Nguyen et al. 's review (2022) reported that typically developing infants take, on average, 1 second to respond vocally, ranging from 0.60 seconds to 3.04 seconds. This aligns with previous research (Gratier et al., 2015), which established that pauses between mother/infant utterances connected by form or content rarely exceed 3 seconds. Longer pauses generally occur when the infant or mother disengages from the current form or topic of the dyad's interaction (Stern et al., 1977; Stern & Gibbon, 1979), signalling an end of the conversational phrase rather than a response. Similarly, Balog and Roberts (2004) found that in children aged 12 to 19 months, silences in their vocalization responses occur within 4.25 seconds of the parent's utterance nearly 90% of the time.

The onset of turn-taking emerges early in infancy, around 2 months, and continues to develop during the first year (Bateson, 1975; Gratier et al. 2015) with mother–infant interactions becoming increasingly more symmetrical and bidirectional (Evans and Porter, 2009). Synchrony develops from unimodal expression to multimodal between 4 and 9 months of age (Lewkowicz, 2000), with bidirectional crossmodal and multimodal synchrony becoming well established by 9-months (Feldman, 2007a).

The ability to share the focus of attention is a crucial precursor to synchrony (Harrist, 2002). Studies indicate that the capacity to synchronize with a group predicts inattentional and hyperactive-impulsive behaviours in school-age children (Khalil et al., 2013). Gaze synchrony has been proposed as a mechanism for capturing shared and joint attention (Tschacher et al., 2021). Interpersonal synchrony has been found to be diminished in individuals with Autism Spectrum Disorder (ASD) (Kasari et al., 2006; Saint-Georges et al., 2010) (as well as in those with Attention Deficit Hyperactivity Disorder (ADHD) (Gvirts Problovski et al., 2021; Puyjarinet et al., 2017; Healey et al., 2010), indicating a link between interpersonal synchrony and joint and shared attention.

Likely for methodological reasons, the prevailing approach in investigating temporal synchrony involves analysing individual modalities (e.g., gaze or movement) independently (Cuadros et al., 2019; Lotzin et al., 2015; Cirelli, Einarson et al., 2014; Cirelli, Wan, et al., 2014; Zeegers et al., 2019). However, dyadic interaction is inherently multifaceted, and synchrony is often manifested through crossmodal (e.g., responding to a vocalization through gaze) and multimodal integration. Few researchers have employed designs that explicitly consider this integration (Feldman, 2003).

Rationale

The existing body of research on temporal synchrony in children often focuses on analysing individual modalities, such as gaze or movement (Lotzin et al., 2015; Cirelli et al., 2014). Some studies extend their analysis to multiple modalities, but few consider the integrated multimodal nature of dyadic interactions (Zeegers et al., 2019; Apter-Levi et al., 2014; Weisman et al., 2013), especially in the context of autism. While studies in TD children have explored synchrony using integrated multimodal approaches (Pratt et al., 2017; Atzil et al., 2014), this methodology has not been applied to the study of autism spectrum disorder (ASD) participants.

In the context of a broader project investigating crossmodal and multimodal temporal synchrony in autistic children undergoing therapy, we developed Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA), a micro-coding tool that enables the quantification of interpersonal aspects of naturalistic communication through high-resolution computerized temporal analyses. SCAEMA is uniquely designed for coding naturalistic interactions where the camera dynamically captures the bodies and faces of moving interacting partners. Drawing from Tronick's Monadic Phases (Tronick et al., 1980), SCAEMA assesses social interaction modalities for each dyadic partner, encompassing: body orientation towards the partner, gaze at the partner's face, positive affect (expressed through smiles and laughter), vocalizations, touch, and body language (including the presence of communicative gestures) as well as including an assessment of joint attention through the Mutual Shared Attention (MSA) measure of the Dyadic Communication Measure for Autism. employed by Green et al. (2010). Further descriptions and explanation of SCAEMA can be found in the methods section of this paper.

This study aims to fill the gap by employing a comprehensive, integrated multimodal approach to analyse temporal synchrony in TD non-verbal infants before extending the investigation to ASD participants.

Aims

Part A: How does temporal synchrony relate to age in TD infants?

Part A of this study aims to assess how the different SCAEMA outputs relate against the chronological age of typical developing infants, from 3-months-old to 21-months-old. The expected results are:

1. [Matching Synchrony] Higher percentage of gaze synchrony in younger children, decreasing around 6-month-old (Lewkowicz and Hansen-Tift, 2012; Pons et al., 2015; Hillairet et al., 2017)
2. [Sequential Synchrony] Longer non-verbal vocal latencies when replying to the partner's vocalisations as children grow older and acquired more language skills (Gratier et al., 2015; Hilbrink et al., 2015; Casillas et al., 2016)
3. [Bidirectional Synchrony] Higher presence of mutimodal mutual synchrony in older children as this required a greater complexity than the unimodal synchrony. (Evans & Porter, 2009; Lewkowicz, 2000 & Feldman, 2007a)

Part B: Does Mutual Shared Attention (MSA) play a role in temporal synchrony?

Part B aims to assess whether Mutual Shared Attention plays a role in the synchrony of the interaction. The hypothesis being that, while Matching Synchrony would increase due to the shared focus of attention, the Sequential and Bidirectional Synchrony of the dyad should not be impacted as, even if the focus of attention differs, the ability to temporally attune to each other temporally should remain stable. Predictions are:

1. [Matching Synchrony] Higher percentage of gaze synchrony when children engage in high MSA with their partners as MSA is a prerequisite for this type of synchrony (Harrist, 2002; Khalil et al., 2013; Tschacher et al., 2021)
2. [Sequential Synchrony] Shorter duration in non-verbal vocal latencies when replying to the partner's vocalisations in the high MSA condition (Harrist, 2002; Khalil et al., 2013).
3. [Bidirectional Synchrony] Higher presence of multimodal mutual synchrony in the high MSA condition (Harrist, 2002; Khalil et al., 2013).

3.3. <u>Part A:</u> How does temporal synchrony relate to age in TD infants?

3.3.1. Methodology

Participants

Twelve full-term typically developing infants (6 girls and 6 boys) aged from 3 to 21-months-old (mean age = 10 months, SD = 6 months) participated along their primary carer.. This sample range afforded the chance to pilot SCAEMA in different pre-verbal ages, as previous literature establishes vocal synchrony appears in infants as early as 3 months old (Wimpory, 2015; Feldman, 2007b). Only videos without the presence of toys (or food) were analysed as these items could distract children from their partner. Subject exclusion criteria were: developmental delay, pre-term birth and any neurological diagnosis.

Procedure

Each dyad was filmed once in a familiar environment (such as home). First, carers were briefed on the project and asked to give consent for both themselves and their children. They were then instructed to play with their children as they would normally do without the presence of toys. The naturalistic face-to-face interaction was either filmed by an assistant psychologist of the research team or filmed by the family and provided to the research team.

To investigate the impact of chronological age and SCAEMA in typically developing children, two minutes were coded after discarding the initial 4 minutes in order to allow the child to acclimate to the play-session. For three participants, less than two minutes (1:37, 1:41 and 1:42) were coded due to their videos being too short. These shorter videos were visually inspected to ascertain their suitability as containing enough engagement to detect synchrony and analysed to corroborate the video length did not constitute a confound.

Study Design and Variables

SCAEMA was coded through Mangold Interact ® version 20.9.16.0. For each partner of each dyad, a set of binary codes were coded: body orientation, gaze, positive affect, vocalisations, touch and body language (Table 1). A secondary independent trained coder, blinded to the child's age, coded 25% of the data for inter-rater reliability.

Table 1

SCAEMA Coding Modalities

Body Orientation	Coded individual’s torso is oriented towards partner's torso
Gaze	Coded individual is looking at partner
Positive Affect	Coded individual is smiling or laughing
Vocalisation	Coded individual is vocalizing
Touch	Coded individual and partner are touching
Body Language	Coded individual is using body language (i.e. hand gesture)

To assess Matching Synchrony, the gaze variable was selected to calculate Matching Synchrony of gaze, indicated by the percentage of time parent and child were looking at each other. Sequential Synchrony was represented by the vocal response latency, indicated by the average latency (in seconds) for the infant to vocally respond to parent vocalisations (in a maximum time latency of 3 seconds). Finally, a multimodal timeseries was derived from the sum of all the coding modalities for each partner. These two time series (one for each individual in the dyad) were individually inspected for stationarity of the data, differenced and modelled with ARIMA. A Cross-Correlation Function (CCF) with the resulting noise residual transformed timeseries enquired on the lagged correlation of the multimodal time series. A binary variable was derived from the Cross-Correlation Function, as proposed by Feldman (2003) and Lotzin et al. (2015): the Presence of Bidirectional Synchrony. This was indicated by at least one significant positive correlation at both lead-lag areas on the CCF.

Analysis

Reliability was assessed with the Cohen’s Kappa test on the coding modalities through the Mangold Interact Software. The Shapiro–Wilk test was the most appropriate tool to analyse normality due to the very small sample of this study. Determining the distribution of the variables would enable selection of the most appropriate statistical method. Data was also inspected for Kurtosis and Skewness. Conventional null hypothesis significance testing, using a standardized alpha level of .05, was employed through a Simple Regression for parametric tests and a Kendall Tau for non-parametric variables. A Logistic regression assessed the relationship between age and presence of Bidirectional Synchrony.

3.3.2. Results

Reliability and Video Length

Reliability between the two coders relayed moderate to strong Cohen's Kappa's through the different SCAEMA modalities (Table 2)

Table 2

Reliability Figures

	Child	**Parent**
Body Orientation Kappa	0.82	1.00
Gaze Kappa	0.73	0.77
Positive Affect Kappa	0.72	0.88
Vocalisations Kappa	0.85	0.86
Body Language Kappa	0.89	1.00
Touch Kappa	0.92	

Cohen's Kappa interpretation levels of agreement suggested by McHugh, 2012: 0–.20 (none), .21–.39 (minimal) .40–.59 (weak), .60–.79 (moderate), .80–.90 (strong), above .90 (almost perfect)

Visual inspection of the normality plots relayed that none of the participants with shorter videos constituted outliers in any of the synchrony measures.

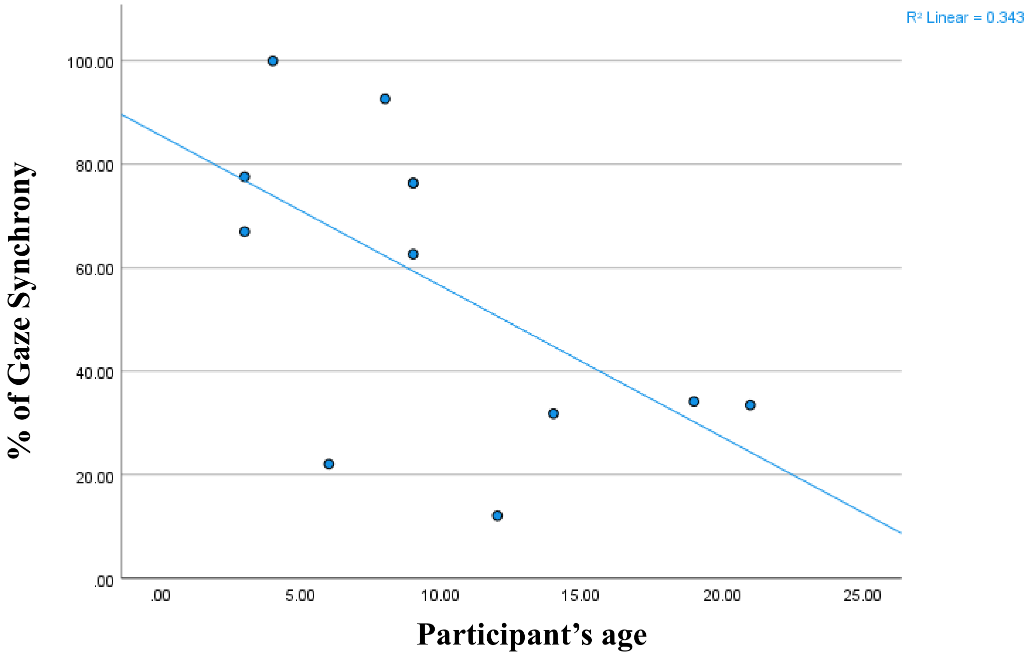
Relationship between temporal synchrony and chronological age

Shapiro-Wilk test showed that no variables' distributions departed significantly from normality.

Matching Synchrony of gaze: The gaze synchrony was significantly lower in older infants with a large effect $F(1,11) = 5.22$, $p < .05$, $\eta2 = 0.98$ as seen in Figure 1.

Figure 1

Scatterplot of the Percentage Matching Synchrony of gaze by Infant Age (in completed months)

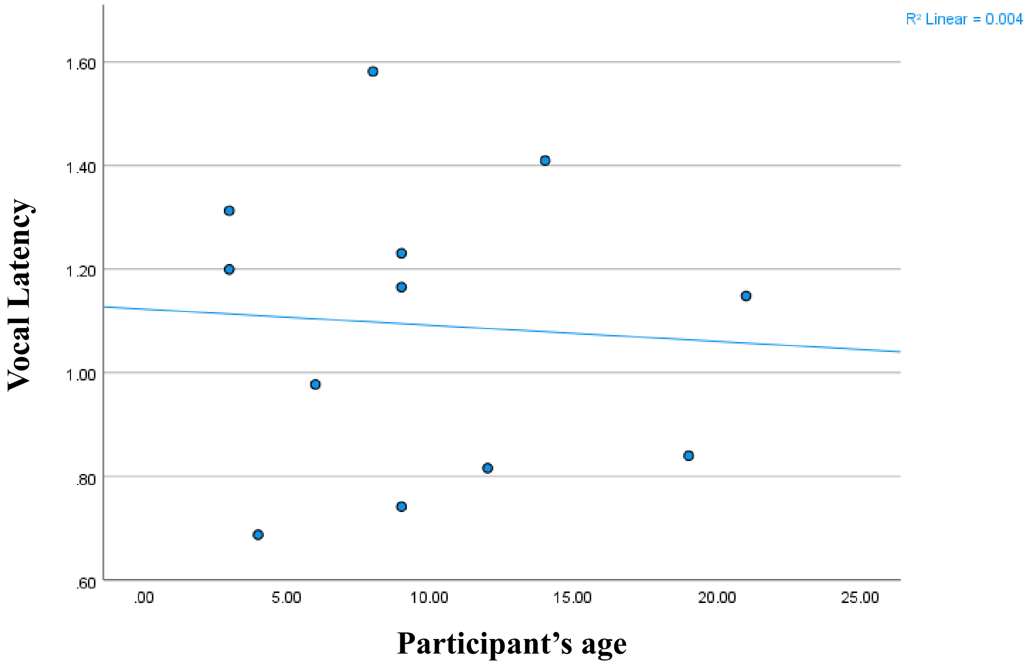


Note. Every dot represents an individual participant. Average percentage of gaze synchrony is displayed across the participant's age.

<u>Sequential Synchrony:</u> Regarding the latency in vocal responses, no significant correlation was found on the average duration of the lag *F*(1,11) = 0.43, p > .05 (Fig. 2).

Figure 2

Scatterplot of the Average Vocal Latency by Infant Age (in completed months)



Note. Every dot represents an individual participant. Average Vocal Latency (in seconds) is displayed across the participant's age.

<u>Bidirectional Synchrony:</u> The cross-correlation analysis relayed that *all children* displayed Bidirectional Synchrony in their analysed segments. For this cumulative measure, logistic regression with the age variable could not be calculated due to the dependent value comprising less than two values.

3.4. <u>Part B:</u> Does Mutual Shared Attention (MSA) play a role in temporal synchrony?

This analysis focused on the interaction of SCAEMA outputs and joint Attention, analysed through the Mutual Shared Attention (MSA) measure of the Dyadic Communication Measure for Autism (DCMA) (Green et al., 2010).

3.4.1. Methodology

Participants

Of the previous sample of twelve, six dyads were selected on the basis of them having long enough videos to be included in this study.

Procedure

The entire videoed segment was coded for MSA. A second independent coder coded 25% of the video files for reliability. Once coded, the two minutes showing the highest MSA and the two minutes featuring the lowest MSA were selected. The small sample of this study and the differences in chronological age among participants posed a risk of confounding variables creating potentially misleading results. For this reason, an intra-subject design was selected to compare the SCAEMA outputs of each participant with themselves at their best and worst MSA scores.

Study Design and Variables

SCAEMA was coded in all video segments and variables of Matched Synchrony (of gaze), Sequential Synchrony (vocal response latency) and presence of Bidirectional Synchrony were extracted from the coding. An intra-group design compared these outputs among the High and Low MSA conditions.

Analysis

Reliability was assessed with the Cohen’s Kappa test on the coding modalities through the Mangold Interact Software. ICC were calculated to assess reliability of MSA scores. The Shapiro–Wilk test was employed to analyse normality as well as Kurtosis and Skewness inspection. Conventional null hypothesis significance testing, using a standardized alpha level of .05, was employed through paired-samples t-test for parametric variables and Wilcoxon Test for non-parametric variables. McNemar was used to compare the binary variable presence of Bidirectional Synchrony.

3.4.2. Results

Reliability:

Moderate to strong Cohen's Kappa's were obtaining when assessing reliability of the different SCAEMA modalities, as well as a very high correlation in the Mutual Shared Attention ICC (Table 2).

Table 3

Reliability Figures

	Child	**Parent**
Body Orientation Kappa	1.00	1.00
Gaze Kappa	0.78	0.88
Positive Affect Kappa	0.76	0.72
Vocalisations Kappa	0.79	0.77
Body Language Kappa	0.90	1.00
Touch Kappa	1.00	
Mutual Shared Attention ICC (2,k)	0.97	

Cohen's Kappa interpretation levels of agreement suggested by McHugh, 2012: 0–.20 (none), .21–.39 (minimal) .40–.59 (weak), .60–.79 (moderate), .80–.90 (strong), above .90 (almost perfect)

Relationship of temporal synchrony and MSA in TD:

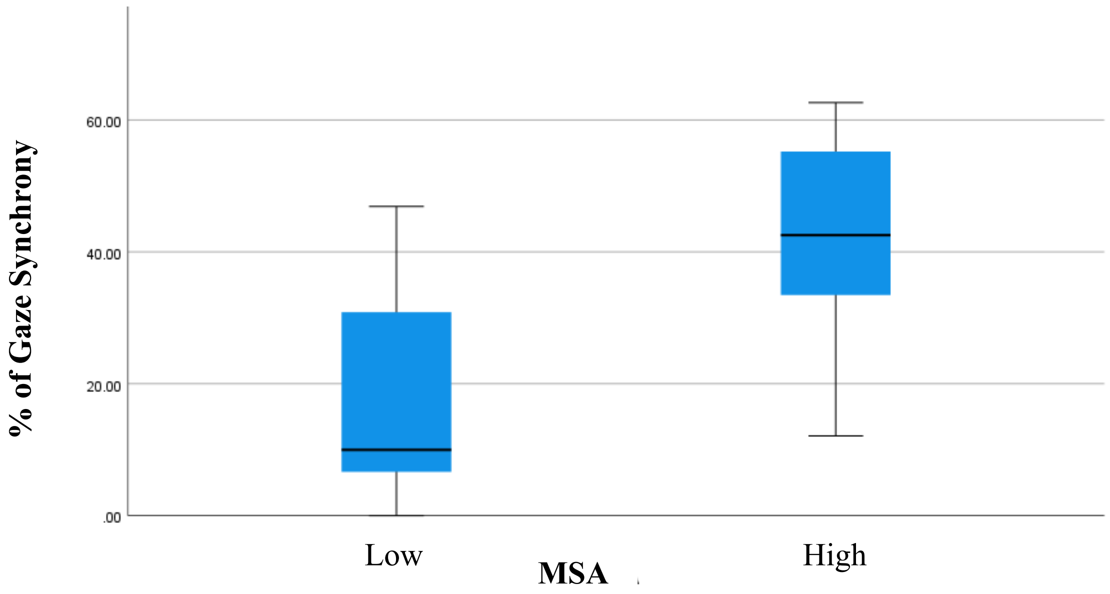
Shapiro-Wilk test showed that no variables' distributions departed significantly from normality.

MSA was significantly different between the two conditions *t*(5) = 13.72, p < .01, r = .99 between the high MSA segments (m = 77.93%) and the low MSA segments (m = 17.75%).

Matching Synchrony of gaze: Infants synchronised their gaze with their partner for a higher percentage of time when mutually sharing attention, this had a large effect (high MSA m = 41.42%; low MSA m = 17.38%, t(5) = 3.27, p < .05, r = .83, Cohen's d = 1.34) (Fig. 4)

Figure 4

Boxplot of the Percentage of Matching Synchrony of Gaze by Mutual Shared Attention

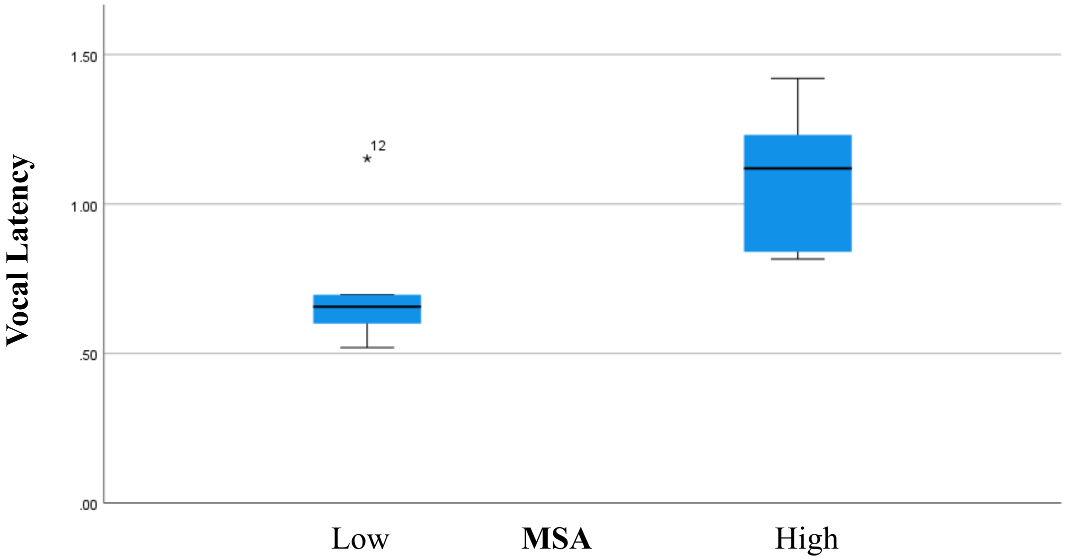


Note. Percentage of gaze synchrony when TD infants were displaying low vs high mutual shared attention.

Sequential Synchrony: MSA did not significantly relate to the length of the lag durations of the children vocalisation responses (high MSA m = 1.06 seconds; low MSA m = 0.72 seconds, t(5) = 1.71, p > .05) (Fig. 5)

Figure 5

Boxplot of the Vocal Response Latency Average by Mutual Shared Attention



Note. Average Vocal Latency (in seconds) when TD infants were displaying low vs high mutual shared attention.

Bidirectional Synchrony: The cross-correlation analysis relayed that *all children* displayed Bidirectional Synchrony both during high MSA and low MSA. For this reason, McNemar could not be calculated as the dependent value assumed less than two values.

3.5. Conclusions

Summary of results

Regarding the relationship between SCAEMA's synchrony measures and chronological age:

1. Supporting the hypothesis, older infants showed less Matching Synchrony of gaze than younger infants.
2. Chronological age did not relate to the Sequential Synchrony of infant's duration latency of vocal response.
3. All analysed children showed Bidirectional Synchrony; the correlation with chronological age and the presence of Bidirectional Synchrony as measured with SCAEMA could not be calculated.

Regarding the relationship of Mutual Shared Attention and SCAEMA's synchrony measures:

1. When infants engaged in high MSA with their partners, the dyad displayed higher percentages of Matching Synchrony of gaze.
2. Sequential Synchrony, the duration of the infant's vocal response latency, did not significantly differ whether the dyad was sharing attention, but there was a trend indicating lower MSA had shorter latencies.
3. Infants engaged in Bidirectional Synchrony whether they were sharing attention with their partners or not.

Discussion of results

Understanding the intricate dynamics of early interactions between infants and their caregivers has been a focal point in developmental research. Our study evaluates the evolving nature of different aspects of infant-caretaker interactions during this crucial period in early social development. It is well established in current literature that, gaze synchrony predominates as the primary modality of interaction during the initial three to four months of life (Feldman, 2007b; Senju & Johnson, 2009). This pattern gradually transitions as infants shift their focus to the parents' mouths, emphasizing synchrony in vocalizations by 8 months of age (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). While our results didn't precisely mirror this gradual decline in gaze synchrony, a distinct division emerged: most children under 10 months exhibited gaze synchrony over 60% of the time, whereas those over 10 months engaged in synchrony less than 40% of the time.

Our study found no significant relationship between vocal response latencies and chronological age. Our participants exhibited an average vocal response latency of 1.09 seconds, consistent with Nguyen's reported 95% estimated latency for the typical baseline model. In revisiting established notions surrounding the relationship between language development and non-verbal vocal response latency, our study introduces a nuanced perspective that diverges from prior research: our findings deviate from the anticipated gradual increase in response latency as language skills develop, as outlined in Nguyen et al., (2022). This discrepancy might be attributed to methodological differences. Unlike studies utilizing sophisticated recording equipment such as several stationary microphones and cameras in a quiet research room (Hilbrink et al., 2015) or sound analysis software (Gratier et al., 2015), our approach involved a single mobile point of video/audio recording in a natural setting. While this may provide less reliable data than more sophisticated methods, it was chosen to mirror conditions encountered with ASD participants in therapy; who would struggle to engage in interactions when their movement is being physically restricted, due to their diagnosis.

Another intriguing possibility is that the linguistic demands of mother/infant interaction in our study were not sufficiently challenging. Unlike studies allowing the use of toys to stimulate language opportunities, our method focused on a direct interaction with no tertiary objects. The presence of toys may introduce an additional factor leading to delays in responsiveness or turn-taking, and this may not be the case in play without toys. Future investigations could explore varying linguistic difficulty to determine its impact on vocal response latency, aligning with the idea of context influencing this latency proposed by Casillas et al. (2016).

Our study found that all participants, even the youngest 3-month-old infants, achieved multimodal Bidirectional Synchrony. Evans and Porter (2009) observed a noteworthy developmental shift from 6 to 12 months, wherein mother–infant interactions progressively evolved toward increased symmetry and bidirectionality. Their study noted symmetrical and bidirectional co-regulations, characterized by joint focus of attention and mutual creation of new actions which occurred at a lower percentage in younger participants compared to older groups: 38% at 4 months, 47% at 6 months, and 67% at 12 months. Similarly, Feldman (2007) reported that 11% of the sample at 3 months achieved mutual synchrony, in contrast to 40% at 9 months.

Crossmodal and multimodal synchrony, a less-explored area, could benefit from further research. Lewkowicz's study (2000) suggested a developmental shift from unimodal to multimodal in detecting synchrony between 4 and 8 months, although this study primarily focused on experimental conditions where stimuli were single syllables. However previous studies by this author (Lewkowicz, 1988a, 1988b) had posited that this developmental shift was not observed when infants were presented with continuous stimuli (i.e. talking or dancing) which provided greater kinematic visual information, with infant directed speech making it easier for the children to detect asynchrony.

It's worth noting that Evans and Porter employed a resolution of 1 second, while Feldman's was 0.25 seconds, both wider temporal resolutions than our method, potentially resulting in the loss of some data. However, our measure identified the occurrence of Bidirectional Synchrony in children but lacked the capacity to quantify the extent of synchrony displayed. Consequently, it might not effectively differentiate younger children who exhibited these interactions but may do so to a lesser degree.

We found a link between the Matching Synchrony of gaze and Mutual Shared Attention, with children and parents directing their gaze towards each other's faces for a greater percentage of time when sharing a common focus of attention. This finding aligns with previous research (Tschacher et al., 2021; Harrist, 2002; Puyjarinet et al., 2017). However, our study did not identify a correlation between MSA and Sequential nor Bidirectional Synchrony. One plausible interpretation of this discrepancy might be rooted in the scope of our Bidirectional Synchrony measure. It is conceivable that our measure of Bidirectional Synchrony encompasses too broad a range, detecting synchrony even when infants are not sharing the focus of attention with their parents.

Additionally, our measure of shared attention emphasises positive attention, implying that infants, while not actively engaging with their parents and, at times, displaying disruptive behaviours such as crying, still vocalized in response to their parents' vocalizations (i.e., saying "no"). The interactive rhythm of temporal synchrony persists whether there is positive MSA, serving as a web that keeps individuals connected and aids in repairing disconnection.

Our study introduces a novel methodology for assessing multimodal, crossmodal Bidirectional Synchrony in natural interactions without the need for stationary filming equipment, providing detailed micro-temporal data. However, it is crucial to acknowledge that this study, serving as a pilot to validate a measure designed for ASD children in a therapeutic setting, is constrained by a modest sample size of 12 participants across a relatively wide age-range. The restricted number of participants may limit the generalizability of the findings to a broader population, affecting the power to see developmental change. For this reason, future research with a larger sample (ensuring a more comprehensive representation of developmental stages including a diverse and well-distributed age representation) is warranted to enhance the external validity of the results and to further explore the robustness of the observed effects. Caution should be exercised in extrapolating these findings to broader contexts due to the inherent limitations associated with the modest participant size. Additionally, examining Bidirectional Synchrony measures to align more closely with shared attention, considering linguistic difficulty variations, and exploring the impact of different contextual demands could further enrich our understanding of early interpersonal synchrony.

While our study contributes valuable insights into multimodal interpersonal synchrony, these findings should be interpreted within the context of acknowledged limitations. As we move forward, a more comprehensive exploration of Bidirectional Synchrony across chronological age and shared attention, along with refinements in methodology, will deepen our understanding of these intricate early interactions.

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Chapter 4

Can SCAEMA detect differences in temporal synchrony in ASD (after controlling for Developmental Delay/Learning Disability)?

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4.1. Abstract

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition marked by apparent difficulties in temporal synchrony, that extend across modalities and impact interactions, as well as postulated diminished joint and shared attention, affecting social engagement and coordination. This study investigates both multimodal and unimodal temporal synchrony during 1:1 naturalistic play interactions with a primary carer in ASD-diagnosed (n=47) and non-ASD (n=18) children, controlling for Developmental Delay/Learning Disability (DD/LD).

We assess for Mutual Shared Attention, then use the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA, a micro-coding tool) to assess: matching synchrony through gaze; sequential synchrony via vocal response latency; and, multimodal bidirectional synchrony through cross-correlation analysis. Results reveal that ASD children exhibited significantly less gaze synchrony, lower bidirectional synchrony, and reduced MSA compared to non-ASD children, irrespective of DD/LD status. Vocal response latencies show no significant differences, indicating a potential role for language proficiency.

The retrospective design limits matched pairs and necessitates caution in generalizing findings. Nevertheless, this research provides insights into the baseline characteristics of multimodal temporal synchrony and shared attention in ASD children, unaltered by therapeutic interventions. Future research should consider a refined design, prospective longitudinal approach, increased sample size, standardised cognitive assessments, and specific therapeutic intervention’s impact(s) on temporal synchrony.

4.2. Introduction

Background

Autism Spectrum Disorder (ASD) is a highly heritable neurodevelopmental disorder (Colvert et al., 2015) with a prevalence of 1–2% of the UK population (NHS Digital, 2021). Persistent difficulties in social communication and interaction as well as restricted and repetitive patterns of behaviours, manifest early in childhood and impede everyday functioning (American Psychiatric Association, 2022).

Research indicates that individuals with ASD exhibit challenges in social timing, a crucial developmental skill (Leclère et al., 2014) defined as the capacity to synchronize temporally with a social partner during interactions (Wimpory, 2015) These difficulties could be the result of mutations in timing genes (Briuglia et al., 2021; Bowton et al., 2014; Wimpory et al., 2002; Nguyen et al., 2010; Guissart et al., 2018; Nicholas et al., 2008; Nicholas et al., 2007; Neale et al., 2012; Yang et al., 2016) or related to other wide-ranging impairments, as detailed below. Irregularities in intrapersonal synchrony observed in individuals with ASD, including challenges in temporal processing of sensory input and motor coordination, might play a role in the difficulties they experience in interpersonal synchrony (Bloch et al.2019). This atypical synchrony extends across various modalities in ASD and is emerging as a potential biomarker for both diagnosis and intervention targets (McNaughton & Redcay, 2020).

Social motor synchrony, which encompasses the tempo and coordination of movement, posture, and orientation during social interactions (Xavier et al., 2018), is impaired in both high and low functioning ASD individuals (Zampella et al., 2020; Kaur et al., 2018; Georgescu et al., 2020), and is correlated with symptom severity (Su et al., 2020; McNaughton & Redcay, 2020; Kaur et al., 2018). Individuals with Autism Spectrum Disorder (ASD) often exhibit abnormal detection of tactile stimuli (Blakemore et al., 2006) and a lack of tactile habituation (Tannan et al., 2008) which may have temporal consequences during interaction. This atypical tactile experience might significantly impact the development of social orientation, given the crucial role of maternal touch in early infancy for developing attachment (Duhn, 2010; Silva et al., 2015)

Perceiving human faces during social interactions demands rapid and intricate visual information processing and integration, capabilities that are compromised in those with ASD (Thye et al., 2018; Charrier et al., 2017). Children who are later diagnosed with ASD exhibit intact gaze-following skills at 7 and 13 months (Bedford et al., 2012) and maintain attention to faces during the initial year of life (Elsabbagh et al., 2013; Yirmiya et al., 2006). However, this social attention to faces undergoes a decline, lagging behind the typical developmental trajectory during the second year (Jones & Klin, 2013; Ozonoff et al., 2010; Gliga et al., 2014). This could, then, contribute to the impairments found in facial emotion recognition (Harms et al., 2010) and ability to express positive affect in ASD (Kellerman et al., 2019; Saint-Georges et al., 2010; Ozonoff et al., 2014).

Gaze synchrony, which occurs when two people look at each other simultaneously, is noticeably reduced in children later diagnosed with autism during their initial two years of life (Saint-Georges et al., 2010). This diminished gaze synchrony has adverse effects on the ability of ASD children to engage in anticipation and build-up interactional games (Trevarthen & Daniel, 2005). In face-to-face naturalistic interactions and goal-oriented activities, ASD children exhibit lower gaze synchrony compared to typically developing (TD) and developmentally delayed (DD) children (Wang et al., 2018). Additionally, toddlers with autism spend less time observing the speaker's face and monitoring lip movements in comparison to their DD and TD counterparts (Chawarska et al., 2012). Extended delays between gaze-gesture nonverbal signals, such as looking at a stimulus and pointing, in adults with high-functioning ASD (HFA) have been linked to increased intrapersonal variability, suggesting a reduced temporal coherence of nonverbal cues within individuals (Bloch et al., 2022). These delays seem to play a role on both sides of a dyadic exchange, as observed by Bloch et al. (2024), where both non-autistic adults and those with HFA exhibited prolonged response times when observing a virtual character displaying behaviors indicative of ASD. Individuals with HFA showed even longer response times, possibly due to non-autistic observers employing a more consistent eyes-focused strategy, enabling efficient and rapid responses, while observers with ASD displayed highly variable decoding strategies.

Atypicalities in conversational patterns are evident in both verbal and non-verbal autistic individuals (Nguyen et al., 2022). Heeman et al. (2010) reported significantly longer latencies (27.3% longer) in verbal HFA children. Similarly, Ochi et al. (2019) observed substantially extended turn-taking gaps characterized by a greater proportion of vocal response latency, less variability, and fewer synchronous changes in children with HFA. Non-verbal vocal synchrony encompassing non-word vocalizations and the timing of silences or pauses, is also compromised in verbal individuals with HFA. HFA individuals display atypical silence duration between verbal conversational turns, the length of which correlate with the severity of ASD symptoms when comparing diagnosed 9-16 years old to TD individuals (Zampella et al., 2020). Similarly, 7-12 year old ASD children have more difficulty in initiating turn-taking compared to TD individuals (Choi & Lee, 2013). Plank et al. (2023) found mixed dyads comprising of one HFA adult and one non-autistic adult exhibited extended periods of silence as opposed to non-autistic dyads. However, Warlaumont et al. (2010) did not observe significant differences in vocal response latency between non-verbal, 1.3 – 4 year old autistic and typically developing children. This suggests that, while there are specific challenges in the temporal non-verbal aspects of communication for verbal individuals with HFA, vocal response latency might not be a differentiating factor for non-verbal individuals with ASD, either due to younger age or intellectual disability.

ASD is characterized by a diminished focus on social information, including what others are paying attention to (Chevallier et al., 2015; Frazier et al., 2017). Joint attention involves a dyad coordinating mutual engagement with a shared focus (Tomasello, 1995). In contrast, shared attention encompasses not only the coordination of mutual engagement but also an awareness in both individuals of their common attentional state (Edwards et al., 2015). Saint-Georges et al. (2010) identified lower rates of shared attention during the first two years of life in children diagnosed with autism. Toddlers with ASD exhibit reduced attention to social scenes compared to their developmentally delayed (DD) and typically developing (TD) peers, particularly when explicit dyadic cues such as eye contact or speech are introduced. This decline in social attention correlates with heightened symptom severity and lower nonverbal functioning (Chawarska et al., 2012). Autistic children struggle in anticipation and build-up of interactional games, which require well-timed coregulation and coherent engagement of shared attention (Trevarthen & Daniel, 2005).

Altogether, prior work suggests that ASD individuals may struggle to engage in and understand social interactions partially as a result of difficulties in intrapersonal and interpersonal synchrony (see above). When quantifying synchrony during *interactions themselves,* previous research has delineated three types of ‘interactive synchronies’ (Feldman, 2007): Matching synchrony refers to content coherence across different sensory modalities. Sequential synchrony is the timing order of the interaction with a lead-lag aspect, where a dyad partner leads the exchange, and the other follows, synchronising with a second’s delay. Bidirectional synchrony results in a non-random patterned interaction with lead-lag aspect that leads to reciprocal adaptation. While prior work has investigated some aspects of interactive synchrony, they have not done so comprehensively, nor during naturalistic interactions.

Rationale

Numerous studies have endeavoured to assess the synchrony of naturalistic dyadic interactions in children with autism, with some considering the various modalities through which synchrony manifests, including crossmodal analysis (Kellerman et al., 2019; Zampella et al., 2020; Schertz et al., 2018). While integrated multimodal methodologies have been proposed and employed in studies involving Typically Developing (TD) individuals (Pratt et al., 2017), as well as those exploring interaction in conditions such as feeding disorders

(Feldman et al., 2004) and prematurity in infants (Feldman, 2003; Feldman & Eidelman, 2007; Silberstein et al., 2009), to our knowledge, no previous study focusing on participants with ASD has comprehensively analysed synchrony using an integrated multimodal approach.

This pioneer study employs the Synchrony of Communication in Autism: Evaluation by Micro-Analysis, or SCAEMA; a micro-coding tool that allows the quantification of interpersonal aspects of naturalistic communication through high-resolution computerised temporal analyses. SCAEMA produces a multimodal measure of bidirectional synchrony as well as unimodal measures of matching synchrony (through gaze synchrony) and sequential synchrony (through latency of non-verbal vocal response). Prior to SCAEMA, we apply Mutual Shared Attention (MSA), a measure of the Dyadic Communication Measure for Autism employed by Green et al. (2010) that assesses joint and shared attention.

Further descriptions and explanation of SCAEMA can be found in the methods section of this paper.

Aims

This study aims to delineate a model in which SCAEMA synchrony outputs elucidate the potential difference in temporal synchrony in children with an ASD diagnosis in comparison to children without the diagnosis.

Developmental Delay/Learning Disability (DD/LD) is integrated into this exploratory model to assess its potential role as a confounding variable. DD is identified when a child under the age of five fails to achieve developmental milestones, while LD represents a neurodevelopmental disorder hindering the acquisition or application of specific academic abilities by the age of 5 years (American Psychiatric Association, 2022).

The hypothesis is that ASD children will display less synchrony than the non-diagnosed children and that Learning Disability/Developmental Delay will not affect synchrony outcomes. In particular, and based on published research findings, the following outcomes are predicted:

1. [Mutual Shared Attention]: A lower percentage of Mutual Shared Attention in ASD participants. (Saint-Georges et al., 2010; Chawarska et al., 2012)

2. [Matching Synchrony]: A lower percentage of gaze synchrony in ASD participants. (Wang et al., 2018; Chawarska et al., 2012; Bloch et al., 2022)
3. [Sequential Synchrony]: Longer vocal delays when replying to the partner’s vocalisations in ASD participants. (Zampella et al., 2020; Heeman et al., 2010 Ochi et al., 2019)
4. [Bidirectional Synchrony]: A lower presence of Bidirectional Synchrony in ASD participants.

4.3. Methods

Participants

Ninety-three children with social communication difficulties had been referred to Music Interaction Therapy (MIT) or Paediatric Autism Communication Therapy (PACT) between 2012 and 2019 and consented to participating in this study. Twenty-seven of them were excluded from this study due to not having yet received an ASD assessment or due to their ASD diagnosis not having a supporting ADOS-2. Eleven children were excluded due to their video data including music or toys, given that 1:1 attempted interaction without the distraction of other items or input, was required for our analysis. Two autistic children were excluded due to a comorbid clinical diagnosis other than ASD/developmental delay/learning difficulty. Twelve non-verbal able typically developing infants were recruited as well as six non-ASD diagnosed children with developmental delay/learning difficulty. The only comorbid clinical diagnoses permitted in the non-diagnosed group were those where previous research had not shown these as related to ASD.

The retrospective design of this study posed a limitation on establishing a matched control group since it was not possible to assess participants for cognitive levels to form matched pairs as data had already been collected. Consequently, we opted to enlist typically developing infants (n = 12) aged 3 to 24 months in their pre-verbal phase, a cohort deemed by expert clinicians to possess communication abilities equivalent to the ASD participants. Additionally, a subset of clinically referred but non-diagnosed children (n = 6) facing challenges in social communication was included in the comparison group. The disparity in age between the samples and the inability to assess the cognitive levels of the ASD participants precluded the classification of this as a matched sample.

Sixty-five non-verbal children were part of this study (51 male and 14 female). Forty-seven children received an ASD diagnosis with a supporting ADOS-2 (average comparison score 7.72, min = 4, max = 10, SD = 1.78). The ASD group were aged from 1.63 years to 5.26 years (mean age = 3.41 years, SD = 0.86).

The eighteen children that comprised the 'comparison group' did not have an ASD diagnosis. This group comprised a sub-group of non-verbal typically developing (TD) infants (n = 12) as well as a sub-group of older non-verbal children with social communication difficulties (n = 6). These six clinically-referred children were assessed by a Consultant Clinical Psychologist specialising in ASD and found not to meet criteria for an ASD diagnosis. The non-ASD group of eighteen children, was aged from 3 months to 3.19 years (mean age = 1.45 years, SD = 1.00) (Table 1).

Table 1

Participants diagnosis distributions

	Non-ASD Group	**ASD Group**	**Totals**
Without DD/LD	n = 14	n = 7	n = 21
With DD/LD	n = 4	n = 40	n = 44
Totals	n = 18	n = 47	n = 65

Procedure & Study Design

Each dyad of parent and child were filmed during a 1:1 play interaction at a familiar setting. Parents played with their children as they would usually do without the presence of toys. The naturalistic face-to-face interaction was filmed for approximately ten minutes.

The initial 4 minutes of each video were discarded as to give the children time to adapt to a change of setting (congruent to Green et al.'s methodology). Minutes 4 to 6 were coded and analysed. Of the 53 video segments analysed, eight could not have the full 4 minutes discarded due to the video data being too short or becoming not suitable (i.e. grandmother joining in the interaction). In those cases, the 2 minutes analysed were the last available after the most extended possible period excluded for adaptation (a detailed table can be found in Appendix B).

Coding and output variables

Joint attention was coded in the two-minute segments by using the Mutual Shared Attention (MSA) measure of the Dyadic Communication Measure for Autism (Green et al., 2010). SCAEMA was coded through Interact Mangold Interact ® version 20.9.16.0. For each partner of the dyad, a set of binary codes were coded: body orientation, gaze, positive affect, vocalisations, touch and body language (Table 2). A secondary trained independent coder, who was unaware of the participant's diagnosis and DD/LD status, coded 25% of the data to assess inter-rater reliability.

Table 2

SCAEMA modalities.

Body Orientation	Coded as present if an individual's torso is oriented towards partner's torso
Gaze	Coded as present if an individual is looking at partner
Positive Affect	Coded as present if an individual is smiling or laughing
Vocalisation	Coded as present if an individual is vocalising
Touch	Coded as present if an individual and partner are touching
Body Language	Coded as present if an individual is using body language (i.e. hand gesture)

For evaluating matching synchrony, the gaze variable was utilized to compute the Matched Synchrony of gaze. This was determined by the percentage of time during which both the parent and child were looking at each other's faces. Sequential synchrony was indicated by the vocal response latency, denoting the average time (in seconds) it took for the infant to vocally respond to parent vocalizations, with a maximum allowable latency of 3 seconds, a duration set according to Nguyen et al.'s (2022) research.

A multimodal time series was constructed by summing all coding modalities for each partner. These two time series (one for each individual in the dyad) underwent individual scrutiny for data stationarity, differentiation, and modelling using ARIMA, as advocated by Feldman (2007). A Cross-Correlation Function (CCF) was applied to the resulting noise residual transformed time series, examining the lagged correlation of the multimodal time series. The presence of Bidirectional Synchrony was established as a binary variable, following the approach proposed by Feldman (2003) and Lotzin et al. (2015). This presence was confirmed by at least one significant positive correlation at both lead-lag areas on the CCF.

Analysis

Reliability was assessed with the Cohen's Kappa test on the coding modalities through the Mangold Interact Software. ICC were calculated to assess reliability of mutual shared attention scores.

Both Kolmogorov–Smirnov and Shapiro–Wilk test were used to analyse normality. Linear Regression was used to model the normally distributed variables against ASD diagnosis and DD/LD status, while Mann-Whitney test were used for the non-normal variables. A binary logistic regression tested for the presence of bidirectional synchrony against the three predictors.

4.4. Results

Reliability

When assessing the reliability of the different SCAEMA modalities, moderate to strong Cohen's Kappa's were obtained, as well as a high correlation in the Shared Attention ICC (Table 3).

Table 3

Reliability Figures

	Child	**Parent**
Mutual Shared Attention ICC (2,k)	0.81	
Body Orientation Kappa	0.73	0.77
Gaze Kappa	0.79	0.80
Positive Affect Kappa	0.79	0.72
Vocalisations Kappa	0.74	0.78
Body Language Kappa	0.92	0.84
Touch Kappa	0.80	

Cohen's Kappa interpretation levels of agreement suggested by McHugh, 2012: 0–.20 (none), .21–.39 (minimal) .40–.59 (weak), .60–.79 (moderate), .80–.90 (strong), above .90 (almost perfect)

Mutual Shared Attention

Independent Samples Mann-Whitney U test found a moderate to large significant relationship between ASD diagnosis and the percentage of Mutual Shared Attention where the non-diagnosed group spent a higher percentage of time sharing attention than the ASD diagnosed group U = 157.00, z = -3.90, p < .001, r = 0.48. The DD/LD status did not statistically differ U = 328.50, z = -1.87, p > .05 (Table 9)

Table 9

Median percentages of MSA by group

	ASD (n = 47)	**Non-ASD (n = 18)**	**Total**
DD/LD (n = 44)	44.63%	67.72%	**49.45%**
No-DD/LD (n = 21)	38.84%	80.75%	**69.76%**
Total	**43.66%****	**78.93%****	

*p < .05. **p < .001

Matching Synchrony

The percentage of gaze synchrony was moderate to large significantly lower for the ASD diagnosed participants than for those without an ASD diagnosis, U = 165.00, z = -3.78, p < .001, r = 0.47. Percentage of Gaze synchrony for participants with DD/LD status did not statistically differ from participants without an DD/LD status, U = 1316.5, z =1.90, p = .057 (Table 4) although there was a strong trend indicating children with DD/LD synchronised less than those without.

Table 4

Median percentages of gaze synchrony by group

	ASD (n = 47)	**Non-ASD (n = 18)**	**Total**
DD/LD (n = 44)	19.29%	30.36%	**19.65%**
No-DD/LD (n = 21)	8.93%	48.39%	**31.80%**
Total	**18.13%****	**37.81%****	

*p < .05. **p < .001

Sequential Synchrony

Linear regression conveyed that none of the variables, nor their interactions, impacted on the latency of non-verbal vocal response (Tables 5 and 6)

Table 5

Mean duration of vocal response latency (in seconds) by group

	ASD (n = 47)	Non-ASD (n = 18)	Total
DD/LD (n = 44)	1.02	1.11	**1.03**
No-DD/LD (n = 21)	0.88	1.08	**1.02**
Total	**1.00**	**1.09**	

*p < .05. **p < .001

Table 6

Average vocal latency multiple regression model

	B	SE B	β
STEP 1			
(Constant)	1.06	0.08	
ASD Diagnosis	-0.14	0.13	-.20
DD/LD Status	0.10	0.11	.14
ASD*LD Interaction	0.11	0.24	.16
STEP 2			
(Constant)	1.09	0.08	
ASD Diagnosis	-0.08	0.09	-.11

Note: $R^2 = 0.25$ for step 1, $\Delta R^2 = -0.01$ ($p > .05$) for step 2. *$p < .05$

Bidirectional Synchrony

Logistic regression found a clear significant relationship between the presence of bidirectional synchrony and ASD diagnosis. While DD/LD status appeared to have a trend and was included in the model, it was not significant ($p = 0.057$) (Tables 7 and 8).

Table 7

Percentage of participants displaying Bidirectional Synchrony by group

	ASD (n = 47)	Non-ASD (n = 18)	Total
DD/LD (n = 44)	55%	75%	**57%**
No-DD/LD (n = 21)	43%	100%	**81%**
Total	**53%***	**94%***	

*p < .05. **p < .001

Table 8

Bidirectional Synchrony logistic regression multiple regression model

		95% CI for Odds Ratio		
	B (SE)	**Lower**	**Odds Ratio**	**Upper**
Included				
Constant	0.12 (0.31)			
ASD Diagnosis	2.68 (1.18)*	1.47	14.65	146.61
DD/LD Status	0.03 (0.78)	0.22	1.03	4.76

Note: χ^2 = 4.00 (Hosmer & Lemeshow), R^2 = .16 (Cox & Snell), .23 (Nagelkerke). Model χ^2 (2) = 11.79, p < .005. **p* < .05.

4.5. Conclusions

Summary of Results

This study found:

1. [Mutual Shared Attention] There was a lower percentage of Mutual Shared Attention in ASD participants than subjects without ASD, with no significant differences detected regarding to DD/LD.
2. [Matching Synchrony] Autistic children showed significantly less gaze synchrony than their non-autistic peers. While the percentage of gaze synchrony was not significantly different between children with and those without DD/LD there was a strong trend indicating those with DD/LD displayed less gaze synchrony.
3. [Sequential Synchrony] The durations of vocal response latency when replying to the partner’s vocalisations were the same between ASD and non-ASD participants, without being influenced by DD/LD status.
4. [Bidirectional Synchrony] Statistical analyses showed that a significantly lower percentage of ASD diagnosed children were in dyads that displayed bidirectional synchrony than was the case for subjects without an ASD diagnosis. The presence/absence of DD/LD did not show significant effect, although there was a trend where less DD/LD children displayed Bidirectional Synchrony.

Discussion of Results

ASD participants exhibited a lower percentage of Mutual Shared Attention compared to their non-ASD counterparts, and this distinction was not significantly influenced by the presence of DD/LD. These results align with the observations made by Saint-Georges et al. (2010), who reported diminished rates of shared attention in the early years of life among individuals with ASD. Additionally, our findings are also consistent with Chawarska et al.'s (2012) research, which indicated that ASD toddlers display reduced attention to social scenes not only in comparison to typically developing children but also in relation to those with developmental delay.

The autistic group exhibited less gaze synchrony compared to non-autistic children and infants. This finding aligns with existing literature suggesting that individuals with ASD, have diminished gaze synchrony (Trevarthen & Daniel, 2005; Wang et al., 2018); a phenomenon observed not only in comparison to typically developing children but also in contrast to those with developmental delays (Chawarska et al., 2012); as ASD children struggle with sustained gaze towards faces (Jones & Klin, 2013; Gliga et al., 2014; Ozonoff et al., 2010).

The duration of vocal response latencies represents a crucial aspect of interpersonal communication. These durations did not exhibit significant differences between ASD and non-ASD participants, irrespective of concurrent DD/LD challenges. Our findings support prior research by Warlaumont et al. (2010), who reported comparable vocal response latencies in non-verbal autistic and typically developing children. Studies indicating prolonged response times in ASD often involve high-functioning verbal individuals (Heeman et al., 2010; Ochi et al., 2019; Zampella et al., 2020), perhaps suggesting a potential role played by language proficiency attained by older age and/or functioning level.

Statistical analysis revealed a significantly lower occurrence of Bidirectional Synchrony in dyads involving ASD-diagnosed children. The presence of DD/LD, while not significant, showed a strong trend towards DD/LD children struggling to display Bidirectional Synchrony. Unfortunately, our study’s unique strength in employing an integrated multimodal approach to synchrony analysis in ASD participants prohibits direct comparisons with previous research in this domain. However, some prior work has looked at each of the modalities that constitute our multimodal measure of synchrony. In addition to gaze synchrony and vocal latencies, which we have already explored; touch, body orientation, body language (i.e., gestures) and expression of positive affect have been reported to be affected in ASD. Individuals with ASD show atypicalities to tactile perception in facial and mouth regions, coupled with a failure to orient, which correlate with the severity of their symptoms (Silva et al., 2015). HFA adults display longer delays between gaze-gesture nonverbal signals, such as looking at a stimulus and pointing (Bloch et al., 2022) and both high- and low-functioning autism individuals demonstrate reduced interpersonal motor synchrony when clapping, marching, and/or drumming in a social task (Kaur et al., 2018). Autistic individuals encounter challenges in attending to human faces in social interactions (Thye et al., 2018; Charrier et al., 2017); potentially compromising facial emotion recognition in ASD (Harms et al., 2010). This struggle also appears to extend to showing positive affect (Kellerman et al., 2019; Saint-Georges et al., 2010; Ozonoff et al., 2014). Together, these results support our observation of compromised Bidirectional Synchrony in individuals with ASD.

The retrospective design of our study afforded a unique opportunity to explore temporal synchrony in very young children later diagnosed with ASD before the initiation of therapy. By capturing data before therapeutic interventions, we gained valuable insights into the natural temporal synchrony and shared attention abilities in this population. This approach provides a foundation for understanding the baseline characteristics of ASD participants, untainted by the potential influence of therapeutic interventions. Non-verbal ASD children appear to have impaired shared attention and show decreased multimodal and unimodal (gaze) temporal synchrony, making these areas potential targets for therapy.

However, it's crucial to acknowledge the limitations stemming from the absence of a matched control group, a challenge rooted in the retrospective nature of the study. As the data was already collected, we could not assess individuals' cognitive levels at the same time as the videos were collected, which would have been necessary to establish properly matched pairs. Our comparison cohort, comprising typically developing infants and those with social communication difficulties without ASD, lacked the precise matching required for rigorous comparisons. This limitation underscores the need for caution in generalizing our findings and highlights an avenue for improvements that could be made in future research.

Our study provides a foundational exploration of temporal synchrony in ASD children. Looking ahead, future research in this domain could benefit from a more refined study design that includes a well-matched control group. A prospective longitudinal approach would enable researchers to track temporal synchrony in ASD participants and non-diagnosed counterparts over time, offering a clearer understanding of developmental trajectories and potential therapeutic impacts. Additionally, expanding the sample size and incorporating cognitive assessments could enhance the robustness of the findings. Further investigations might explore the influence of specific therapeutic interventions on temporal synchrony in

ASD populations, shedding light on effective strategies for improving temporal synchrony and shared attention abilities in these individuals.

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Chapter 5

Does Musical Interaction Therapy (MIT) impact on Mutual Shared Attention and temporal synchrony as measured by SCAEMA?

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5.1. Abstract

Social timing, vital for synchronization in interactions, appears impaired in Autism Spectrum Disorders (ASD). Musical Interaction Therapy (MIT) is an early parent-mediated intervention, akin to the Paediatric Autism Communication Therapy (PACT), that introduces a therapeutic approach using live music to scaffold the timing of the interaction, alongside supporting parental synchrony. This study investigates the impact of MIT on temporal synchrony in 21 children (mean age 39 months), clinically diagnosed with ASD, through the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA). SCAEMA analyses various aspects of synchrony, including gaze synchrony, vocal response latency and Bidirectional Synchrony, as well as mutual shared attention. While statistically significant improvements in gaze synchrony and mutual shared attention are observed after six months of therapy, challenges arise in attributing these changes solely to therapeutic interventions due to the absence of control groups and baselines. The study underscores the need for future research with refined designs and introduces an innovative approach to multimodal synchrony assessment. The observed trend of increased Bidirectional Synchrony during therapy sessions warrants further exploration in larger samples.

5.2. Introduction

Background

Social timing, or temporal synchrony in social interactions (as reviewed by Wimpory, 2015), coordinates both content and process (Delaherche et al., 2012). Previous research (Feldman, 2007) identifies three types of synchronies that can be expressed unimodally, crossmodally or multimodally: Matching Synchrony (coherence of content in and across modalities), Sequential Synchrony (timing order), and Bidirectional Synchrony (organized turn-taking).

Autism Spectrum Disorder (ASD) is characterised by impairments in communication and social interaction (World Health Organization, 2023; American Psychiatric Association, 2013). Elements of temporal synchrony are diminished in individuals with ASD across various domains (McNaughton & Redcay, 2020), such as social motor synchrony (Xavier et al., 2018; Kaur et al., 2018; Fitzpatrick et al., 2016), non-verbal vocal synchrony (Zampella et al., 2020; Choi & Lee, 2013; Heeman et al., 2010; Nguyen et al., 2022), gaze synchrony (Wang et al., 2018; Saint-Georges et al., 2010; Trevarthen & Daniel, 2005; Elias-Masiques et al., 2024), lower shared attention (Chawarska et al., 2012; Saint-Georges et al., 2010; Elias-Masiques et al., 2024) and even multimodal Bidirectional Synchrony (Elias-Masiques et al., 2024).

Music perception appears unaffected in ASD (Altgassen et al., 2005; DePape et al., 2012; Mottron et al., 2006), potentially offering a rhythmic framework for interactional synchrony (Tarr et al., 2014). Music, being a motivating non-verbal tool, holds promise for developing social and communication skills in ASD individuals (Jamey et al., 2019). Early synchrony in dyadic interactions correlates with improved communication outcomes in autistic children even after 1, 10, and 16 years (Siller & Sigman, 2002). A growing body of evidence underscores the mediating role of temporal synchrony in various therapeutic interventions for young children with autism, irrespective of learning disabilities (Dvir et al., 2020; Forti et al., 2020; Griffioen et al., 2020; Pickles et al., 2015; Srinivasan et al., 2015).

ASD difficulties in synchrony, evident in early development for both low and high functioning subjects (Murat Baldwin et al., 2022; Bloch et al., 2019; McNaughton & Redcay, 2020), underscore what appears to be critical periods for intervention. Early intervention significantly influences joint attention, social communication, and adaptive functioning (Fuller & Kaiser, 2020; Nahmias et al., 2019; Reichow, 2012; Schertz et al., 2012). In early interventions for ASD, parent-mediated approaches are pivotal; these focus on toddlers engaging with a main carer in their natural environment (Ratliff-Black & Therrien, 2021). Temporal synchrony has been identified as both originating from and fostering a sense of shared motivation, thereby reducing the cognitive challenges associated with interpersonal interactions, influencing language, cognition, and social development (Cross et al., 2020; Dideriksen et al., 2020). For example, Cirelli et al. (2014a, 2014b) demonstrated that typically developing infants exhibited a greater inclination toward altruistic behaviour after engaging in synchronous movement (such as bouncing). Research on parent-mediated early interventions has revealed promising effects on social communication outcomes (Schertz et al., 2012; Meadan et al., 2009; Patterson et al., 2012). However, the impact of these types of interventions in temporal synchrony remains unexplored.

Previous MIT and PACT results

MIT is an early intervention, parent-mediated therapy employing triadic collaboration, which guides the interaction between the autistic child and a familiar adult (usually a parent), aiming to enhance communication within and beyond the therapy. MIT aims to offer a prolonged and exaggerated form of preverbal interaction where the therapist merely supports the dyad with initiations coming from them, making the music’s rhythm, pitch and melodies reflect the interaction. For instance, if the child sits quietly, the music softens, while when the child is jumping, the music becomes bouncy and energetic. The musical therapist role resembles that of a pianist in an early black and white films.

Betsi Cadwaladr University Health Board (BCUHB) of the NHS provide grant-funded Musical Interaction Therapy (MIT) through (in this case, Integrated Care Funding). MIT shares conceptual similarities with the Paediatric Autism Communication Therapy (PACT), emphasizing synchrony as the medium of change by enabling adults to synchronize with the child's focus of interest rather than redirecting it. Examples of MIT sessions are detailed in Daniel et al.’s (2022) supplementary material. A MIT case study (Wimpory et al., 1995) found significant improvements in a severely autistic child's social acknowledgment, eye contact, and initiation of interactive involvement, over a therapy period of 7 months, contrasting with 4 months baseline and sustained at a two-year follow-up.

While temporal synchrony has not been investigated in early interventions in autism, we have taken advantage of available datasets that evaluated Mutual Shared Attention (MSA) to see how the measure changes with different types of therapy. Green et al.’s randomized controlled trial (2010) evaluated MSA in children receiving NHS England Therapy as Usual (NHS England TAU) and PACT. Additionally, an ongoing project with the Welsh Arts Council has assessed gaze synchrony and MSA in (ADOS-2 confirmed) children receiving NHS Wales Treatment as Usual (NHS Wales TAU). Lastly, locally delivered PACT in BCUHB between 2017 and 2019 as part of the IMPACT project published a MSA evaluation through IMPACT Quarterly data returns (Table 1).

Table 1

Percentage of time the dyad is engaged in Mutual Shared Attention (MSA) in different samples. Part 1, subject/study characteristics (continued below)

Sample	**Source**	**N**	**ASD Status**	**Age in months (range)**	**Cognitive Level**	**Verbal Proficiency**
NHS England TAU	Green et al. (2010)	75	100%	45 (24-60)	Mullen non-verbal IQ 25.3 months	67% Non-Verbal 33% Phrase Speech
NHS Wales TAU	Welsh Arts Council Grant Evaluation	7	100%†	39 (27-47)	78% with DD/LD†††	100% Non-Verbal
PACT RCT	Green et al. (2010)	77	100%	45 (26-60)	Mullen non-verbal IQ 27 months	71% Non-Verbal 29% Phrase Speech
PACT LOCAL	Quarterly Data Returns to Welsh Government	11	72%††	35 (19-61)	81% with DD/LD††††	Not conducted

† Through research ADOS-2 (the majority being scored Autistc rather than ASD).
†† The remaining 28% were referred for social communication difficulties and in waiting list to receive an ASD assessment.
††† Clinical Psychologist judgment in the context of supporting ADOS-2/MIT.
†††† Had clinical notes confirming Developmental Delay/Learning Disability (DD/LD). The remaining had no comment on cognitive difficulties.

Percentage of time the dyad is engaged in Mutual Shared Attention (MSA) in different samples. Part 2, MSA Scores.

Sample	**Therapy Length**	**Therapy Frequency**	**MSA at start point**	**MSA at endpoint**	**Gaze Synchrony at start point**	**Gaze Synchrony at endpoint**
NHS England TAU	13 months	fortnightly / monthly†	67.0%	55.6%*	N/A	N/A
NHS Wales TAU	6 weeks	monthly	46.55%	32.38%	21.9%	16.67%
PACT RCT	13 months	fortnightly / monthly†	65.3%	64.0%	N/A	N/A
PACT LOCAL	6 months	fortnightly	65.5%	77%	N/A	N/A

$*p<0.05$
† During the first 6 months, therapy was delivered fortnightly. The rest of the therapy period was delivered monthly.

Rationale and Aims

To our knowledge, this is the first study to examine the impact of MIT in MSA and aspects of temporal synchrony. While previous assessments in other early parent-mediated intervention have delved into the effects on social communication and interaction, the aspect of temporal synchrony, closely tied to the aforementioned factors, remains unexplored. We initially measure MSA, an assessment derived from the Dyadic Communication Measure for Autism by Green et al. (2010), focusing on joint and shared attention. Our study then assesses the potential impact of MIT on different aspects of ASD children's temporal synchrony as measured through the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA), a micro-coding tool that allows the quantification of interpersonal aspects of naturalistic communication through high-resolution computerised temporal analyses. SCAEMA generates a comprehensive evaluation of Bidirectional Synchrony, Matching Synchrony (via gaze synchrony), and Sequential Synchrony (through the latency of non-verbal vocal response). Further descriptions and explanation of SCAEMA can be found in the methods section of this paper.

Our hypothesis was that we would find an **immediate** positive effect on MSA and synchrony due to the therapy (Dyads would display more MSA and synchrony during the therapy session when compared to their preceding 1:1 play interaction on the same day) *as well as* **over time** improvements (Dyads would be more synchronous and display more MSA after six months of therapy). Specifically, these positive effects would be indicated by:

1. [Mutual Shared Attention] A higher percentage of Mutual Shared Attention.
2. [Matching Synchrony of gaze] A higher percentage of gaze synchrony.
3. [Sequential Synchrony of vocal response latency] Shorter vocal lags when replying to the partner's vocalisations.
4. [Bidirectional Synchrony] A higher incidence of Bidirectional Synchrony.

5.3. Methods

Participants

Sixty-Four children with social communication difficulties were referred to MIT between 2012 and 2019. This comprised two periods of MIT, one from 2012 to 2016 and one from 2017 to 2019, a statistical comparison of the output means and proportions yielded that both periods were comparable and that this could not constitute a confounding factor (more details can be found in Appendix C). Thirty-eight children were excluded from this study due to not having attended the therapy long enough or not having suitable video data. Because of delays in NHS waiting lists, certain children received interventions while still awaiting assessment. However, only those children who were later diagnosed with ASD (with a supporting ADOS-2) were considered for inclusion, which excluded six further children.

Twenty-one children had attended at least 6 months of weekly therapy sessions with their primary carer/parent (19 male and 2 female) aged from 20 months-old to 58 months-old (mean age = 39 months, SD = 10 months). These children were clinically diagnosed with ASD. Diagnosis was supported by ADOS-2 (average comparison score 7.67, min = 5, max = 10, SD = 1.71). IQ was not assessed through standardised means, although IQ level was obtained by Clinical Psychologist notes in the patient files: with 90.5% of the children being developmentally delayed or learning disabled and all of them were non-verbal.

Procedure and Study Design

Each dyad of parent and child were filmed twice on the same day: during 1:1 play interaction (without music) before the therapy session and during the therapy session on the first day of therapy. They were again filmed twice (before and during) at 6 months from the start of the therapy. This led to the study having two predictive variables: *session type* (1:1 no music interaction vs therapy session) and *time point* (at the beginning of the therapy period vs six months after).

Before the therapy, parents were asked to play with their children as they would normally do without the presence of toys. The naturalistic 1:1 interaction was filmed for approximately ten minutes by a member of the research team. After this, the Musical Interaction Therapist would enter the room and the therapy would begin. The rest of the therapy was then filmed.

The initial 4 minutes of each video were discarded to give the children time to adapt to a change of setting, as practised by Green et al (2010). Minutes 4 to 6 were coded and analysed. Of the 84 video-segments analysed, 9 could not have the full 4 minutes discarded due to the video data being too short or becoming not suitable (i.e. child playing with toys, mother speaking with the therapist, etc.). In those cases, the 2 minutes analysed were the last available after the longest possible period excluded for adaptation (a detailed table can be found in Appendix B).

Coding and output variables

The Mutual Shared Attention measure from the Dyadic Communication Measure for Autism (Green et al., 2010) was coded in the two-minute segments. MSA is a binary code reflecting whether the dyad demonstrates a joint focus of attention during the interaction.

SCAEMA was coded through Mangold Interact ® version 20.9.16.0. For each partner of the dyad, a set of binary codes were coded: body orientation, gaze, positive affect, vocalisations, touch and body language (Table 2). A secondary trained independent coder, blinded to the study hypothesis and observation dates, coded 25% of the data to ensure inter-rater reliability.

Table 2

SCAEMA modalities.

Body Orientation	Coded individual's torso is oriented towards partner's torso
Gaze	Coded individual is looking at partner
Positive Affect	Coded individual is smiling or laughing
Vocalisation	Coded individual is vocalizing
Touch	Coded individual and partner are touching
Body Language	Coded individual is using body language (i.e. hand gesture)

Matching Synchrony was assessed through gaze synchrony: the percentage of time the parent and child spent looking at each other. Sequential Synchrony, assessed through the latency in vocal responses, was indicated by the time delay (in seconds) for the child to respond vocally to parent vocalizations, with a maximum allowable time delay of 3 seconds. This threshold was informed by previous research indicating an average response time of 1.3 seconds for ASD children (Nguyen et al., 2022) and guided by our analysis with typically developing infants.

Two multimodal time series was constructed by summing the individual indices for each partner. These time series underwent individual checks for data stationarity, differencing, and modelling using ARIMA. The resulting noise-residual transformed time series were subjected to a Cross-Correlation Function analysis to investigate lagged correlations. The Presence of Bidirectional Synchrony was determined based on at least one significant positive correlation in both lead-lag areas of the Cross-Correlation Function, following the approach outlined by Feldman (2003) and Lotzin et al. (2015).

Analysis

Cohen’s Kappa test assessed reliability on the coding modalities through the Mangold Interact Software. ICC were calculated to assess reliability of MSA scores. McNemar’s test compared the proportion of children displaying Bidirectional Synchrony during the analysed segment in the no-therapy vs therapy session condition, while Cochran’s Q assessed differences in this proportion in the beginning vs 6 months’ time points. Repeated Measures ANOVA assessed the mean differences among the session type and time point conditions for the latency in vocal responses, gaze synchrony and MSA.

5.4. Results

Reliability

Reliability of the different SCAEMA modalities relayed moderate to strong Cohen’s Kappa’s, as well as a high correlation in the Mutual Shared Attention ICC (Table 3).

Table 3

Reliability Figures.

	Child	Parent
Mutual Shared Attention ICC (2,k)	0.85	
Body Orientation Kappa	0.71	0.79
Gaze Kappa	0.75	0.80
Positive Affect Kappa	0.76	0.65
Vocalisations Kappa	0.70	0.74
Body Language Kappa	0.94	0.90
Touch Kappa	0.79	

Cohen’s Kappa interpretation levels of agreement suggested by McHugh, 2012: 0–.20 (none), .21–.39 (minimal) .40–.59 (weak), .60–.79 (moderate), .80–.90 (strong), above .90 (almost perfect)

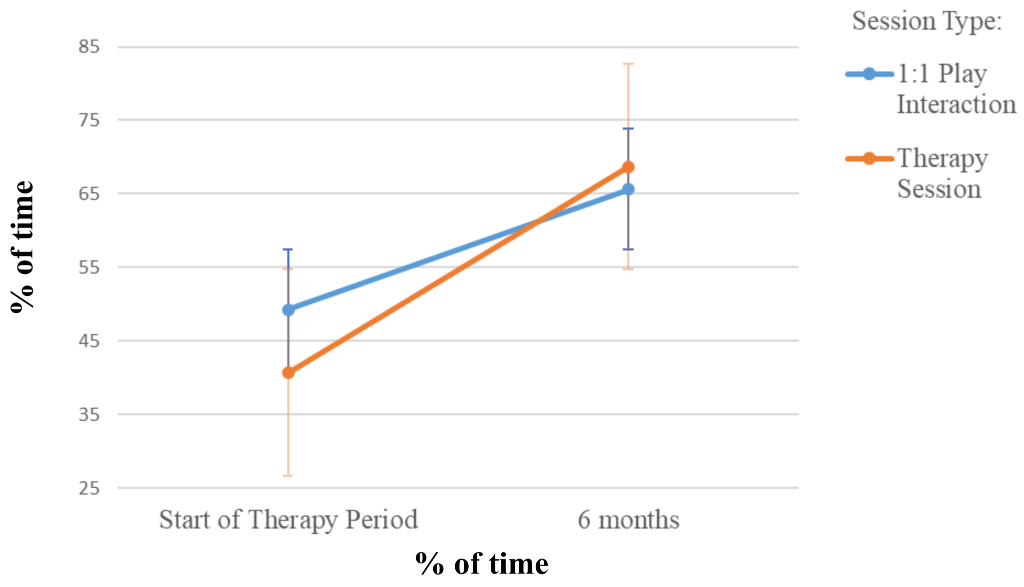
Mutual Shared Attention

There was a large significant main effect in the percentage of time the dyad engaged in MSA between the two time points observed: $F(1, 20) = 19.84$, $p = .00$ $\eta2 = 0.50$. No significant differences were found between play and therapy sessions, nor was there an interaction between session type and time effects $F(1, 20) = 1.75$, $p = .20$.

This shows that, after six months of therapy, children shared their attention with their parents/carers a significantly higher percentage of time (68.69% in therapy session, 65.61% in 1:1 play interaction) than when the therapy period began (40.69% in therapy session, 49.23% in 1:1 play interaction) (Fig 5).

Figure 1

Percentage of times the child and parent engaged in mutual shared attention



Note. Percentage of time the dyad engages in mutual shared attention across analysed conditions. Error bars show standard errors.

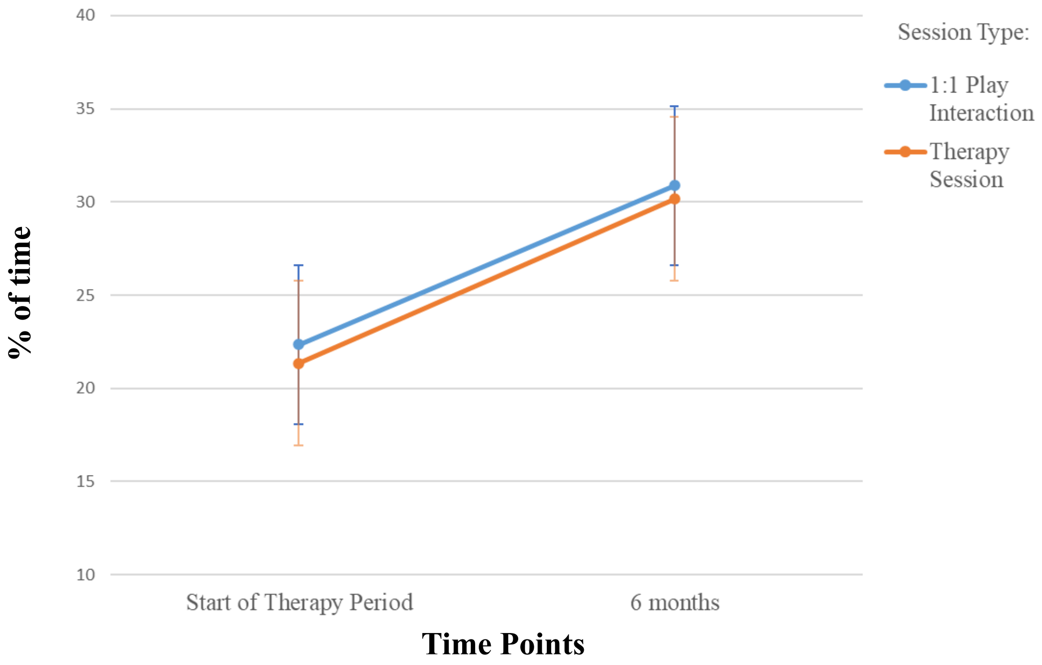
Matching Synchrony of gaze

Repeated measures ANOVA found a large significant effect for the percentage of time for which the dyad's gaze was synchronised in the time point variable F(1, 20) = 4.85, p = .04 η2 = 0.20. No significant effects were found between session type F(1, 20) = 0.62, p = .81 nor for the interaction of time and type of session F(1, 20) = 0.00, p = .97.

This analysis indicates that, after six months of MIT, children synchronised their gaze to their mothers for a higher percentage of time (22.34% outside of therapy sessions and 21.34% within therapy sessions) than when they started MIT (30.89% outside therapy session and 30.16% in therapy session). Children did not show an immediate change in their gaze synchrony when in MIT sessions (Fig 2).

Figure 2

Percentage of time the dyad engaged in gaze synchrony.



Note. Percentage of time the dyad engaged in gaze synchrony across analysed conditions. Error bars show standard errors.

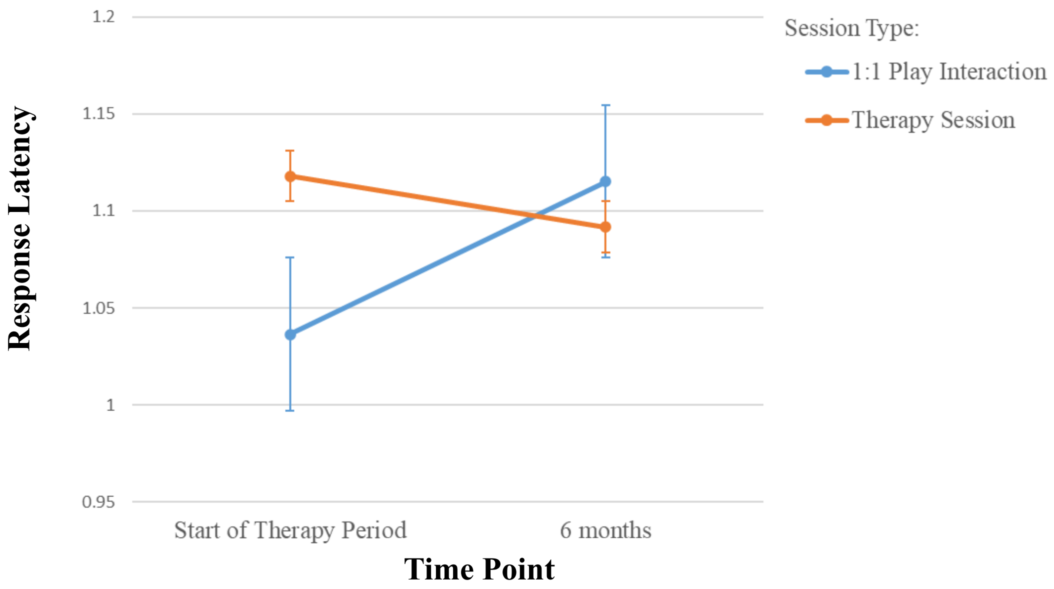
Sequential Synchrony in vocal response latency

Seven children were excluded from this analysis due to either them or their carer's not having done enough vocalisations for the variable to be calculated, leaving 14 participants to analyse the average latency of vocal response. There were no significant effects for session type F(1 ,12) = 0.10, p = .76, time point F(1 ,12) = 0.38, p = .85, nor interaction between these two types of effects F(1 ,12) = 0.30, p = .59.

When vocally answering their mother's vocalisations, children took, on average, 1.12 seconds (in therapy session) and 1.04 seconds (in 1:1 play interaction) on the first observation, which changed to 1.09 seconds (in therapy session) and 1.12 seconds (in 1:1 play interaction) after six months of MIT (Fig 3).

Figure 3

Average duration of the lag in the child vocally responding to parent's vocalisations.



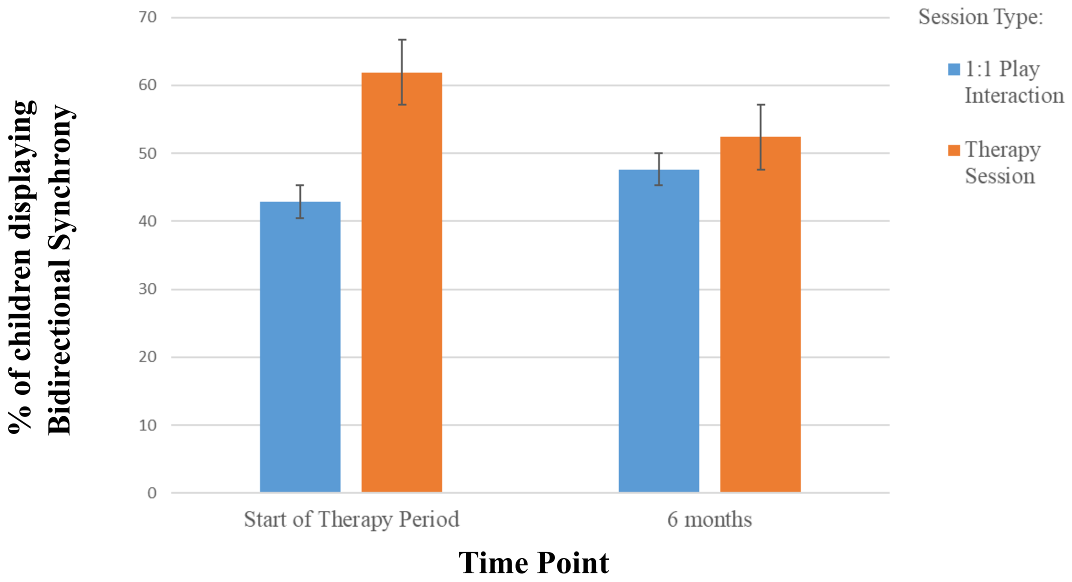
Note. Response latency (measured in seconds) across analysed conditions. Error bars show standard errors.

Bidirectional Synchrony

While overall more children displayed Bidirectional Synchrony during the therapy session as opposed to the 1:1 play interaction, those differences were not significant for either of the time points analysed (McNemar at start of therapy session = 1.50, p = .22; McNemar at Six Months = 0.00, p = 1.00). There were also no significant differences in the proportion of Bidirectional Synchrony over time, neither during 1:1 play interactions (Q = 0.01, p = 1.00) nor in therapy sessions (Q = 0.83, p =.77) (Fig 4).

Figure 4

Percentage of children displaying Bidirectional Synchrony.



Note. Average percentage of children displaying Bidirectional Synchrony across analysed conditions. Error bars show standard errors.

5.5. Conclusions

Summary of results

Regarding the impact of MIT in ASD children's temporal synchrony as measured through SCAEMA, this study found that:

1. [Mutual Shared Attention] There was a higher percentage of MSA after six months of therapy both during therapy session and in 1:1 play interaction. There was no effect due to being in the therapy session.
2. [Matching Synchrony] Results relayed a higher percentage of gaze synchrony after six months of therapy both during therapy session and in 1:1 play interaction. With no effect due to being in the therapy session.
3. [Sequential Synchrony] Vocal latencies when replying to the partner's vocalisations did not statistically differ by session type, nor as therapy period progressed.
4. [Bidirectional Synchrony] While overall more children displayed Bidirectional Synchrony during the therapy session as opposed to 1:1 play interaction, the difference was not statistically significative. No change was seen over time.

Discussion of results

Our results relayed a clear improvement over time in MSA and gaze Synchrony. However, discerning whether this observed enhancements stem from therapeutic interventions or natural developmental maturation remains challenging. The absence of an intersubject control group, undergoing standard therapy procedures, or an intrasubject baseline, further complicates this distinction. Given the retrospective nature of this study, much of the data was collected before its design, rendering impossible the establishment of a baseline preceding the therapy phase. The main reason why a baseline was not recorded was as some of those participant's families were extremely vulnerable and there was no justification to make them wait for therapy after they had been referred. Additionally, the constraints imposed by the COVID-19 pandemic hindered the recruitment of a diagnosed control group engaged in Treatment as Usual. Recognizing this limitation, and in the context of post-covid NHS ND waiting lists now being extremely long for local ND, future evaluations of MIT have adopted the inclusion of a baseline period while children are in the waiting list before their referral being accepted, documenting the developmental trajectory of children on waiting lists before their engagement in therapy.

Fortunately, there is an existing dataset on ASD diagnosed children of similar age and verbal proficiency, who underwent assessment for MSA. Green et al.'s (2010) findings indicated that children's MSA did not exhibit improvement with age maturation over a 13 months period: Children undergoing the PACT RCT maintained their MSA scores, while children attending NHS England Treatment as Usual experienced a decline. A small sample of children undergoing NHS Wales Treatment as Usual for 6 weeks also showed a small, non-significant, decline in MSA percentages. BCUHB PACT children started from a similar percentage to those in the RCT and experienced some improvement. This could be due to this therapy being delivered by a very qualified team rich in clinical psychologists who were experts on the therapy and/or to it taking place in a more familiar setting (usually at the participant's home) than the RCT. Our MIT participants demonstrated substantial improvement, despite starting with lower MSA scores (Figure 6) (Table 4). It is noteworthy that, in the PACT offered locally by BCUHB's IMPACT project, children referred for MIT were characterized as more low-functioning and faced greater social communication difficulties compared to those referred to PACT. These samples provide an encouraging basis for considering that the significant positive change in MSA we observed is like to be more related to therapeutic outcomes than to natural maturation.

Table 4

Percentage of time the dyad is engaged in Mutual Shared Attention (MSA) in different samples. Part 1, samples characteristics (continued below)

Sample	Source	N	ASD Status	Age in months	Cognitive Level	Verbal Proficiency
NHS England TAU	Green et al. (2010)	75	100%	45 (24-60)	Mullen non-verbal IQ 25.3 months	67% Non-Verbal 33% Phrase Speech
NHS Wales TAU	Welsh Arts Council Grant Evaluation	7	100%†	39 (27-47)	78% with DD/LD†††	100% Non-Verbal
PACT RCT	Green et al. (2010)	77	100%	45 (26-60)	Mullen non-verbal IQ 27 months	71% Non-Verbal 29% Phrase Speech
PACT LOCAL	Quarterly Data Returns to Welsh Government	11	72%††	35 (19-61)	81% with DD/LD††††	Not Assessed
MIT LOCAL	Elias-Masiques et al. (2024)	21	100%	39 (20-58)	90.5% with DD/LD††††	100% Non-Verbal

† Thorough research ADOS-2 (the majority being scored Autistc rather than ASD).
†† The remaining 28% were referred for social communication difficulties and in waiting list to receive an ASD assessment.
††† Clinical Psychologist judgment in the context of supporting ADOS-2/MIT.
†††† At least 81% of the children had clinical notes confirming Developmental Delay/Learning Disability (DD/LD). The remaining 19% had no comment on cognitive difficulties.

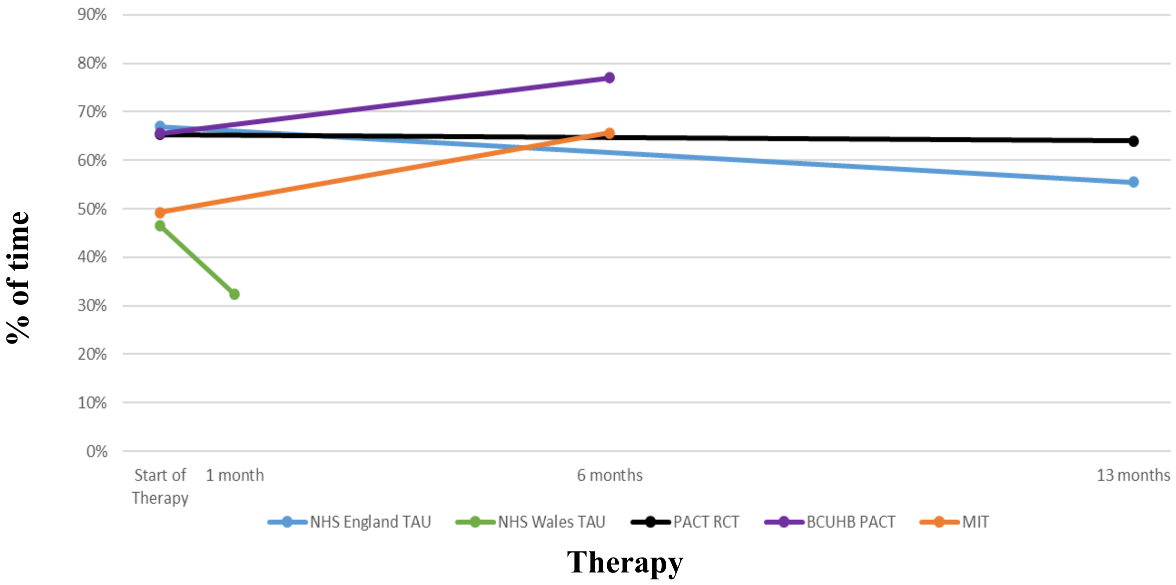
Percentage of time the dyad is engaged in Mutual Shared Attention (MSA) in different samples. Part 2, MSA and Gaze Synchrony Scores

Sample	Therapy Length and Frequency	MSA at start point	MSA at endpoint	Gaze Synchrony at start point	Gaze Synchrony at endpoint
NHS England TAU	13 months, fortnightly / monthly†	67.0%	55.6%*	Not Assessed	Not Assessed
NHS Wales TAU	6 weeks, monthly	46.6%	32.4%	21.9%	16.67%
PACT RCT	13 months, fortnightly / monthly†	65.3%	64.0%	Not Assessed	Not Assessed
PACT LOCAL	6 months, fortnightly	65.5%	77%	Not Assessed	Not Assessed
MIT LOCAL	6 months, weekly	49.2%	65.6%*	21.34%	30.16%*

$*p<0.05$
† During the first 6 months, therapy was delivered fortnightly. The rest of the therapy period was delivered monthly.

Figure 5

Percentage of time the dyad is engaged in MSA in different samples



Note. Percentage of time parent-child dyads engaged in MSA in groups undergoing different treatments. All measures have been taken in 1:1 naturalistic interactions outside of therapy sessions. TAU= Treatment as Usual / no therapy offered. RCT= Random Controlled Trial.

Our findings indicated an increased percentage of gaze synchrony following six months of therapy, observed in both therapy sessions and one-on-one play interactions. In a preceding earlier case study of a severely autistic child undergoing MIT conducted by Wimpory et al. (1995), notable improvements, sustained during a two-year follow-up period, were identified in eye contact, among others. The augmented eye contact observed in this context, which did not improve in the 4 months baseline period but significantly improved during the 7 months therapy period ($p = .008$), could potentially contribute to heightened gaze synchrony. Additionally, in a small sample of children undergoing NHS Wales Treatment as Usual, gaze synchrony demonstrated a small, non-statistical, decrease over the period of six weeks (Table 4). These findings would support the observed rise in gaze synchrony we observed in this study following 6 months of MIT.

Vocal latencies did not statistically differ between analysed conditions. Children took on average between 1.04 to 1.12 seconds to vocally respond; durations that are consistent with findings from prior research (Nguyen, 2022) in children diagnosed with ASD. Our study introduces an innovative approach to assessing multimodal synchrony, marking a distinctive contribution to the field. Our hypothesis was that therapy would make a positive impact in multimodal Bidirectional Synchrony, based on the findings of a prior unpublished study from our team (Elias-Masiques et al., 2024) identified that ASD children exhibit diminished multimodal Bidirectional Synchrony compared to typically developing (TD) children, with developmental delay/learning difficulties (DD/LD) not acting as a confounding factor. Despite not achieving statistical significance, a trend emerged indicating that, when children were undergoing therapy, they displayed an increased tendency toward Bidirectional Synchrony. This warrants consideration in future research due to the crucial role of interpersonal temporal synchrony in early development and socialization.

The generalizability and robustness of these results is somewhat constrained due to the relatively small sample size. A larger sample would enhance the statistical power of our study and provide a more comprehensive understanding of the observed effects. Our current study revealed improvements in both gaze synchrony and MSA, although we exercise appropriate caution in attributing these changes solely to therapy as well as a trend signalling higher multimodal Bidirectional Synchrony during MIT sessions. These promising observations warrant further investigation in larger samples with refined designs to ascertain their significance.

5.6. References

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Chapter 6

Discussion

This thesis has examined various forms of synchrony using the Synchrony of Communication in Autism: Evaluation by Micro-Analysis (SCAEMA) across three distinct cohorts: an initial pilot involving typically developing (TD) non-verbal infants, a group encompassing both ASD-diagnosed and non-diagnosed non-verbal children and infants, and a smaller sample featuring ASD-diagnosed children undergoing Music Interaction Therapy (MIT).

SCAEMA provides a thorough assessment of three types of synchronies: Matching Synchrony (via gaze synchrony), Sequential Synchrony (measured by the latency of non-verbal vocal responses) and Bidirectional Synchrony. Furthermore, this thesis has also included evaluation of Mutual Shared Attention (MSA), an assessment adapted from Green et al.'s (2010) Dyadic Communication Measure for Autism. MSA specifically examines joint and shared attention within the dyad during interactions.

6.1. Mutual Shared Attention

Considering the pivotal role that joint and shared attention play in social interactions, their role as a precursor to Matched Synchrony (Harrist 2002) and its relevance to ASD (Saint-Georges et al., 2010; Chawarska et al., 2012), this thesis incorporates Mutual Shared Attention (MSA), a measure that assesses shared attention, encompassing joint attention in less adept children.

- In the TD infants' pilot study, there was a significant positive correlation between MSA and Matching Synchrony, while no significant correlations were observed between MSA and Sequential or Bidirectional Synchrony.
- ASD children exhibited a lower percentage of MSA compared to those without ASD. This could not be explained by developmental delay/learning disability status.
- A statistically higher percentage of Mutual Shared Attention was observed after six months of MIT therapy, both during therapy sessions and 1:1 play interactions, whilst no immediate effect was evident during the therapy session itself.

SCAEMA revealed a link between matching gaze synchrony and MSA, where TD infants and parents directed their gaze at each other's faces more often when sharing a common focus of attention. This aligns with prior research (Tschacher et al., 2021; Harrist, 2002; Puyjarinet et al., 2017). SCAEMA did not unveil a correlation between MSA and Sequential Synchrony of vocal responses. This was expected as, even when not actively engaging with their parents and sometimes displaying disruptive behaviours such as crying, infants still vocalized in response to their parents' vocalizations, showing similar latencies as when they shared a focus of attention. Interestingly, SCAEMA unexpectedly did not reveal a correlation between MSA and Bidirectional Synchrony in TD infants. It's plausible that SCAEMA's measure of Bidirectional Synchrony encompasses too broad a spectrum, as it detected synchrony even when infants were not jointly focusing attention with their parents. A more nuanced measure capable of detecting the degree of synchrony rather than just its presence, may be able to tease out a potential Bidirectional Synchrony change related to MSA.

ASD participants displayed a significantly lower percentage of MSA compared to non-ASD participants, and this difference was not significantly affected by the presence of developmental delay / learning disability. These outcomes correspond with observations by Saint-Georges et al. (2010), who noted decreased rates of shared attention in early life among individuals with ASD. They are also congruent with Chawarska et al.'s (2012) finding that ASD toddlers exhibit less attention to social scenes in comparison with both typically developing children and those with developmental delay.

ASD-diagnosed children participating in weekly MIT sessions for six months exhibited a noteworthy significant improvement over time in MSA. Various meta-analyses and reviews underscore the positive impact of early interventions on joint attention in ASD (Nahmias et al., 2019; Reichow, 2012; Schertz et al., 2012). However, due to this study lacking an intrasubject baseline or an intersubject control group, we cannot be entirely certain whether the higher percentages of MSA observed can be entirely explained by the intervention. Some of the increase in MSA could be due to natural developmental maturation rather than to therapeutic intervention.

One indication that MIT sessions may, indeed, be driving the change in MSA comes from a published dataset of ASD-diagnosed children, similar in age and verbal proficiency to our study participants, who underwent MSA assessment in Green et al.'s (2010) study. Green et al. found that children's MSA did not exhibit improvement with age maturation over a 13-month period. Instead, there was a decline for children attending NHS England Treatment as Usual (TAU) and a maintained (plateau-like) effect for children undergoing PACT therapy. In contrast, participants undergoing MIT exhibited significant progress, even though their initial MSA percentages were markedly lower than those in Green et al.'s study. Within the IMPACT program provided by BCUHB, children referred to MIT were lower-functioning and more socially impaired compared to those referred for PACT. One important possibility is that improvements in MSA may be more striking in individuals starting from a lower baseline.

6.2. Matching Synchrony of gaze

Gaze synchrony is indicated by when both child and parent/carer simultaneously look at each other's faces. The relevant findings within this thesis are:

- Older TD infants exhibited less gaze synchrony than their younger counterparts. High MSA during interactions led to an increase of gaze synchrony.
- Autistic children demonstrated significantly lower gaze synchrony than their non-autistic peers. In contrast, the percentage of gaze synchrony was not significantly different between children with developmental delay or learning disability and those without.
- ASD-diagnosed children participating in MIT showed a higher percentage of gaze synchrony after six months of therapy, observed both during therapy sessions and 1:1 play interactions. There was no immediate effect observed during the therapy session itself.

The existing literature highlights that gaze synchrony dominates as the primary mode of interaction during the initial three to four months of a typically developing infant's life (Feldman, 2007b; Senju & Johnson, 2009). This tendency undergoes a gradual shift, with infants directing their attention to parents' mouths, emphasizing vocal synchrony by around 8 months (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). SCAEMA's results in a TD sample don't precisely mirror this gradual decline; instead, children under 10 months exhibited gaze synchrony over 60% of the time, whereas those over 10 months engaged in synchrony less than 40% of the time.

This difference in our results might stem from the manual coding nature of SCAEMA, as opposed to using automated methods. Additionally, SCAEMA's focus on detecting synchrony in gazing at the face, rather than the more intricate synchrony of eye contact, could contribute to this discrepancy. Additionally, our findings revealed a connection between matching gaze synchrony and mutual shared attention, indicating that children and parents directed their gaze towards each other's faces for a greater percentage of time when sharing a common focus of attention. This observation aligns with prior research (Tschacher et al., 2021; Harrist, 2002; Puyjarinet et al., 2017).

SCAEMA showed that autistic children consistently displayed a noticeable decrease in gaze synchrony compared to non-autistic children and infants, irrespective of comorbid developmental delays/learning disabilities. This aligns with the existing body of literature, which indicates that individuals with ASD struggle in maintaining prolonged gaze toward faces (Jones & Klin, 2013; Gliga et al., 2014; Ozonoff et al., 2010) and exhibit reduced gaze synchrony not only when compared to typically developing children (Trevarthen & Daniel, 2005; Wang et al., 2018) but also in contrast to those with developmental delays (Chawarska et al., 2012).

For ASD-diagnosed children attending weekly MIT sessions for six months, SCAEMA showed a significant improvement over time in gaze synchrony. However, due to the study design (which did not include an intersubject control group undergoing standard therapy nor an intrasubject baseline) it was not possible to delineate whether this enhancement resulted from therapeutic interventions or natural developmental maturation. In a previous case study (Wimpory et al.,1995), a severely autistic child undergoing MIT showed improved eye contact after the therapy period, sustained over a two-year follow-up. The increased eye contact observed in that study could be extrapolated as contributing to our finding of greater gaze synchrony.

6.3. Sequential Synchrony of vocal response latency

The latency of vocal response is determined by the average duration (in milliseconds) of the time it takes for a child to vocally respond to a parent/carer’s vocalization, with a maximum allowance of 3 seconds. The relevant findings within this thesis are:

- The duration latency of vocal response in TD infants did not correlate with chronological age nor with the amount of MSA the dyad displayed. Although there was a trend suggesting that lower MSA was associated with shorter latencies, this was not statistically significant.
- The durations of vocal response latencies were significantly consistent, regardless of the presence of an ASD diagnosis and/or learning disabilities or developmental delays.

- Vocal latencies did not differ between play session and MIT therapy sessions, nor did they change across the six-month therapy period.

SCAEMA showed that TD infants displayed an average vocal response latency of 1.09 seconds, aligning with Nguyen's et al. (2022) reported latencies in their 95% estimated latency for the typical baseline model. Our data, however, did not show the gradual increase in response latency experienced alongside language skill development in TD infants that was found by Nguyen et al. This discrepancy may stem from SCAEMA involving a single mobile point of video/audio recording in a natural setting rather than sophisticated stationary recording equipment in controlled environments (Hilbrink et al., 2015; Gratier et al., 2015) which produce more reliable sound data but could present negative challenges for prospective ASD participants and their potential discomfort with physically restricted movement. Another explanation is that the linguistic demands in these naturalistic parent/infant toy-free interactions could pose fewer challenges than interactions that involve toys or more structured interactions, aligning with the idea of context influencing this latency (Casillas et al. (2016).

SCAEMA found no significant differences in the duration of vocal response latencies between ASD and non-ASD participants, regardless of concurrent developmental delay / learning disability status. This aligns with prior research by Warlaumont et al. (2010), reporting comparable vocal response latencies in non-verbal autistic and TD children. Studies indicating prolonged response times in ASD often involve high-functioning verbal individuals (Heeman et al., 2010; Ochi et al., 2019; Zampella et al., 2020), suggesting a potential role played by language proficiency or more complex contexts and conversations.

Vocal latencies did not statistically differ when analysed during MIT session as opposed to 1:1 play sessions. Additionally, the vocal latencies did not change after a period of 6 months of MIT, neither during the therapy sessions or in a generalised context. On average, latencies ranged from 1.04 to 1.12 seconds; durations that are consistent with findings from prior research (Nguyen, 2022) in children diagnosed with ASD.

6.4. Bidirectional Synchrony

SCAEMA is an innovative tool, generating a Bidirectional Synchrony measure. This is achieved through a pair of time series incorporating body orientation, gaze, positive affect, touch, vocalizations, and body language of the dyad, subsequently cross-correlated to assess lagged synchrony. The relevant findings within this thesis are:

- In the TD infant cohort, every participant demonstrated Bidirectional Synchrony, independent of chronological age or levels of MSA.
- A significantly lower percentage of ASD-diagnosed children displayed Bidirectional Synchrony compared to those without an ASD diagnosis. The presence or absence of comorbid developmental delays/learning disabilities did not exert a significant effect on Bidirectional Synchrony although there was a trend with fewer children with DD/LD displaying Bidirectional Synchrony.
- In the context of MIT, a higher overall number of children exhibited Bidirectional Synchrony during the therapy session compared to when in 1:1 (music-free) play interactions. However, this difference did not reach statistical significance, and no observable change was noted over the six-month therapy period for either context.

SCAEMA showed that all TD infants analysed, even those as young as 3 months, achieved Bidirectional Synchrony. Lewkowicz's study (2000) suggested a developmental shift from unimodal to multimodal synchrony between 4 and 8 months in experimental conditions involving single syllables. It's worth noting that previous studies by the same author (Lewkowicz, 1988a, 1988b) suggested that this shift might not be as evident when presented with more naturalistic continuous stimuli, such as talking or dancing, which provide a more substantial amount of kinematic visual information.

Additionally, Evans and Porter (2009) observed a significant developmental shift between 6 to 12 months, noting an increasing trend towards symmetry and bidirectionality in mother–infant interactions. The authors found bidirectional co-regulation occurring at higher frequencies as children aged: 38% at 4 months, 47% at 6 months, and 67% at 12 months. In a similar vein, Feldman (2007b) reported a rise of children achieving Bidirectional Synchrony from 11% at 3 months to 40% at 9 months. Additionally, while SCAEMA identifies the occurrence of Bidirectional Synchrony, it lacks the capacity to quantify the amount of synchrony displayed, limiting its ability to quantifiably differentiate younger children exhibiting these interactions to a lesser degree.

SCAEMA revealed dyads involving ASD-diagnosed children struggled in displaying Bidirectional Synchrony, with a non-significant trend of the presence of developmental delay / learning disability impairing this further. SCAEMA's innovative approach to aggregated synchrony analysis in ASD participants means that direct comparisons with previous research in this domain not possible. However, there is existing research on the components that make up our measure of synchrony. Besides the previously discussed gaze synchrony and vocal latencies, additional aspects such as touch, body orientation, body language (i.e., gestures), and the expression of positive affect have been noted to be affected in individuals with ASD: Individuals with ASD exhibit atypicalities in tactile perception in facial and mouth regions, along with a failure to orient, and these each correlate with the severity of their ASD symptoms (Silva et al., 2015). High-functioning adults with ASD show prolonged delays between gaze-gesture nonverbal signals, such as looking at a stimulus and pointing (Bloch et al., 2022). Both high- and low-functioning individuals with autism demonstrate diminished interpersonal motor synchrony during activities such as clapping, marching, and drumming in a social context (Kaur et al., 2018). Autistic individuals encounter challenges when attending to human faces in social interactions (Thye et al., 2018; Charrier et al., 2017), resulting in compromised facial emotion recognition in ASD (Harms et al., 2010). This struggle extends to the display of positive affect (Kellerman et al., 2019; Saint-Georges et al., 2010; Ozonoff et al., 2014). Together, these results support this thesis' observation of compromised Bidirectional Synchrony in individuals with ASD.

When analysing the impact of MIT on Bidirectional Synchrony, ASD diagnosed children appear to increase Bidirectional Synchrony when in therapy as opposed to during 1:1 naturalistic play. While this increase was not statistically significant, it is encouraging and suggests that future work with a larger sample and/or with a measure capable of evaluating not only the presence but also the degree of synchrony would be warranted.

6.5. Strengths and Limitations

SCAEMA presents an innovative approach to evaluating Bidirectional Synchrony in natural interactions offering detailed micro-temporal data. This observational coding measure is specifically tailored for ASD children in a therapeutic setting, enabling the collection of video data during naturalistic interactions in a minimally intrusive manner. This approach avoids the need of restraining low functioning children (i.e. sitting in a highchair) or creating experimental conditions that could introduce confounding factors.

While SCAEMA was designed to analyse synchrony in a multimodal, integrated way, it remains unclear whether all communication modes are captured in the time-series resulting from SCAEMA's coding. It is possible that the child and mother are using only one or two modalities (e.g., gaze and/or vocalizations), and this could vary throughout the time series. Additionally, we cannot determine if the time-series reflects cross-modal interactions; while bidirectional synchrony reveals a turn-taking pattern, it does not show whether these interactions are cross-modal (e.g., the child responding to the mother's vocalizations with gaze or body orientation instead of vocalizations). Therefore, the validity of conceptualizing bidirectional synchrony as multimodal synchrony is questionable. This limitation highlights the need for more detailed coding and analysis techniques that can accurately capture and differentiate between various communication modalities, ensuring a more comprehensive understanding of the interaction's synchrony dynamics.

The retrospective collection of data from individuals diagnosed with ASD offered an important opportunity to investigate temporal synchrony in very young children (later diagnosed with ASD) before undergoing any therapy. By capturing data before the initiation of therapeutic interventions, we gained valuable insights into social timing and shared attention abilities in this population. This approach establishes a foundation for understanding the characteristics of ASD participants, uncontaminated by the potential influence of therapeutic interventions.

The generalizability and robustness of the SCAEMA results reported here are somewhat limited, however, primarily due to the relatively small sample sizes, particularly in the case of the TD sample and the participants undergoing MIT. Expanding the sample size would significantly enhance statistical power and contribute to a more comprehensive understanding of the observed effects. Additionally, the sample consisting of non-ASD individuals (including children with social communication difficulties and TD non-verbal infants) lacked the precise matching required for rigorous comparisons. Assessing individuals for cognitive level to establish matched pairs was not feasible within the retrospective design. Furthermore, the retrospective design precluded the establishment of an intrasubject baseline for the MIT sample. As indicated earlier, this limitation hinders the ability to discern whether the observed results can be entirely attributed to therapeutic interventions or may partially be a result of natural developmental maturation. The alternative of an intersubject control group undergoing Treatment as Usual was not possible due to Covid-19 restrictions during the time of the study.

6.6. Future Research

This thesis initiates a foundational exploration into temporal synchrony within naturalistic settings. To bolster the external validity of observed effects and delve deeper into their robustness, future investigations should encompass larger samples. A more thorough examination of Bidirectional Synchrony across chronological age (with a more expansive sample, encompassing a diverse and evenly distributed representation across various developmental stages), focusing not only on its presence but also its degree, promises to enrich our understanding of the development of this pivotal skill. Furthermore, a closer exploration of Bidirectional Synchrony in conjunction with shared attention, variations in linguistic difficulty, and the impact of diverse contextual demands could provide additional layers to our comprehension of early interpersonal synchrony.

Future research endeavours should scrutinize Bidirectional Synchrony in ASD, incorporating a well-matched control group and integrating cognitive assessments to clarify the robustness of present findings. Alternatively, adopting a prospective longitudinal approach would afford researchers the opportunity to track temporal synchrony in both ASD and TD participants over time, potentially affording insights into both clinical impact and developmental trajectories. To comprehensively investigate the effects of MIT, a rigorous randomized control trial is imperative. Establishing either a control group undergoing Treatment as Usual or an intrasubject baseline equivalent in duration to the therapy period would shed light on the impact of this therapeutic intervention on temporal synchrony.

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Appendices

Appendix A, B and C

Appendix A – SCAEMA Manual (Chapter 2)

The **Synchrony of Communication in Autism: Evaluation by Micro-Analysis** (SCAEMA) can analyse interaction videos of parent/carer and child with ASD allowing quantification of interpersonal aspects of naturalistic communication through high resolution (0.1 seconds) computerised temporal analyses.

SCAEMA evaluates both child and parent's/carer's social interaction indicators and adds them into a multimodal timeseries.

Coding is performed by an observer using Mangold Interact™ software to electronically code the video-recordings and uses a video logging system driven by this time code to achieve a resolution of 0.1 seconds.

Coding Segment Selection

The first 4 minutes of video are discarded to allow the child to acclimate to the session, and the 2 minutes segment following is coded. In the event the total video length of the file is less than 6 minutes, the initial number of minutes discarded can be shortened in order to have 2 whole minutes for coding.

Modalities Coded

These codes are all mutually exclusive and are coded separately for parent and child within the same Interact™ file. If the coder cannot see the person they are coding (or for example, cannot see their eyes whilst trying to code "gaze"), continue on the code that was pressed last for the current modality, code as normal when they come back into view. Though each individual code may not necessarily indicate communication intention, it can be assumed that a high sum of these would correlate with high communication intention to the other person. For all modalities, if unsure and have to keep replaying video clip to try and work out if there is a change (perhaps due to camera angle), keep on same code as when were last certain.

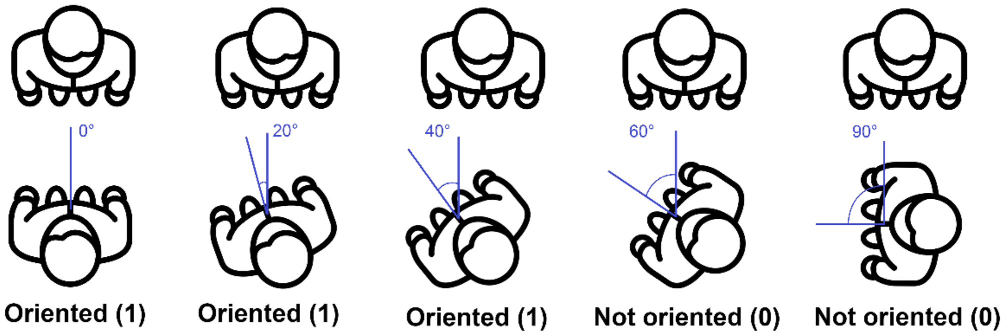
Body Orientation:

When the child or adult is angling their torso towards the other person, this will be coded as a 1 (ON) for this modality. When the torso is not angled towards them, a score of 0 (OFF) will be given.

Code 1 as long as the torso is more oriented than not. Full orientation is a 0-degree angle between the orientation and the other person. If the coded person rotates less than 45 degrees away this would still code as oriented (1) (Figure 1)

Figure 1

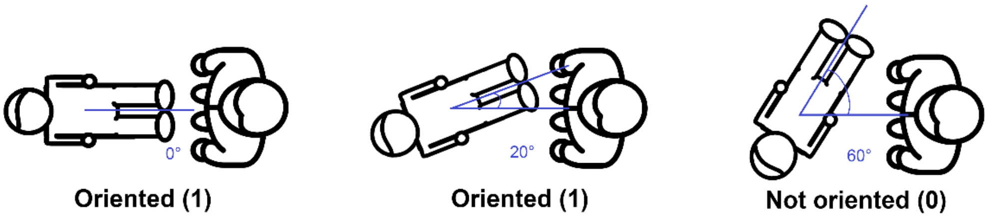
Body Orientation Angles



If the child is laying on the floor and his torso is completely orientated towards the ceiling, then count the orientation by using their whole body rather than their torso. Do not code as oriented if, for example, the child is laying on floor with legs pointing away from adult. Apply the same rule if the child's torso is orientated towards the floor (i.e. while crawling) (Figure 2).

Figure 2

Body Orientation Angles when Child is Lying



Gaze:

If the gaze is directed towards the other person, a code of 1 (ON) will be given will be given for this modality. If the gaze is directed elsewhere, the code will be 0 (OFF). If the face is oriented towards the other person, and it is not clear that the eyes are looking elsewhere (or that they are closed), then count this as looking. If you cannot see (e.g. filming from behind their head) – keep code on previous one unless there is a very obvious change (e.g. head orientation moves away or towards and it is very clear). In the case the start of the coded segment does not show the face, move forwards until this is visible and apply the first code (1 or 0) retrospectively.

Positive Affect:

If the child or adult smiles or laughs a score of 1 (ON) will be given. When no positive affect (smile or laughter) is shown, a score of 0 (OFF) will be given. Code changes in positive affect only when they are definite (e.g. from definite smile to definite non-smile / from definite non-smile to definite smile, and where there is obvious cheek lift or fall. Again, as with gaze, if cannot see, keep code on previous one unless obvious change (e.g. can hear laughter) or until can see again. In the case the start of the coded segment does not show the face, move forwards until this is visible/hear laughter and apply the first code (1 or 0) retrospectively.

Vocalisations:

When the person being coded makes any kind of vocalisation (verbal or otherwise), this will be coded as 1 (ON). When no noise is made, 0 (OFF) score will be given. When vocalisations happen close together without considerable pause, code as one event. If pause is a second or longer, count as separate vocalisations. Make sure to wear good headphones when coding this modality, as some quiet or low tones can be difficult to hear otherwise. Code only when definite noise through vocal cords, for example, coughing, blowing, or huffing is not counted as a vocalisation.

Touch:

If the person being coded touches the other person (including being carried), a score of 1 (ON) will be given. When they are not touching the other person at all, this shall be coded as 0 (OFF). Be sure to code even the smallest touches/non-touches by slowing the video to check for very quick changes. Any body part can touch any other person body part and will be coded as 1 (ON).

Since touching values are the same for adult and child, it does not need to be coded separately and can be coded only once.

Body Language:

Body language can be considered as any communicative movement (including blowing on the other person, for example) that is not touching, (with the exception of kissing or copying). It excludes body orientation (which is a mutually exclusive code already), and self-stimulatory behaviour (as this is not related to communication). It includes gestures, body noises (E.g. clapping), giving or showing an object, waving, reaching out, and using/guiding the parent's hand in order to accomplish something (e.g. to open a bag). If the child or parent does any of these actions, this will be coded as 1 (ON). No obvious body language will be coded as a 0 (OFF). Non-verbal imitation is included in this category (this can include touching if it is clearly imitation). Also code here if child is using hands expressively while talking (only count if happens consistently e.g. not a fluke). If playing a body language game (such as using hands coming closer to create excitement about tickling), where pauses are part of this game, include these, and stop the '1 (ON)' code when the game seems to have actually stopped, rather than at each anticipatory pause. If child is moving in a repetitive way, that would sometimes be considered self-stimulatory, (e.g. shaking head side to side), but it is in time with the music, they are smiling/ looking at parent/ parent is doing it too, use your judgement as to whether it is body language.

Reliability Tests:

Reliability can be assessed through Kappa or Intraclass correlation coefficient (ICC).

Kappa is the ideal test as it compares each time points between raters. Values of Kappa from 0.40 to 0.59 are considered moderate, 0.60 to 0.79 substantial, and 0.80 outstanding (Landis & Koch, 1977).

ICC compares the overall time spent in the different coded categories. Inter-rater reliability is generally considered being poor for ICC values less than .40, fair for values between .40 and .59, good for values between .60 and .74, and excellent for values between .75 and 1.0 (Koo & Li, 2016).

Resolution Adjustment

While Interact™ codes at a resolution of 24 frames per second (0.0416 seconds), it exports the data to a .cvs file at a 0.01 seconds resolution. The .cvs file can be exported into an Excel™ file where the resolution can be adjusted to 0.1 seconds by aggregating all the values within each 0.1 second, setting a bigger resolution more suited to analysis while still maintaining the rich data given by the lower original resolution.

This creates 12 time series (2 for each modality: one for the Child and one for the Parent). These can be aggregated into the two multimodal time series for the analysis of Mutual Synchrony.

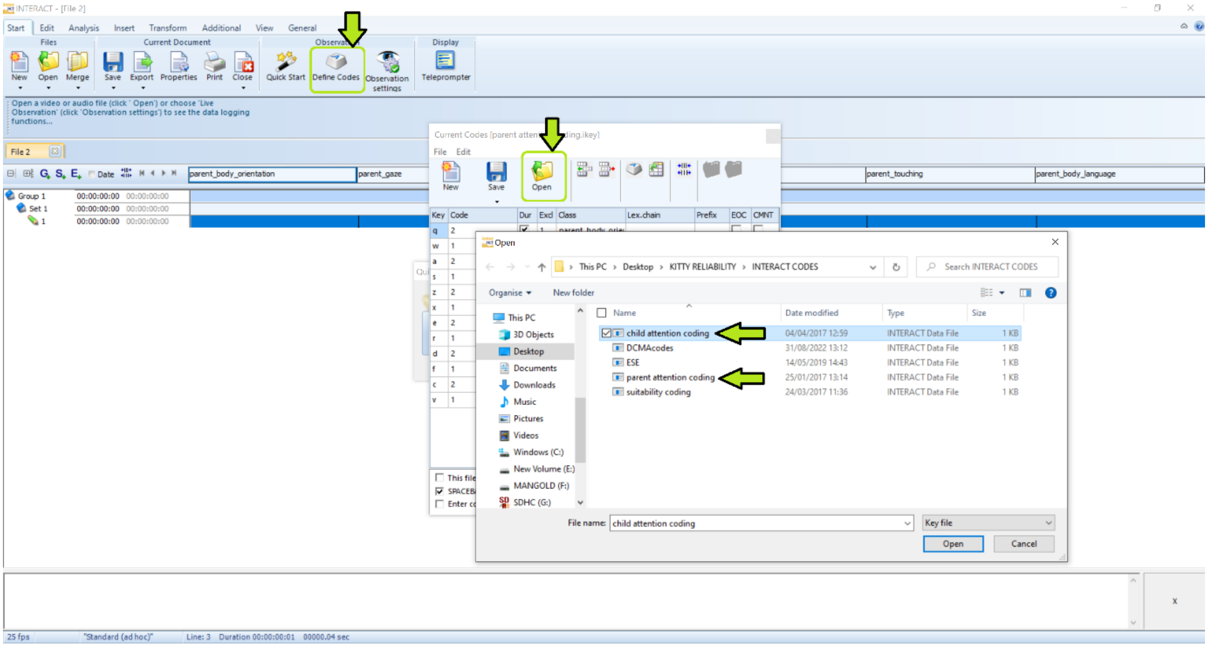
Matching and Sequential Synchrony Variables

Matching Synchrony (gaze synchrony) is calculated by aggregating all the values in which both child and mother timeseries have been coded as 1 (ON) and dividing this by the length of the time series, resulting in a percentage value indicating the time Mother and Child were simultaneously gazing at each other.

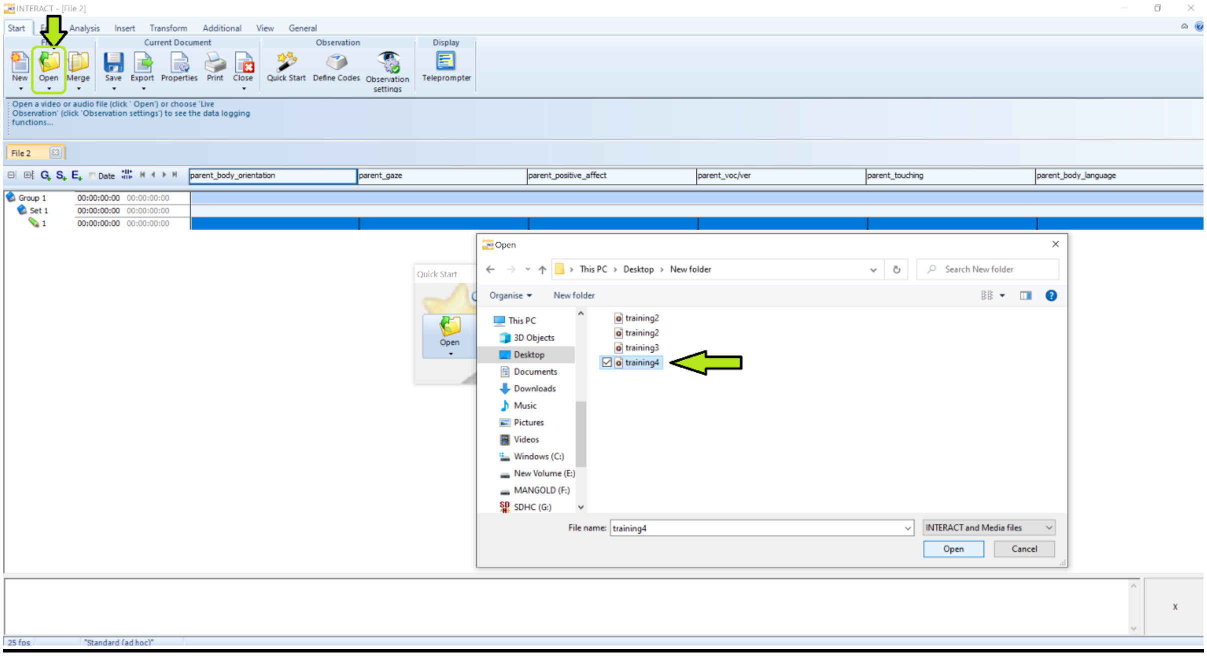
Sequential Synchrony (vocal response delay) is calculated by aggregating the number of 0 (OFF) before the first subsequent 1 (ON) in the Child's vocalisation time series after the last mother's vocalisation (in a maximum time delay of 3 seconds) to translate into the time delay (in seconds). The average duration (in seconds) and standard deviation (in seconds) are calculated among all vocal responses.

Coding with Mangold Interact ™

Open a new Mangold Interact file and save it in folder. Press "Define the Codes" and "Open" to set the coding keys (start by "Child Attention Coding". Once completed, move into "Parent Attention Coding").



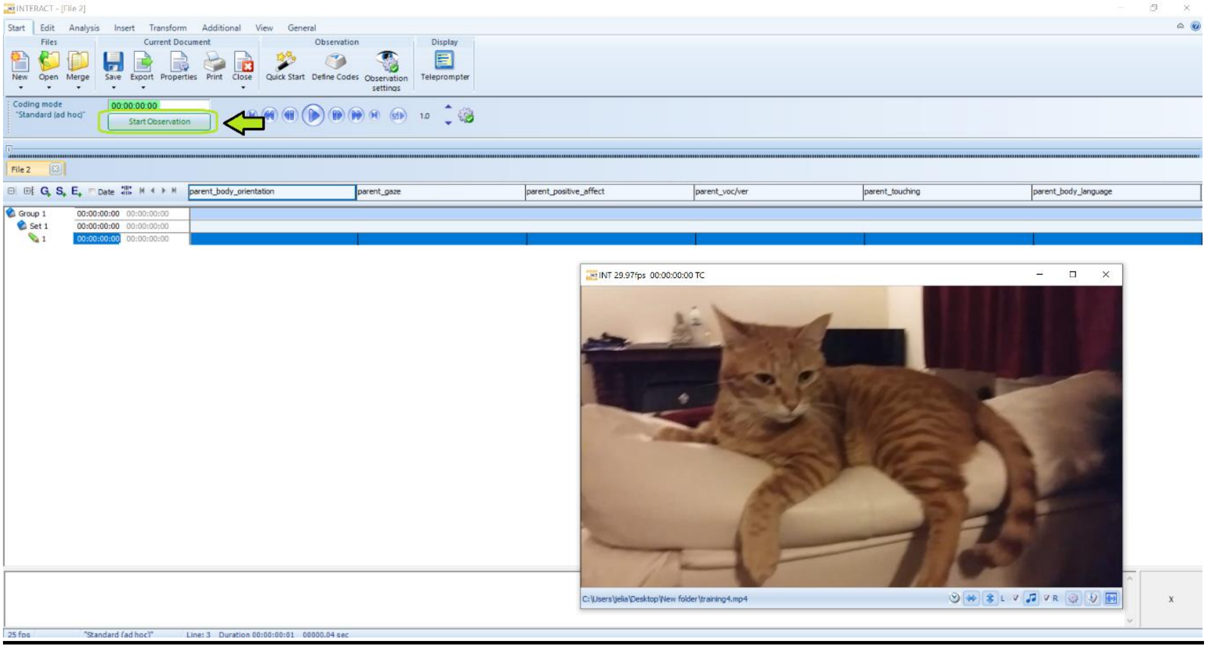
To open the video file, select "Open" and search the video location.



Open a video or audio file (click 'Open') or choose 'Live Observation' (click 'Observation settings') to see the data logging functions...

File name: training4

Start the observation (press the green button under the time display).

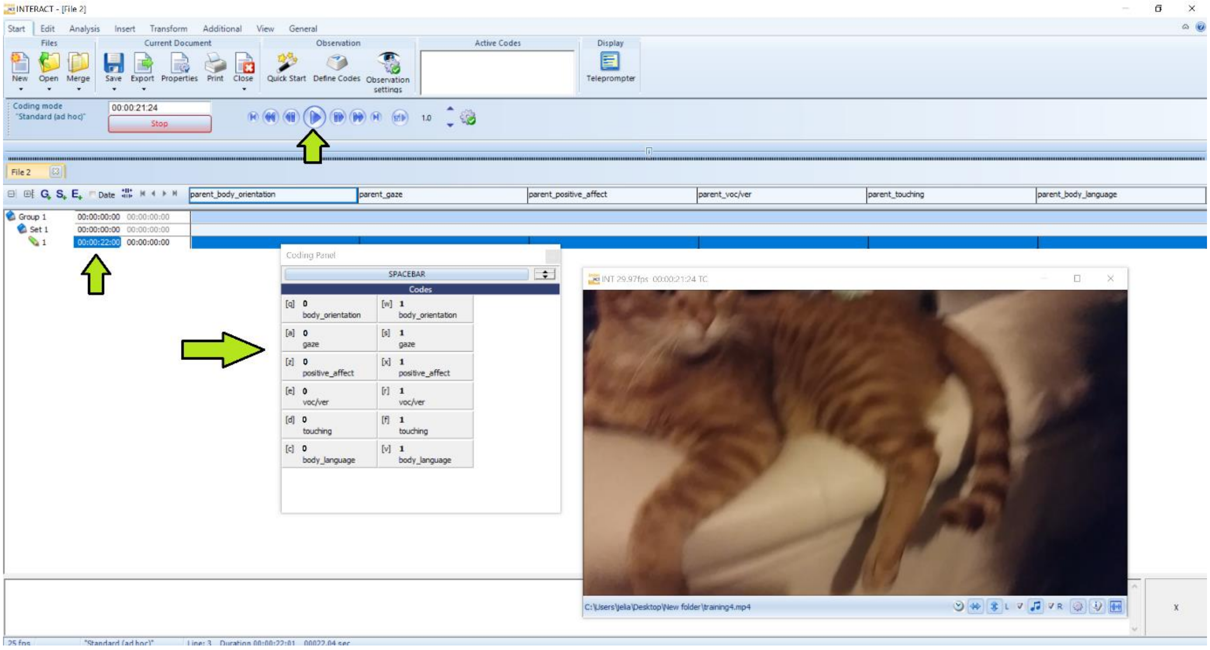


Coding mode "Standard (ad hoc)"

C:\Users\jelia\Desktop\New folder\training4.mp4

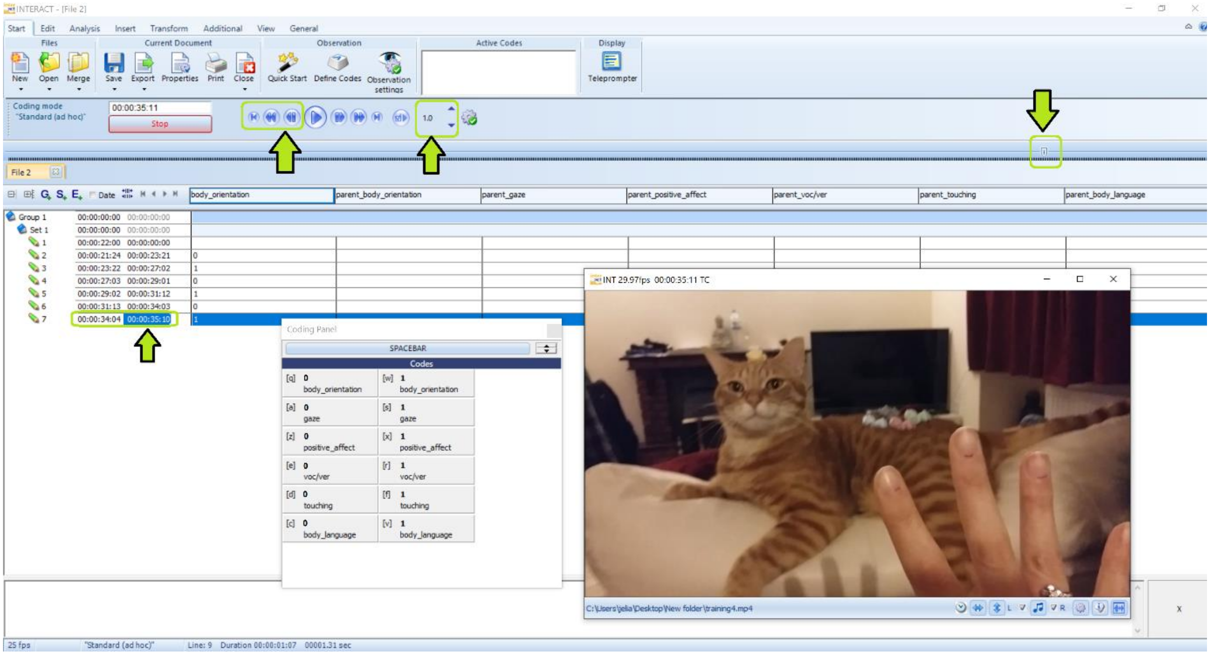
Line: 3 Duration 00:00:00:01 00000.04 sec

The screen will show a reminder Key-list for each code. The start of the coded segment can be set by double-clicking and changing the first event (time in Interact is expressed as hours : minutes : seconds : fractions of a second). To start the coding press the play button.



Group 1 00:00:00:00 00:00:00:00
Set 1 00:00:00:00 00:00:00:00
1 00:00:22:00 00:00:00:00

Code one modality at a time, moving onto the next when its coding is complete.



			body_orientation
Group 1	00:00:00:00	00:00:00:00	
Set 1	00:00:00:00	00:00:00:00	
1	00:00:22:00	00:00:00:00	
2	00:00:21:24	00:00:23:21	0
3	00:00:23:22	00:00:27:02	1
4	00:00:27:03	00:00:29:01	0
5	00:00:29:02	00:00:31:12	1
6	00:00:31:13	00:00:34:03	0
7	00:00:34:04	00:00:35:10	1

Coders are allowed to stop and replay the video as many times as needed. To do so, they can make use of the different Interact tools:

1. The rewind/forward buttons: which will move the video at double speed backwards/forward.
2. The rewind frame/forward frame buttons: will move backwards/forward one frame (a 24th of a second).

3. The play speed: which can be adjusted to be higher or slower (speed 0.5 is excellent for pinpointing start-end of each vocalisation)
4. The timeline cursor: allows the coder to move quickly through the video to the point you desire.
5. The event time-points: a double click with the left button of the mouse will place the video in the event time point written. A further third click will let the coder edit it.

Appendix B – Exceptions to coding from minute 4 to 6 (Chapter 4 and 5)

Of the 53 video segments analysed in **Chapter 4**, eight could not have the full 4 minutes discarded due to the video data being too short or becoming not suitable.

Table 1

Exceptions to full 4 minutes discarded.

Participant	Minutes Coded	Notes
IMPACT02	3:00-5:00	Last minutes filmed available.
IMPACT03	1:20-3:20	Last minutes filmed available.
IMPACT11	3:25-5:25	Last minutes filmed available.
IMPACT17	3:20-5:20	Grandmother joins the dyad at 5:20 making it unsuitable.
MIT50	2:55-4:55	Last minutes filmed available.
MIT51	2:41-4:41	Last minutes filmed available.
PACT29	2:06-4:06	Last minutes filmed available.
PACT42	0:00-2:00	Child starts to play with toys at 2:00 making it unsuitable.

Of the 84 video-segments analysed in **Chapter 5**, nine could not have the full 4 minutes discarded due to the video data being too short or becoming not suitable.

Table 2

Exceptions to full 4 minutes discarded.

Participant	Video File (1 to 4)	Minutes Coded	Notes
11	1	3:25-5:25	Last minutes filmed available.
17	1	3:20-5:20	Last minutes filmed available.
13	2	0:30-2:30	Baby sister joins play at 2:30 making it unsuitable.
26	2	1:00-3:00	Mother starts talking with psychologist at 3:00 until end, making it unsuitable.
28	2	0:55-2:55	Last minutes filmed available.
46	2	3:00-5:00	Last minutes filmed available.
48	2	2:04-4:04	Last minutes filmed available.
27	3	1:15-3:15	Last minutes filmed available.
24	4	3:00-5:00	The session was interrupted at 5:00, making it unsuitable.

Appendix C – Musical Interaction Therapy Period Comparison (Chapter 5)

In **Chapter 5**, sixty-four children with social communication difficulties were referred to MIT between 2012 and 2019. This comprised two periods of MIT, one from 2012 to 2016 and one from 2017 to 2019. Below are the results of a statistical comparison of the output means and proportions, which yielded that both periods were comparable and that this could not constitute a confounding factor.

Table 1

Exceptions to full 4 minutes discarded.

Measure Analysed	T (df)	p (two-sided)	Measure Analysed	Z	p (two-sided)
MSA I1	0.16 (19)	.87	Bidirectional Synch. I1	-0.25	.80
MSA I2	0.72 (19)	.49	Bidirectional Synch. I2	0.21	.84
MSA M1	3.41 (19)	.00	Bidirectional Synch. M1	0.73	.47
MSA M2	1.52 (19)	.72	Bidirectional Synch. M2	-0.21	.84
Gaze Synch. I1	0.17 (19)	.87			
Gaze Synch. I2	0.66 (19)	.52			
Gaze Synch. M1	-0.02 (19)	.98			
Gaze Synch. M2	1.77 (19)	.09			
Vocal Response I1	-1.35 (16)	.20			
Vocal Response I2	-1.75 (18)	.10			
Vocal Response M1	-1.43 (15)	.18			
Vocal Response M2	0.72 (16)	.48			