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### **Social Timing in Preschoolers with Autism Spectrum Disorder (M.Phil)**

Muth, Anne-Katrin

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# Social Timing in Preschoolers with Autism Spectrum Disorder

by

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MPhil Thesis

Submitted in fulfilment of the requirements for the award of  
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## Summary

Social timing plays a concurrent and long-term role in social interactions. Cyclicity (a person's coordination of speech, body movements etc.) and synchrony (the coordination between individuals) are especially important. Synchronous interactions in childhood affect later developments, such as language development and emotion regulation.

In ASD, timing and social timing are abnormal, which may adversely affect or even cause impairments. Evidence of interactional synchrony skills in ASD is sparse, therefore I sought to investigate cyclicity and synchrony skills in ASD.

Video-recordings of interaction with and without music between children with ASD and a caregiver ( $N = 14$ ; 2 to 8 years) were analysed using an adaptation of the well-established Monadic Phase coding scheme. Time-series analysis enabled quantification of cyclicity, level of synchrony (coherence) and significant synchrony.

Cyclicity was present in most interactions (76-90%). Coherence scores ranged from .08-.39. Synchrony was present in 19% of time-series without and 60% of time-series with music. Music significantly enhanced presence of synchrony ( $p < .000$ ) and indicated a trend for enhanced cyclicity ( $p = .058$ ) and coherence ( $p = .063$ ). No change over time was observed.

Therefore, preschoolers with ASD engaged in rhythmic social timing but consistency was low and diminished compared to neurotypical infants. Music enhanced social timing considerably. No change over time was likely due to fluctuations in children's willingness to engage. Findings are limited by the lack of interrater reliability and control group.

The aim of the thesis, to contribute to social timing evidence in ASD was achieved. The method successfully quantified social timing parameters, compared data to previous studies and showed that music enhanced social timing performance. Recommendations for further study include replication with a larger group, more time points, and control groups. This method could be applied to other settings to investigate the concurrent effect of music on social timing.

## Acknowledgements

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## Acronyms

ACF	Autocorrelation function
AD	Autistic Disorder
ADOS	Autism Diagnostic Observation Schedule
ARIMA	Autoregressive integrated moving averages
ASD	Autism Spectrum Disorder
CCF	Cross-correlation function
DD	Developmental delay
DSM	Diagnostic and Statistical Manual
HFA	High-functioning autism
HR	High risk
LR	Low risk
MBD	Multi-system Brain Disconnectivity-Dissynchrony
MIT	Musical Interaction Therapy
MP	Monadic Phase
MSI	Multi-sensory integration
NT	Neuro-typical
PACF	Partial autocorrelation function
PDD-NOS	Pervasive Developmental Disorder - not otherwise specified
RCT	Randomised controlled trial
TD	Typical development/developing
TSA	Time-series analysis
TSPD	Temporo-spatial processing disorders
WCC	Weak Central Coherence



# 1 General introduction

## 1.1 Context

Timing plays a vital role in communication. It allows perception and coordination of communication tools such as speech, facial expressions, and body language. For example, neurotypical individuals naturally sense when it is their turn to speak, and use pauses to emphasise or alter the meaning of what they are trying to convey. When timing is optimal and communication flows evenly, people remain largely unaware of its importance. On the contrary, erratic timing is noticed immediately. For example, when the audio or video transmission during a Skype-conversation lags behind, one can still carry on with his or her conversation but it becomes harder to read social cues and communication becomes tedious.

Scholars refer to this type of timing as 'social timing'. Its role is to structure and organise the timing of verbal and non-verbal communication tools. Social timing is further split into the temporal organisation of our own body language and speech ('intrapersonal') and that between self and other ('interpersonal').

Social timing in parent-infant interaction<sup>1</sup> plays a key role for long-term development of communication and social skills (e.g. Feldman, 2007b; Feldman & Eidelman, 2004). The pioneers of developmental social timing studies focused on describing rhythmicity of pre-verbal communication in the 1970s. A decade later, advances in statistical methods allowed examination of intra- and interpersonal timing, which can be cyclical and synchronous respectively.

Evidence of emerging social timing is already present in neonates and young infants. Cyclical and synchronous social timing patterns emerge long before a child develops language, and are stimulated during parent-infant interactions and 'social games'. Further evidence for the importance of early social timing skills stems from studies on children or

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<sup>1</sup> Traditionally, research has focused primarily on mother-infant interaction. Some studies (e.g. Feldman, 2003) examined father-infant versus mother-infant interactions, and found that interactions differed in content but not temporal parameters. However, gender matched (i.e. father-son or mother-daughter) interactions showed higher levels of synchrony, more balance in leading-and-following and shorter time needed to reach synchrony.

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parents at risk. For example, preterm infants or mothers suffering post-partum depression show lower levels of interactional synchrony (Granat, Gadassi, Gilboa-Schechtman, & Feldman, 2017). In sum, social timing plays a big part in the development of mature communication and social interaction abilities.

Poor social timing in Autism Spectrum Disorder (ASD) may be responsible for communication and social interaction difficulties (Allman, 2011; Amos, 2013). Plenty of timing research found disruptions in people with ASD across several domains, including cognition, genetics, circadian rhythm and motor skills. This is supported by self-reports from people with ASD and their caregivers who attest to experiencing temporal events at a different pace than typically developing individuals.

Much less evidence exists for social timing difficulties in ASD, even though it seems like a promising approach to forming theories and optimising interventions. Existing studies are few in number and suffer from methodological limitations. Several scholars proposed hypotheses that attribute symptoms in ASD to timing and social timing problems, yet knowledge gaps still exist. In short, it is plausible that timing problems in ASD include social timing difficulties and that they may cause subsequent communication problems.

## 1.2 Problem statement

Despite decades of developmental social timing research, few studies have examined social timing in ASD, and even fewer have investigated cyclicity and synchrony parameters. Furthermore, existing studies suffer from limitations that make comparisons across studies and populations difficult, such as the use of varying approaches and the lack of establishing discrete social timing parameters. Finally, some of the evidence is based on case and at risk studies, thus limiting generalisation. In sum, more knowledge is needed about cyclicity and synchrony abilities in ASD, along with a method that overcomes previous drawbacks.

The main difference between previous social timing studies in typical development (TD), at risk children, and children with ASD is their age: infants in those studies (e.g. Feldman, 2006; Yirmiya et al., 2006) were 3 or 4 months old, whereas ASD is only diagnosed at around 2 or 3 years of age. While pre-verbal infants and children with severe forms of ASD both rely on pre-verbal communication, what they can do physically differs in many ways. For this reason, previously established methods cannot be applied directly to the study of social

timing in young children with ASD. As a solution, a pre-existing method could be adapted so that desired features are preserved and comparisons between studies are enabled.

Undertaking this study is worthwhile for two reasons: firstly, it produces a method which can be subjected to further testing if promising, or discarded if it proves flawed. Secondly, any knowledge about social timing in ASD gained from this study may inform future research, theories, and clinical practice. If social timing is shown to be disrupted, and enhancing factors are uncovered, then strategies to foster social timing skills in early childhood can be developed or existing ones refined.

## 1.3 Aim and objectives

The aim is to learn more about social timing in ASD and contribute knowledge about cyclicity and synchrony performance in preschoolers with ASD. In order to achieve this aim, a method is required that addresses previous methodological shortcomings. The following objectives are defined to achieve this aim:

- Gain an understanding of social timing in early development in individuals with and without ASD.
- Identify a methodology that allows studying social timing in young children with ASD.
- Adapt the chosen method to the sample of this study and describe the method used.
- Present outcomes of statistical analysis of cyclicity and synchrony performance in ASD.
- Analyse and interpret findings in the context of previous studies.
- Provide recommendations based on the findings and critically evaluate study.

## 1.4 Scope

The emphasis of this study is on social timing during parent-child interaction in a real-life environment in preschoolers with ASD. As an additional feature, the children and adults in this sample received Musical Intervention Therapy (MIT; Wimpory, Chadwick & Nash, 1995; see Appendix D) in North Wales in the United Kingdom (UK). This allows comparison of interaction with music (hereafter referred to as 'Music') and without music ('Interaction') within an MIT setting.

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This thesis is a pilot study because an existing method is adapted and used for the first time, which means findings are tentative until replication can confirm its validity and reliability. Generalisability only extends as far as the sample allows, which are mostly pre-verbal children with ASD and their caregiver (usually the mother). Thus, findings cannot be extended to make conclusions about fully verbal children with ASD, nor children who are much younger or older. Findings can only inform about interactions with a familiar adult caregiver, rather than peer interactions or strangers. This study is confined to a naturalistic setting as the data comes from video tapes recorded to support intervention. This means that variables were not as carefully controlled as expected in a laboratory setting. While these limitations may affect study outcomes, any insights gained and the resulting method are expected to be useful for further research and clinical practice.

## 1.5 Research questions

The following questions were addressed in this study:

- Do children with ASD show cyclicity during Music and Interaction?
- Is cyclicity more consistently present in Music compared to Interaction?
- Is Music associated with an increased level of synchrony (or 'coherence') compared to Interaction?
- Is there more significant synchrony in Music compared to Interaction?

## 1.6 Significance of this study

I hope that this study contributes to ASD research in two ways: firstly, I intend to advance the knowledge about social timing in young children with ASD. As existing evidence is limited, my goal is to add insights that follow rigorous scientific standards as far as possible. In particular, I aim to add knowledge about cyclicity and synchrony during social interaction, which is under-researched in ASD.

Secondly, the method designed to achieve this aim is intended to produce output that is comparable across studies and easily replicable. Furthermore, it is designed to enable



studying social timing of other populations, such as older typically developing, developmentally delayed and at risk groups.

## 1.7 Definitions of terms and key concepts

ASD is marked by impairments in social interaction and communication as well as restricted, repetitive and stereotyped patterns of behaviour, interests and activities. Symptoms must be present in early development, and cause clinically significant impairment (American Psychiatric Association, 2000).

Social timing consists of intrapersonal and interpersonal timing. Intrapersonal timing refers to the individuals own rhythmicity<sup>2</sup> during interaction, in other words how one temporally coordinates communication tools such as speech, gesture, facial expressions, and body movement. This rhythm has been referred to as cyclicity, the term I adopt here.

Interpersonal timing relates to the temporal coordination between individuals (Jaffe et al., 2001). One way in which such coordination may manifest is called (interactional) synchrony. In general, synchrony describes the relationship of events happening at the same time. The study of synchrony has been applied to a range of scientific fields, such as physics, mathematics, populations growth, weather change or genetics (De Jaegher, 2006; Feldman, 2007b). Of interest for this study is interactional synchrony, or the temporally organised flow of social interaction between people. Research has looked at synchrony in dyadic, triadic, and multi person interactions, at early infancy, childhood, adolescence and adulthood. In this thesis, I focus on parent-child dyads during pre-verbal playful interactions.

## 1.8 Thesis structure

This thesis consists of six further chapters including the literature review, findings and conclusion (see Figure 1.1 below).

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<sup>2</sup> The term rhythm, when used in connection to social interaction, is meant to be flexible and allows for variations. This is in contrast to the musical term, which is characterised by mathematical regularity and repetitiveness.

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Chapter 2 and 3 review the literature. Chapter 2 establishes the broader context by outlining the connection between timing, social timing, early development and ASD. It begins by explaining the role of timing in communication and development and defining social timing terms. Next follows an overview of how social timing unfolds in the first year of life in typical development. Finally, social timing in ASD is explored. Social and communication difficulties in ASD are presented, followed by a brief overview over timing hypotheses pertaining to ASD. Finally, existing evidence on timing and social timing abilities in ASD are addressed.

Chapter 3 investigates available methods to study social timing. I give an overview over existing methods and critically evaluate their merits and drawbacks. The Monadic Phase method stands out from other available ones and is presented in more detail.

My intended contribution is contained in Chapters 4, 5 and 6. Chapter 4 presents this study's methodology including a discussion of the choices that were made and how the research instrument was adapted. This is followed by a description of the chosen method to study social timing in ASD complete with procedures and data analysis plan.

Chapter 5 contains the results of the study. It begins with preliminary analyses and is followed by a presentation of the results that address cyclicity and synchrony performance.

Chapter 6 analyses and interprets research findings and sets them into the context of previous studies. I first answer the research questions, then address unexpected findings and finally evaluate the chosen approach.

Finally, Chapter 7, the conclusion, provides a brief summary of key findings, then addresses this study's contributions and limitations and suggests further research agendas and gives recommendations for both research and clinical practice.

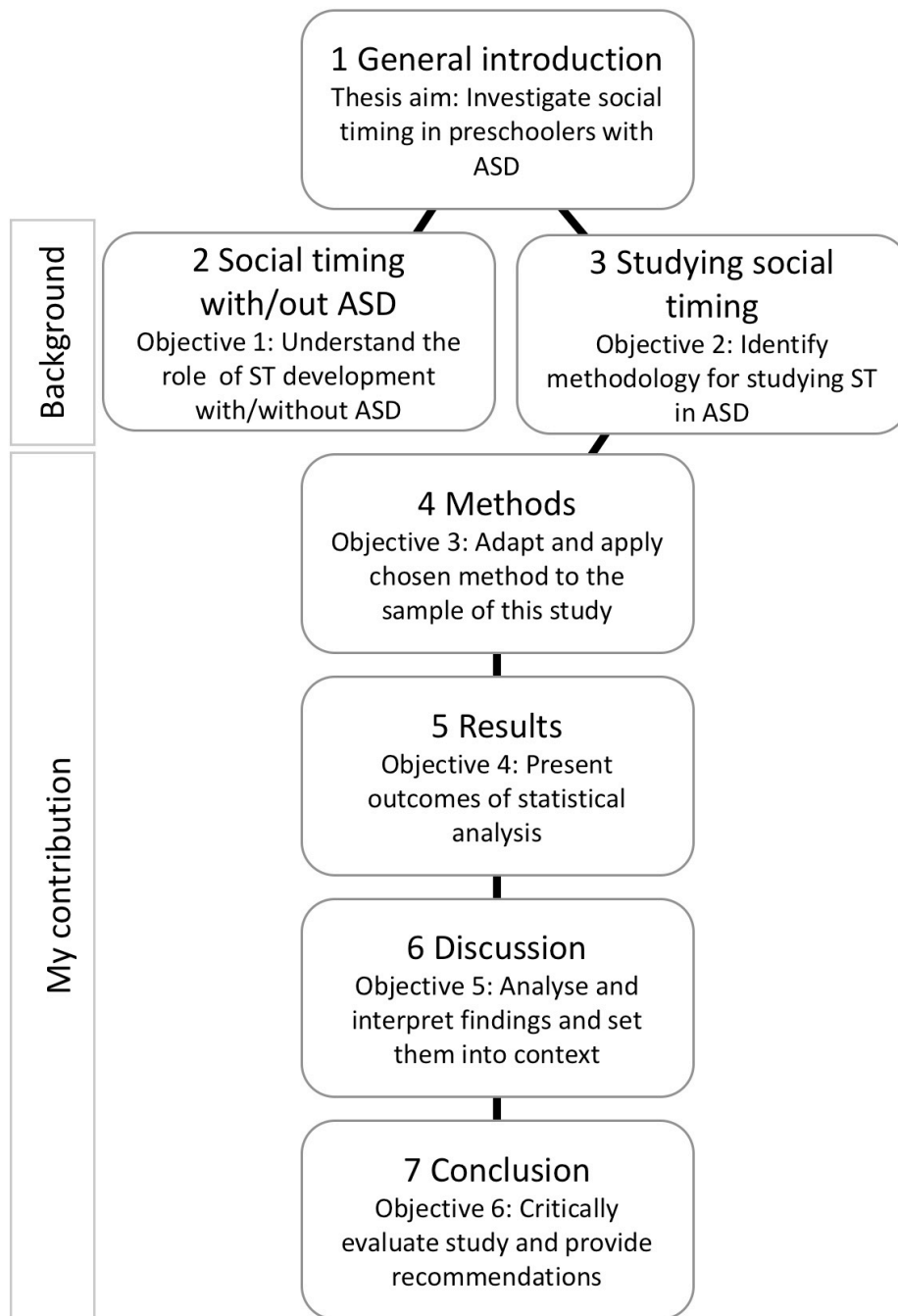


Figure 1.1 Thesis structure



## 2 Social timing in young children with and without ASD

### 2.1 Introduction

Chapter 1 established the context of this thesis; social timing is important for the development of social interaction and communication skills including language. Children with an ASD have difficulties with timing, yet relatively few studies have investigated social timing in ASD. One major problem was the lack of an appropriate method that enables replication and comparison of results across studies. Thus, a need for such a method and further study of social timing in ASD was identified.

The objective of Chapter 2 is to give the reader an understanding of social timing in young children with and without ASD. In order to do that, background information is provided on the connections between timing, development, social and communication skills.

This chapter is split into three sections (see Figure 2.1 below). The first provides an introduction to social timing. It explains the role of timing in communication and development, through cognition, movement, and the central nervous system. This is followed by definitions of the terms social timing, cyclicity and synchrony. Section two looks at social timing through a developmental perspective; how it develops in the first year of life and how it affects development beyond that time. The third section looks at social timing in ASD. It begins by summarising what social, communication and language deficits prevail in ASD. This is followed by hypotheses that attribute social and communication deficits in ASD to underlying timing deficits. Next, evidence of timing abilities in ASD is presented, for which a multi-disciplinary approach was adopted. Finally, social timing abilities in ASD are considered. A summary and conclusion is provided at the end of the chapter.

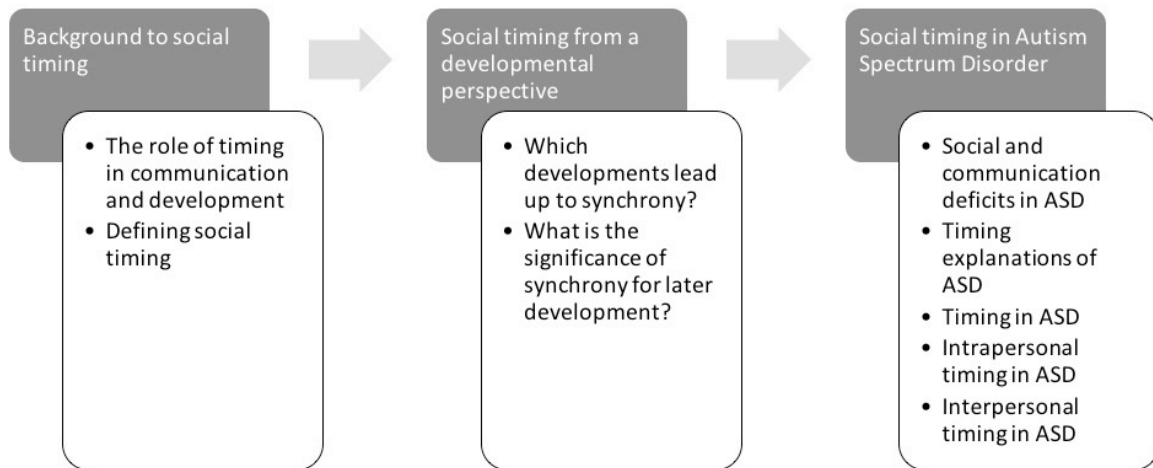


Figure 2.1 Chapter overview

## 2.2 Background to social timing

Time plays an omnipresent role in each of our lives. Our innate sense of timing allows us to judge fairly accurately when it is time for tea, for example. Time perception lets us 'feel' time, in the sense of whether something goes by quickly or seems to be never-ending.

This ability stems from internal 'clocks' that help us keep track of time. Time's subconscious nature can be revealed by studies of temporal processing, binding, or motor timing. Examples include measuring how quickly our brain can recalibrate its movements when encountering an unexpected obstacle, how efficiently audio-visual stimuli are integrated, and at what threshold a desynchronisation is noticed. The importance of timing in social interaction is discussed below, followed by research findings about timing in cognition, motor skills and in the brain with an emphasis on early childhood development.

### 2.2.1 The role of timing in communication and development

Social interactions are fast and subtle, requiring quick and complex integration of multiple sensory inputs. For example, a parent's interaction approach may include leaning over his child, smiling, vocalising, and stroking the child's head. This requires the infant's nervous system to combine incoming visual, auditory, and tactile information to derive full meaning from this interaction event. Unsuccessful or delayed processing of just one modality could eliminate perceived simultaneity among these inputs, thereby disrupting the event's significance (McPartland et al., 2004).

Appropriate timing in communication is important for conveying mood (Natale, 1978), empathy (Welkowitz & Feldstein, 1970), theory of mind abilities (Blakemore et al., 2003) and affiliation (Hove & Risen, 2009; Ramseyer & Tschacher, 2011). The connection between social timing and neuro-cognition was first made over three decades ago; Lester and colleagues (1985) suspected that social timing is affected by temporal expectancies in cognition and emotion driven by underlying cerebral timing.

Aspects of a timing mechanism are already manifest in pre-verbal children, as shown by studies on synchrony (e.g. Feldman, 2007b; Feldman & Eidelman, 2007). From a developmental perspective, temporal organisation is crucial for increasingly sophisticated pre-

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verbal interactions, such as the 'conversations' infants have with their caregivers before they can speak (Trevvarthen & Aitken, 2001). Timing of social interactions shows a correspondence with later years' development in language, attachment, pretend play, theory of mind and empathy (reviewed by Feldman, 2007b). Successful social timing is characterised by coordinated and timely turn-taking even in preschoolers (Trevvarthen & Aitken, 2001). The following sections give the reader an idea of how temporal aspects impact on social interaction skills and their development.

### *Perception*

The ability to estimate time intervals is crucial for predicting when to respond, for example, when catching a falling object (Meck, 2005). In communication, this is important for keeping up a smoothly flowing conversation. Infants can perceive time both at birth and even before birth (DeCasper & Carstens, 1980, DeCasper & Fifer, 1980), and are able to distinguish rhythm and rate (for a review, see Lewkowicz, 2000). Evidence from an electroencephalogram study demonstrated evidence of scalar property<sup>3</sup> in 6-month-olds (Allman et al., 2012). Within the first half year of life, infants perceive temporal structures, can detect subtle changes in auditory and visual stimuli, and distinguish between rhythms (Gratier, 2003; Malloch, 2000).

### *Temporal processing and multi-sensory integration*

Incoming stimuli need to be processed in a timely fashion, or the response may become redundant. Most, if not all, sensory experiences are made up of various modalities. Stimuli registered closely in time, have likely co-occurred and need to be combined meaningfully, through a process called multi-sensory integration (MSI; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011). MSI research covers how simultaneously occurring stimuli are perceived, how our brains bind them, and within which time-windows binding occurs. It is generally agreed that (near) temporal synchrony is the most important factor for MSI to occur (de Boer-

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<sup>3</sup> The scalar property is a fundamental characteristic of interval timing and manifests through mean accuracy and variance when perceiving or reproducing time intervals (Falter, Noreika, Wearden, & Bailey, 2012). Mean accuracy means that on average, perceived or reproduced time intervals are equal or nearly equal to the true length of the time interval. The variance principle requires that the timing sensitivity remains constant, even as the time to be perceived or reproduced, varies. Scalar property is thought to reflect the analogue mental representations that obey Weber's law, which are also found in other forms of perception (Allman, Pelfrey, & Meck, 2012).



Schellekens, Eussen, & Vroomen, 2013). MSI performance matures as adolescence is reached, but depends on the type of stimuli to be combined, their complexity, and whether they are of a social nature or not. Finally, the order of incoming stimuli affects temporal parameters because visual and oral stimuli reach the brain at different speeds (de Boer-Schellekens et al., 2013).

Various studies have explored MSI at different ages. For example, 10-16-week-old infants presented with audio-visual synchronised and non-synchronised (off by 400 ms) nursery rhymes preferred the synchronised presentations (Dodd, 1979). Toddlers, with an average age of 2.4 years, preferred watching synchronous displays of audio-video information when given the choice during the preferential looking paradigm<sup>4</sup> (Bebko, Weiss, Demark, & Gomez, 2006).

Infants between 2-8 months detected audio-visual asynchrony of simple non-social stimuli when both events were 350 ms apart (sound first) and 450 ms apart (sound last) (Lewkowicz, 1996). Adults needed considerably smaller gaps to detect asynchrony: 65 ms (sound first) and 112 ms (sound last; Lewkowicz, 1996). In a flash-beep illusion task, multiple beeps are presented with one flash of light. If the flash is close enough to the beeps, the participant perceives an additional flash. TD children, aged between 8 and 17 years, experienced the illusion within a 300 ms time-window of proximity (Foss-Feig et al., 2010).

### *Motor timing*

Motor timing research includes, for example, studies of motor coordination, postural control, eye-blink responses, and finger tapping. Motor timing is of considerable importance in development because a baby's first mode of communication with his caregivers is through volitional movements (Schmitz et al., 2003). Children with motoric difficulties show less active play with peers (Trawick-Smith, 2014). In turn, less active play and/or impoverished social skills that hindered play decreased opportunities to practise motor skills during play/interaction. In sum, hindered motor skills may negatively affect opportunities for social

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4 In this preferential looking paradigm participants saw non-verbal, simple verbal or complex verbal video segments. Two screens showed a video segment each, accompanied by a single identical sound track available to the participant. One of these audio-video displays was asynchronous by 3 seconds, whereas the other was synchronised. Participants' gaze was video-recorded and coded for time spent looking at each screen. The screen most looked at was assumed to be the preferred one.

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interaction and exacerbate symptoms of repetitive/stereotypical behaviours and mannerisms (Lloyd, MacDonald, & Lord, 2011).

### *Brain anatomy and neurological findings*

The brain regions associated with the internal clock are the cerebellum, basal ganglia, supplementary motor area and prefrontal cortex (Cope, Grube, Singh, Burn & Griffiths, 2013). These areas are linked anatomically and functionally (Cope et al., 2013). While they interact, these parts also act slightly differently, for example, the cerebellum has been shown to adjust to timing information and the basal ganglia to task order predictability (Dreher & Grafman, 2002).

The cerebellum is mainly associated with motor coordination (Gowen & Miall, 2005), which affects executive function, learning and language (Courchesne et al., 2004; Schmahmann & Sherman, 1998). Integrity of basal ganglia and cerebellum was found to play a key role for motoric synchronisation (Claassen et al., 2013).

Most relevant for this thesis' topic is the cerebellum's connection to timing perception in the millisecond range, which impacts on social cognition (Van Overwalle, Baetens, Mariën & Vandekerckhove, 2013). Courchesne (1994) highlights the cerebellum's implications for development through its role in selective attention and rapid attention shifts. He argued that the locus of information, which can be on objects, actions, sounds, speech, feelings and so on, changes rapidly and unpredictably in interaction, thus requiring frequent attentional shifts. Young children usually begin to master joint attention and rapid shifting to subtle cues at around 12-15 months (Bakeman & Adamson, 1984; Meindl & Cannella-Malone, 2011). This ability is thought to be one of the key factors for the healthy development of communication (Bakeman & Adamson, 1984).

## 2.2.2 Defining social timing

The term 'social timing' incorporates two aspects: intrapersonal timing, and interpersonal timing. Intrapersonal timing refers to the coordination of communicative expression and comprehension by an individual (including auditory perception, pitch, body language, etc.). Intrapersonal timing can take on a quality known as cyclicity, an important concept discussed below.

Interpersonal timing is about the timing of interactive behaviour between two people. In other words, it describes the coordination of communication modes (body language, vocalisations, verbalisations, etc.) between individuals (Jaffe et al., 2001). Predictability is a key feature of coordinated interpersonal timing; each interaction partner's timing must be predictable from that of the other (Jaffe et al., 2001). Interpersonal timing requires adequate perception and understanding of social and communicative signals, and the ability to adapt to the other interaction partner continuously (Delaherche et al., 2012). It can take on the quality of synchrony (see below). Synchrony appears to be a universal feature as it has been observed in human interactions cross-culturally, including in interactions of Mayan Indians, Kung Bushmen, Eskimos (as reviewed by Condon & Sander, 1974).

#### *What is interactional cyclicity?*

The concept of cyclicity in humans was first noticed in biological rhythms<sup>5</sup> to describe events recurring at regular intervals, such as a woman's menstrual cycle. While in some contexts cyclicity implies strict regularity, as in the case of music, in others it is regarded less stringently, for example in the study of interaction (Jaffe et al., 2001; Lewkowicz, 2000).

Interactional cyclicity is alternatively referred to as self-synchrony and describes the mathematically definable rhythm of one's own coordination of verbal and non-verbal communicative modes (Condon & Sander, 1974; Petitto, Holowka, Sergio, & Ostry, 2001). It quantifies the integration of communicative behaviour of one individual, for instance how change in someone's own speech corresponds with their change in body movements (Condon & Sander, 1974). Some view cyclicity as a prerequisite for interactional synchrony and argue that one needs to be able to coordinate his own communication modes before one can coordinate them with someone else's (Lester, Hoffman, & Brazelton, 1985, p.24). Yet others are less certain that it is essential, and only suspect that deficits in intrapersonal coordination may reduce interpersonal timing (Marsh et al., 2013).

In parent-child interaction, cyclicity is thought to provide a framework within which caregiver and child co-ordinate their rhythms, both constraining and enabling interactive behaviours (De Jaegher, 2006; Lester et al., 1985). The repetitive nature of cyclical behaviour provides temporal expectancies by organising the infant's and caregiver's cognitive and

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<sup>5</sup> Biological rhythms are the circadian 24-hour rhythms within which physiological functions are regulated, including for example, sleep, body temperature, and hormone production.

affective expectancies (Stern, 1971), thereby making future actions more predictable (e.g. Lester et al., 1985; Tronick, Als, & Brazelton, 1980). In other words, cyclicity is thought to facilitate timing of both the infant's and caregiver's actions.

Mother-infant pre-verbal 'conversations' can be parsed into cycles of attention and non-attention, or positive and negative affect. For example, when a mother soothes her crying infant, the child moves from a negative state through a neutral to a more positive state (Brazelton, Koslowski, & Main, 1974).

### *What is interactional synchrony?*

Interactional synchrony was first defined as rhythmic coordination between two people<sup>6</sup> (Condon & Ogston, 1971), for example when a listener's coordinates his movements to the speaker's speech. Since then, the term synchrony in the context of interpersonal interactions has been used by many different researchers, each using different words, concepts and methodologies to describe this concept (Bernieri, Davis, Rosenthal, & Knee, 1994; Delaherche et al., 2012). See Table 2.1 below for definitions. Chapter 3 looks at different approaches to studying synchrony.

Descriptions that have been used to express this concept include entrainment (Condon & Sander, 1974; Malloch, 2000), attunement (Stern, 1985), mutual influence (Cohn & Tronick, 1988), co-regulation (Fogel, 1993), contingency (Nichols, Gergely, & Fonagy, 2001) and coordination (Jaffe et al., 2001). The term synchrony is used interchangeably with closely related concepts or requirements, such as mutuality (Delaherche et al., 2012) or congruence (Green et al., 2010), which will be explored in more detail below (see 2.2.3 and Table 2.2 below).

Table 2.1 Interactional synchrony definitions

Author(s)	Term used	Description	Elements
Condon & Ogston 1971	Interactional synchrony (movement and vocal)	Rhythmic coordination between the listener's and speaker's movement and speech	Coordination rhythmic interpersonal movement and vocal
Feldstein et al. 1982	Synchrony Entrainment (vocal) (p.452)	'...Called pattern matching, synchrony, or congruence. The average durations of the pauses and switching pauses tend to become similar during the course of the interactions.' (p. 452)	Interpersonal vocal assimilation of tempo

<sup>6</sup> This thesis focuses on dyadic interaction, i.e. interaction between two people. However, some studies also examined triadic interaction.

Feldstein et al. 1993	Coordinated interpersonal timing (vocal)	'Coordinated interpersonal timing concerns the relationship between the temporal patterns of two interacting partners and exists when the temporal pattern of each partner in a dialogue is predictable from that of the other.' (p. 456)	Coordination vocal interpersonal predictability dynamic
Bernieri et al. 1994	Coordination; interactional synchrony	'Aspects of interactional synchrony include simultaneous movement, tempo similarity, general coordination and smoothness and posture similarity.' (p. 304)	Interpersonal coordination dynamic harmonic
Jaffe et al. 2001	Coordination	'We define coordination most generally as interpersonal contingency, such that each partner's behaviour can be predicted from that of the other. The coordination of interpersonal timing involves the prediction of each partner's timing pattern from that of the other' (p. 1) Synchrony is a form of coordination. (p. 20)	Coordination interpersonal dynamic predictability
Harrist & Waugh, 2002	Synchrony	'A type of interaction between two people (in particular a child and caregiver), an observable pattern of dyadic interaction that is mutually regulated, reciprocal, and harmonious.' (p. 557) Synchrony involves dynamic adaptation on the part of both partners.	Interpersonal interaction reciprocal harmonic dynamic adaptation
Gratier 2003	Interactional synchrony (vocal)	'A precise and flexible temporal and prosodic coordination between the vocal expressions of mother and infant. This definition is based on evidence from previous studies suggesting that mothers and infants co-construct a shared timing which enables them to accurately anticipate each other's expressions in time and to "play" with each other's expectations' (p. 535)	Flexibility coordination interpersonal vocal predictability
Feldman 2007b	Interaction synchrony	'Interaction synchrony in the context of parent-infant relatedness, the focus of this review, addresses the matching of behaviour, affective states and biological rhythms between parent and child that together form a single relational unit. Synchrony describes the intricate "dance" that occurs during short, intense, playful interactions (...) and depicts the underlying temporal structure of highly aroused moments of interpersonal exchange (...)' (p. 329)	Interaction interpersonal multimodal dynamic reciprocal
Delaherche et al. 2012	(Interpersonal) synchrony	'The dynamic and reciprocal adaptation of the temporal structure of behaviours between interactive partners' (p. 351).	Dynamic reciprocal multimodal interpersonal interactive
Venuti et al. 2017	Synchrony	'Synchrony is characterized by a continuous dynamic and reciprocal adaptation of the temporal structures of behaviour and emotion that are shared between interactive partners' (p. 163)	Dynamic reciprocal multimodal interpersonal interactive

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Delaherche (2012) defined interactional synchrony as the 'dynamic and reciprocal adaptation of the temporal structure of behaviours between interactive partners' (p. 351). Her definition is in agreement with the most frequent elements found in other researcher's definitions, which are coordination, dynamic (pertaining to temporal), reciprocal, predictability and rhythmicity (see Table 2.1 above). Each of these elements will be addressed in turn.

Dynamic emphasises the importance of an interaction's flowing nature rather than the actions contained within it, which distinguishes interactional synchrony from simply mirroring the other person (Delaherche et al., 2012; Fitzpatrick, Diorio, Richardson, & Schmidt, 2013). Reciprocity highlights the exchanging of behaviour of both interaction partners. In other words, the change of one person's behaviour drives change in that of the other and vice versa (Condon & Ogston, 1971). While this seems to follow the dynamic criterion logically, not all studies examining 'synchrony' have actually studied both interaction partner's behaviours (e.g. Green et al. 2010). Behaviours is set in plural to indicate that communicative behaviours are mostly multimodal events, describing meaningful units of communicational behaviour (Delaherche et al., 2012). However, some researchers have chosen to study isolated modalities such as speech or movement, thus studying vocal or movement synchrony (Feldman & Eidelman, 2004; Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011; Feldstein, Konstantareas, Oxman, & Webster, 1982; Jaffe et al., 2001). Finally, the interactive element covers the various forms interaction can take, including verbal and non-verbal communication or play (Delaherche et al., 2012).

Scholars have also highlighted the following qualities of synchronous interaction; predictability (e.g. Feldstein, Jaffe, Beebe, & Crown, 1993; Jaffe et al., 2001), a harmonious smooth flow (e.g. Bernieri et al., 1994; Harrist & Waugh, 2002) and adaptation to the other (Feldstein et al., 1982; Harrist & Waugh, 2002).

### 2.2.3 Related but different uses of 'synchrony'

The term 'synchrony' is used to describe similar concepts in the interaction literature (for a review see Harrist & Waugh, 2002; Warner, 2002) yet they differ from interactional synchrony because they do not contain all of the criteria established by Delaherche and colleagues (2012). Thus, they lack one or more of the following: the temporal dynamic

aspect, reciprocity, and occurring within an interactive setting (which can be verbal, pre-verbal or play) between interaction partners. Below three different but related concepts are described (see Table 2.2 Different uses of the term 'synchrony' below).

Table 2.2 Different uses of the term 'synchrony'

Author(s)	Term used	Description	Elements	Missing
Hedenbro & Tjus 2007	Synchronisation	'Emotional engagement and interactive flow' during interaction (p. 208)	Reciprocal interpersonal interaction	Dynamic multimodal
Green et al. 2010	Parental synchrony	Parental closeness or congruence in following their child's attentional or behavioural focus; focusing on one interaction partner (parent) instead of the interaction between them (p. 2154)	Interpersonal interaction dynamic behavioural	Reciprocal multimodal
Fitzpatrick et al. 2013	Social coordination/ social synchronisation (motoric)	Engagement in the same action at the same time (p. 5)	Interpersonal dynamic motoric	Multimodal interactive reciprocal
Hudry et al. 2013	Parent synchrony	Parental synchronous acts are defined as communication acts which seek to support the child's current attentional focus and comment on the child's play or activity, while asynchronous acts seek to direct/redirect the child's attention or behaviour or place a demand on the child. (p. 3403)	Interpersonal interaction dynamic behavioural	Reciprocal multimodal
Lorenz et al. 2015	Movement synchronization and synchronous behaviour	' <i>Movement synchronization</i> is a coordination behaviour (...). It is usually established when two actors perform the same action at the same time.' (p. 126) ' <i>Movement synchronization</i> and imitation are referred to as synchronous behaviour.' (p.127)	Dynamic interpersonal	Multimodal interactive reciprocal
Srinivasan et al. 2015	Interpersonal synchrony	Involves coordinating one's actions with those of social partners and it requires appropriate social attention, imitation, and turn taking skills.	Interpersonal dynamic motoric	Multimodal interactive reciprocal

### *Interactive flow*

Firstly, synchrony has been used to describe the concept of 'emotional engagement and interactive flow' during interaction (e.g. Hedenbro & Tjus, 2007), which is established through the rater's global perception (Delaherche et al., 2012) but lacks a clear temporal element.

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### *Synchronisation*

Secondly, the term 'synchrony' has been defined as engagement in the same action at the same time during social tasks, and is used interchangeably with the term 'synchronisation', which it will be referred to hereafter (e.g. Fitzpatrick et al., 2013; Koehne, Hatri, Cacioppo, & Dziobek, 2016; Srinivasan et al., 2015). Synchronisation is closely related to imitation; however, they differ in that imitation does not necessarily focus on the temporal aspect (Fitzpatrick et al., 2013). To clarify, synchronisation occurs when both dyad partner's actions coincide temporally and modality-wise, such as tapping at the same time. Synchronisation is distinct from interactional synchrony because it lacks reciprocity, interaction and behaviours may not be of a communicative nature. It is not reciprocal because in synchronisation tasks the parent was asked to follow a rhythm rather than starting a rhythm and then adapting to his child. It is not interactive because the tasks are neither of a conversational nor playful nature.

### *Congruence*

Finally, synchrony has been used to refer to parental closeness or congruence in following their child's attentional or behavioural focus. Congruence studies differ from interactional synchrony studies because they lack reciprocity. Instead, these studies focus on one interaction partner only during social interaction, typically the adult caregiver (Green et al., 2010; Hudry et al., 2013).



## 2.3 Social timing from a developmental perspective

The following section explores the role that social timing plays in the development of cognitive, social and communicative abilities during a child's first year. The first part looks at developments leading up to synchrony and its increased sophistication. The second part explores the effects of synchrony on long-term outcomes.

### 2.3.1 Which developments lead up to synchrony?

A 'feeling' for time in pre-verbal communications is instilled at an early age, long before language is acquired (Stern, 1977). Early interactions pave the way for increasingly mature communication skills. Parents help the infant along by practicing timed interchanges unconsciously through their interactions, such as when playing games like 'peek-a-boo'. The build-up of suspense uses timing, and eye glances are exchanged to signify surprise and joy. The repetitive nature of such early play serves an important function: by building up the infant's attention, the parent allows for an optimal level of information intake. Too little or too much information can cause the infant to grow tired or turn away, and be detrimental to learning (Brazelton et al., 1974). By carefully balancing familiar and novel stimuli, such interactions further serve to facilitate cognitive growth, information processing skills and motivation (Feldman, 2012c). The following paragraphs lead the reader through developments in the first year related to social timing and interaction skills.

#### *Before birth*

During pregnancy, physiological systems mature in both mother and unborn child to prepare them for interactional synchrony (Feldman, 2012a). In the first trimester, the mother's oxytocin level predicts the amount of postpartum behaviour that she will express after birth as well as her coordination with the baby (Feldman, Weller, Zagoory-Sharon, & Levine, 2007). During the last trimester of pregnancy, the infant's neurological basis for coordinated interactions develops in the brain (Feldman, 2007b). Firstly, the 'biological clock' matures and the sympathetic nervous system gains control over heart rhythms. This is

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followed by structural and functional brain development, including the assembly of brain nuclei, rapid increase in synaptic growth, and maturation of neuro-chemical systems (Feldman, 2006).

#### *One to two months*

Maternal postpartum behaviour is genetically programmed and triggered right after birth, and serves a crucial role for the infant's care, survival and development (Feldman, 2012a; Feldman & Eidelman, 2007). It includes gazing at the infant, 'motherese' vocalisations, positive affect, and affectionate touch (Feldman, 2012a). These behaviours sensitise an infant to micro-level alterations of the mother's interactional tools (Feldman & Eidelman, 2007), thereby preparing the infant for communicational interchanges early on.

A newborn's interest in faces is present right from birth (Johnson, Dziurawiec, Ellis, & Morton, 1991) and considered paramount for developing social interaction and cognition skills (Williams, Whiten, Suddendorf, & Perrett, 2001). In the first month of life, interactions revolve around the infant's basic attention to the mother's face (Lavelli & Fogel, 2005), and there is a readiness to respond to human speech and a preference for their mother's voice (DeCasper & Fifer, 1980).

Condon and Sander (1974) found that American-born neonates, as young as 12 hours, synchronised their movements to adult speech using micro-analysis of video-tapes. Synchronisation was found when the adult speaker was present and addressing the neonate, but also when the voice came from an audio tape. Remarkably, both American English and Chinese language fragments elicited coordinated movements by the infant but disconnected vowel sounds and tapping sounds failed to do so (Condon & Sander, 1974).

Additionally, babies were found to be innately equipped to detect contingencies (Tarabulsky et al., 1996), which depended on the baby's autonomic maturity, indicated by cardiac vagal tone, and predictive of later parent-infant synchrony (Feldman & Eidelman, 2007). Infant and maternal preparedness provided the components for the baby's first experiences of temporally matched interactions. Such early means of communication were indexed by the rhythmicity in neonate activity, such as crying, nursing, or sucking (Feldman, 2007b). Furthermore, mothers were shown to model interaction rhythms on such patterns, for example, the burst-pause pattern typical of early face-to-face interaction (Tronick, Als, & Brazelton, 1977).

To emphasise the importance of maternal behaviour, examples are considered whereby maternal mental health is compromised, such as in mothers suffering from depression, anxiety or those who experienced stressful preterm labour. These mothers showed more hostility, dominance and lower responsiveness to their child, engaged less often and experienced difficulties with providing optimal levels of stimulation and appropriate responding (Feldman et al., 2009; Zlochower & Cohn, 2001). Additionally, mothers affected by depression or anxiety engaged less in postpartum behaviour, which was a main predictor of parent-infant synchrony at 3 months (Feldman et al., 2009, Feldman & Eidelman, 2007). Less affective touch and problems with emotion regulation further exacerbated difficulties in reaching synchrony, which was disturbed in all of its aspects, including taking twice as long to reach synchrony compared to dyads with non-depressed mothers (Feldman et al., 2009; Granat et al., 2017).

Dyads with premature babies were doubly at risk for lower levels of synchrony (Feldman & Eidelman, 2007). Firstly, mothers of preterm babies tended to show less maternal behaviour, looked, smiled, vocalised and touched their children less frequently. Secondly, preterm infants were more irritable, less tolerant for changes in affective behaviour and showed more poorly organised cues for interaction. This in turn, made it harder for their mothers to 'read' their infants, and possibly led them to adopt disadvantageous behaviours, such as overactive stimulation, intrusiveness and interaction dominance (Feldman & Eidelman, 2007).

### *Three to four months*

In an infant's second month, mother-infant interaction undergoes a shift from simple attention to active and emotionally positive attention (Lavelli & Fogel, 2005). From the second to the third month, the child gains the ability to display temporally coordinated facial expressions and vocalisations, including cooing, gazing, and smiling (Lavelli & Fogel, 2005; Yale et al., 2003). Interactions mature further to involve recurring rhythmic cycles using different modalities to communicate, such as gaze, touch, affective expressions, bodily movements, and arousal indicators. Parent-infant pre-verbal 'conversations' start showing a temporal structure; behaviour between interaction partners starts to match, and turn-taking emerges (Feldman, 2007b; Trevarthen, 1974).

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It was first suggested that the ability to coordinate timing in social situations emerged at 4 months of age (Jasnow, Crown, Feldstein, Taylor, & Beebe, 1988). However, Feldman has shown that 3 months marks the initial period of gaze synchrony (Feldman, 2007b; Feldman & Eidelman, 2007), and most studies on parent-infant interaction test synchrony at this age<sup>7</sup>. Touch synchrony, defined as the coordination of affectionate touch and shared gaze, increases significantly from 3 to 9 months with the development of the infant's fine-motor skills (Feldman, 2007b). Mothers and their babies were found to synchronise their heart rhythms within one-second time lags, with even closer matching during episodes of vocal and affect synchrony (Feldman et al., 2011).

Interactions are parent-specific. Interactions with mothers are more rhythmic and socially oriented, whereas interactions with fathers are more environmentally oriented, encouraging exploration and are jerkier, including high arousal and a less rhythmic contour (Feldman, 2003). Triadic synchrony, between both parents and the infant, emerges at this age. Infants have to coordinate their behaviour to each parent as well as to non-verbal cues between parents (Gordon & Feldman, 2008).

#### *Five to 12 months*

Infant's social interactions evolve further and by 6 months, mothers' and infants' interaction patterns are well-established, benefitting from intimate knowledge and the ability to anticipate each other's temporal expressions (Sigman, Dijamco, Gratier, & Rozga, 2005). Intentionality emerges and interactions become more reciprocal in nature (Feldman, Greenbaum, & Yirmiya, 1999). Facial expressions become more complex, as infants coordinate smiles, gaze and gestures to communicate about objects while maintaining joint attention (Sigman et al., 2005).

Infants enter the age of intersubjectivity at around 9 months (Stern, 1985), which has been hypothesised to affect the lead-lag structure, which shifts from infant dominance (or the parent following the child) to mutual influence (see Appendix A for a deeper discussion). Nine months also marks the end of the 'sensitive period' of synchrony development (Feldman, 2015). Dyads sustain mutual coordination across time (Feldman, 2007b). Time-lag

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<sup>7</sup> The age of 4 months is especially suitable because at this stage of development infants are interested and able to take part in face-to-face interactions with their caregivers but not quite able yet to grasp for objects and move about the room, so that all their attention is directed to human interaction (Hane, Feldstein, & Dernetz, 2003).

to synchrony decreases from 3 to 9 months, reflecting increased familiarity with the partner's interaction style and maturing of the relationship, both facilitating faster matching (Feldman, 2007b). Once established, the individual degree of synchrony (coherence) remains stable across the first year (Feldman, 2007b). Following the first stages of prefrontal maturation, the ability to self-regulate emerges, which shapes an individual's regulation skills throughout life (Feldman, 2012a).

Post-partum depression and anxiety, not due to premature birth, single parenthood, poverty, or teenage parenthood, negatively affects gaze and touch synchrony measured during dyadic interactions with 9-month old infants (Granat et al., 2017). Depression was associated with lower levels of synchrony, whereas anxiety predicted higher levels of synchrony linked with maternal intrusiveness, yet both indicated suboptimal synchrony (Granat et al., 2017).

#### *Beyond the first year*

Once established, non-verbal (gaze, touch, affect expressions) and verbal-symbolic synchrony remains a feature of close social interaction throughout life (Feldman, 2012a). For instance, interactions between romantic couples show both of these aspects during an intimate conversation. Levels of synchrony are reflected in vagal tones and oxytocin levels, mimicking early synchronous interactions between mother and child during bonding (Feldman, 2012b). Later in life, synchrony also manifests in switching pauses in spoken conversational language (e.g. Feldstein et al., 1982).

### 2.3.2 What is the significance of synchrony for later development?

Synchrony measured at 3 or 5 months promotes a range of developmental skills, including turn-taking, emotion regulation, symbolic use and language. It further promotes healthy attachment. Each is briefly addressed below.

#### *Turn-taking*

Early pre-verbal interactions lay the groundwork for turn-taking and reciprocity, and both play a key role for increasingly sophisticated interactions (Dominguez, Devouche, Apter, & Gratier, 2016; Lorenz, Weiss, & Hirche, 2015). Rhythmic temporal patterns facilitated the ability to expect behaviour in pre-verbal turn-taking, which is a necessary step towards fluent

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verbal conversations (Jaffe et al., 2001). Mastering interactional synchrony requires the ability to anticipate and predict when it's one's turn to speak, as prolonged or shortened pauses may be awkward and even alter meaning (Feldstein et al., 1982).

### *Attachment*

Early attachment relationships are believed to provide models for all later social interactions, and thus play an important role for long-term outcomes (Main, Kaplan and Cassidy, 1985). Synchrony at 3 and 4 months predicted attachment security at 12 months (Isabella et al., 1989, as cited in Hane et al., 2005; Jaffe et al., 2001). Likewise, dyads who interacted in a well-timed, reciprocal and mutually enjoying manner at 3 and 9 months developed a secure attachment style later (Feldman, 2012c). In contrast, dyads with minimally involved, insensitive or intrusive mothers were later insecurely attached or showed an avoidant attachment style (Isabella & Belsky, 1991).

### *Emotion regulation*

Maternal positive engagement preceded the infant becoming more positive at 3 and 6 months (Cohn & Tronick, 1988). As the infant matured, his growing independence allows him to self-regulate. At 9 months, maternal positive engagement was not necessary anymore for the infant to become more positive (Cohn & Tronick, 1988). Feldman (2007b) hypothesised that infants who did not experience coordinated interactions with a caregiver very early in life may suffer pervasive difficulties in their social, emotional, and self-regulatory development. This is because participation in well-structured interaction with a sensitive adult was seen to foster several skills; firstly, the ability to empathise with the emotional states of others, using symbols and generally function in society. In fact, Feldman (2007a) provided evidence that level of synchrony across the first year predicted level of empathy in adolescence. Synchrony and empathy were found to mediate a child's self-regulatory abilities at 2, 4, and 6 years (Feldman, 2007a).

Further, synchrony with either parent at 3 months was related to fewer behavioural problems 2 years later, indicating that better self-regulation is enhanced following the achievement of synchrony (Feldman & Eidelman, 2004). Conversely, parents of triplets who provided the same amount of parenting but reduced coordination between their and their infant's social cues, showed diminished levels of parent-infant synchrony at 3 months. Lower

synchrony predicted lower attachment at 12 months and more behavioural problems at 24 months; deficits which could be recovered from 5 years later (Feldman & Eidelman, 2004).

#### *Symbolic use and theory of mind skills*

Correlations between synchrony at 5 months, symbolic play at 3 years and theory of mind skills at 4 years suggest a preparedness for the development of the abstract and creative facets of language, and the ability to see several perspectives (Feldman, 2007b).

#### *Language development*

Lester et al. (1985) speculated that evidence for synchrony's effect on language may be provided by his study on cyclicity in term and pre-term infants. Premature infants, compared to full-term infants, were found to show less coordination with their mothers and to subsequently have more difficulties with language development (Lester et al., 1985).

In sum, these findings attest to the importance of synchronous interactions in the first year of life. Examples from dyads at risk for achieving optimal synchrony showed how easily it is disrupted and may affect other developments during this sensitive phase.

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## 2.4 Social timing in ASD

ASD<sup>8</sup> is marked by impairments in social interaction and communication, and restricted and repetitive patterns of behaviour (see Table 2.3 below). Impairments must be present in early development, and cause clinically significant impairment (American Psychiatric Association, 2000). The term ASD combines three previously separate diagnoses: Autistic Disorder, Asperger's Syndrome and Pervasive Developmental Disorder - not otherwise specified (PDD-NOS; American Psychiatric Association, 2000).

Restricted, repetitive patterns of behaviour, interests or activities may include stereotyped or repetitive motor movements, rigidity involving routines or ritualising behaviour, highly focused interests and being overly sensitive to sensory input (American Psychiatric Association, 2013).

### 2.4.1 Social and communication deficits in children with ASD

Difficulties with social interactions and communication are one of the main features of ASD and needed for a diagnosis (American Psychiatric Association, 2000; 2013). Already present in infancy, these deficits impact on and exacerbate other symptoms, thereby affecting individuals throughout their life (American Psychiatric Association, 2000; Wimpory, Hobson, Williams, & Nash, 2000). The following paragraphs illustrate the nature of social and communication impairments in ASD with a focus on pre-verbal interaction.

#### *Social deficits in ASD*

A variety of social deficits are present in children with ASD that set them apart from typical developing (TD) peers and from children with developmental delay (DD). Firstly, children with ASD do not engage in spontaneous initiation of interaction or joint attention as frequently as TD peers. When they do, these interactions are classified as low-level

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<sup>8</sup> Note that throughout this dissertation, the term ASD is used to refer to all manifestations of the condition as defined in the DSM-V. Where appropriate, for instance when reporting research, there is a distinction made between AD, AS and/or HFA.



interactions<sup>9</sup> in contrast to TD children and those with DD (Loveland & Landry, 1986; Mundy, Sigman, Ungerer, & Sherman, 1986; Sigman, Mundy, Sherman, & Ungerer, 1986). Long-term effects of initiations in early childhood predicted later language gains (Siller & Sigman, 2008).

Deficits in social-emotional reciprocity are also commonly found in children with ASD. From a large sample of children diagnosed with ASD or PDD-NOS, a third were found to engage on a need-fulfilment basis only, however the majority of children (40%) showed both reciprocity and need-fulfilment activities (Greenspan & Wieder, 1997).

Turn-taking, the back-and-forth between interaction partners that structures non-verbal and verbal conversations, is often diminished or absent in ASD (Chiang, Soong, Lin, & Rogers, 2008; Mundy et al., 1986; Wimpory et al., 2000).

Children with ASD also show abnormal responding to speech stimuli. For example, infants with ASD regularly failed to respond to their name, which is considered an early warning sign, and consistently distinguished children with ASD from others (Baranek, 1999; Osterling & Dawson, 1994; Saint-Georges et al., 2010; Zwaigenbaum et al., 2005). Furthermore, preschool children with ASD preferred noises over their mother's speech. This was reflected by differential brain activation for speech stimuli and may account for abnormal responding and impaired language development (Klin, 1991; Kuhl, Coffey-Corina, Padden, & Dawson, 2005).

Imitation plays an important role in learning new skills via copying, symbolic play and expressive language skills (Stone, Ousley, & Littleford, 1997). Copying of facial and bodily movements seems impaired in ASD, and more difficult than action imitation using objects (Biscaldi et al., 2015; Rogers, Hepburn, Stackhouse, & Wehner, 2003; Stone et al., 1997). Compared to TD peers, children with ASD imitate less frequently and accurately (Vivanti, Trembath, & Dissanayake, 2014) but performance depends on task, difficulty, and symptom severity (Biscaldi et al., 2015; Rogers et al., 2003).

Finally, individuals with ASD often suffer difficulties with relationships, for example with forming, maintaining and understanding relationships. In addition, they may experience problems with adjusting behaviour to situational circumstances (American Psychiatric Association, 2013). In early childhood, such deficits surface as a lack of imaginative play and an apparent disinterest in peers (American Psychiatric Association, 2013). Besides deficits in

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<sup>9</sup> Low level initiations include making eye contact with other while holding a toy, while high level initiations include pointing/showing or giving toy.

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the social realm, individuals with ASD also experience deficits with communication, which are addressed below.

### *Communication deficits in ASD*

Non-verbal communication impairments in ASD may manifest as abnormalities in eye contact, facial expressions, body language, and problems with making and understanding gestures. In other words, problems arise with non-verbal pragmatics<sup>10</sup> of communication. More severely affected children with ASD might show a profound lack of drive to communicate, which is in stark contrast to young children not affected by ASD (Rapin & Dunn, 1997). Comprehension of gestures, facial expressions and tone of voice is also widely impaired in ASD (Rapin & Dunn, 1997). Finally, deficits in this category include poor integration of non-verbal and verbal communicative behaviours, such as integration of eye contact or gestures with speech (Silverman, Eigsti, & Bennetto, 2017).

Joint attention is also often difficult for people with ASD (Bruinsma, Koegel, & Koegel, 2004; Charman, 2003; Vivanti et al., 2014). Imperative joint attention<sup>11</sup> was found to be relatively intact in children with ASD, however, there seem to be major difficulties with declarative joint attention<sup>12</sup> (Loveland & Landry, 1986; McEvoy, Rogers, & Pennington, 1993; Mundy et al., 1986; Mundy, Sigman, & Kasari, 1990; Sigman et al., 1999; Stone et al., 1997).

### *Language deficits in ASD*

Heterogeneity of language development and skills in ASD is large, and a language deficit is not required for a diagnosis of ASD today (American Psychiatric Association, 2013; Kjelgaard & Tager-Flusberg, 2001). If language develops, onset may be later and the developmental trajectory differs compared to typical language development (Mitchell et al., 2006). Loss of language abilities, is rare, but has been recorded in ASD (Pickles et al., 2009).

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10 Pragmatics of language refer to the implicit rules for using language communicatively and appropriately, so that conversation is meaningful and engaging (Rapin & Dunn, 1997). Verbal pragmatics refers to such things like turn-taking, staying on topic, providing conversational partners with appropriate information to clarify meaning and so on.

11 Requesting help in attaining an object or event from a caregiver by using gestures, pointing, showing, and following someone's gaze to where they are looking (Doussard-Roosevelt, Joe, Bazhenova, & Porges, 2003).

12 Directing a caregiver's attention to an object, action, or entity. Declarative joint attention may include pointing to, showing, or giving of objects (Gabig, 2013).

Pragmatics, comprehension and formulation of discourse is often impaired (Rapin & Dunn, 1997). Comprehension abilities may vary. In one study with children suffering from an auditory processing deficit, receptive skills were absent in more than half the sample<sup>13</sup> (55%), while the other half (41%) had some receptive skills including understanding of single words and simple directions (Greenspan & Wieder, 1997). Only 4% showed an understanding of more complex directions (Greenspan & Wieder, 1997).

Speech of people with ASD often differs in prosody (either very high-pitched and squeaky, or robotic and monotonous), phonology<sup>14</sup> and syntax<sup>15</sup> (Kargas, López, Morris, & Reddy, 2016; Lyakso, Frolova, & Grigorev, 2016; Nakai, Takashima, Takiguchi, & Takada, 2014). Echolalia, the repetition of a word or phrase, is often seen in very young children with ASD and often does not fade as the child's language abilities mature (Rapin & Dunn, 1997).

Language development may be predicted by pre-verbal communication skills in early childhood, functional play skills and responsiveness to joint attention requests (Mundy et al., 1990; Sigman et al., 1999). Non-verbal IQ score may play a role in subsequent language development (Bopp, Mirenda, & Zumbo, 2009). Conversation content is often ritualistic and revolves around special topics.

In summary, there is a range of deficits and abnormalities that characterise social, communication and language abilities in individuals with ASD. For an overview see Table 2.3 below.

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13 These findings were based on a clinical records review of 200 children diagnosed with autism or PDD-NOS according to the DSM-IV. Children were between 22 months and 4 years (Greenspan & Wieder, 1997).

14 Phonology refers to the auditory code, or speech sounds that make up words. If deficient, words can be distorted and hard to understand (Rapin & Dunn, 1997).

15 Syntax refers to the grammatical rules that constitute well-formed, clear sentences (Rapin & Dunn, 1997).

Table 2.3 Overview over ASD deficits

Category	Deficits
Social deficits	<ul style="list-style-type: none"> <li>• Lack of spontaneous initiation of interaction or joint attention</li> <li>• Impaired social-emotional reciprocity</li> </ul>
Restricted and repetitive behaviours	<ul style="list-style-type: none"> <li>• Stereotyped or repetitive movements, use of objects, or speech</li> <li>• Insistence on sameness, inflexibility concerning routines</li> <li>• Restricted interests</li> <li>• Hyper- or hyporeactivity to sensory input</li> </ul>
Communication deficits	<ul style="list-style-type: none"> <li>• Abnormalities in non-verbal pragmatics</li> <li>• Lack of drive to communicate</li> <li>• Impaired comprehension of body language</li> <li>• Poor integration of non-verbal and verbal communicative behaviours</li> </ul>
Language deficits	<ul style="list-style-type: none"> <li>• Late onset, slow progress of language development</li> <li>• Abnormal pragmatics, comprehension and formulation</li> <li>• Prosody, phonology and syntax often odd</li> <li>• Content often ritualistic and restricted</li> </ul>

## 2.4.2 Timing explanations of ASD

Timing abnormalities may explain diagnostic features seen in ASD (e.g. Allman, 2011; Amos, 2013; Grossberg & Seidman, 2006; Wimpory, Nicholas, & Nash, 2002). Perceptual, learning, memory and central coherence problems could be ascribed to difficulties in integrating complex sensory information (Bertone, Mottron, Jelenic, & Faubert, 2005). Social and communication difficulties may be due to atypical social timing patterns. For instance, poor social timing skills act to reduce social bonding in early childhood, joint attention and social reciprocity (Jaffe et al., 2001). Restricted and repetitive behaviours and interests may serve by 'segmenting time' and thus be a coping mechanism aimed at organising temporal stimuli (Amos, 2013; Spiker, Lin, Van Dyke, & Wood, 2012). Finally, problems with skills that involve putting oneself in someone else's point of view such as pretend play, empathy, theory of mind, might require the 'mental time travel' that people with ASD find challenging and confusing (Amos, 2013; Feldman, 2012c).

This section introduces timing explanations of ASD. Cognitive hypotheses which function at a descriptive level in that they explain perceptual and comprehensive processes are illustrated first. It is shown how temporal anomalies at the cognitive level may affect processing, comprehension and behaviour in ASD. Next, neural causes which possibly

underlie cognitive changes are discussed. Finally, genetically driven timing explanations of ASD are investigated and their possible role as the ultimate cause of ASD as they may determine neural and cognitive changes.

### *Cognitive timing theories of ASD*

In line with Weak Central Coherence<sup>16</sup> theory (Happé & Frith, 2006), it has been suggested that autistic features may be caused by a deficit in temporal binding due to a reduced integration of neural networks (Brock, Brown, Boucher, & Rippon, 2002). The problem seems to lie with binding between networks (Brock et al., 2002). In contrast, binding within networks is thought to be intact or even enhanced, explaining an enhanced local focus and impaired global processing.

Difficulties with language processing may be due to reduced contextual influence. Impaired attentional shifting could be ascribed to reduced connectivity between frontal lobes and posterior regions, further causing behavioural inflexibility in joint attention. Theory of mind impairments could be associated with poor integration of multiple sources of information (Brock et al., 2002). A real-life example of what poor integration may mean for an individual with ASD is provided by Amos (2013), who explains that her own son with ASD copes by watching television muted with captions, so that he only needs to attend to visual instead of audio-visual information. In sum, a temporal binding deficit may underlie ASD symptoms and could explain social and communication deficits, restricted behaviours and why some skills are seemingly enhanced in ASD. However, it remains unclear where this binding deficit stems from.

A different proposition suggests that ASD is a temporo-spatial processing disorder (TSPD) affecting multi-sensory flows caused by multi-system Brain Disconnectivity-Dissynchrony (MBD; Gepner & Féron, 2009). MBD describes increases/decreases of functional connectivity and neural synchrony within/between brain regions. In general, temporo-spatial processing problems affect (1) detection and integration of visual motion; (2) coding and parsing language; and (3) anticipation and programming postural adjustments (see Table 2.4 below).

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<sup>16</sup> Weak Central Coherence posits that individuals with ASD tend to process locally rather than globally unlike neurotypicals, who are biased to a global processing style (Happé & Frith, 2006).

Table 2.4 Temporo-spatial processing problems

Domain	Problems
Detection and integration of visual motion	<ul style="list-style-type: none"> <li>• Avoidance of rapid sensory flow</li> <li>• Inadequate responding to and perception of movements, including facial movements</li> <li>• Deficits in imitation and emotion recognition</li> </ul>
Coding and parsing language	<ul style="list-style-type: none"> <li>• Impaired auditory processing and speech comprehension</li> <li>• Difficulties extracting relevant information amongst noise and speech phoneme categorisation</li> </ul>
Anticipation and programming postural adjustments	<ul style="list-style-type: none"> <li>• Weak postural reactivity in response to visual information</li> </ul>

In response to overwhelming environmental demands, people with ASD may compensate by focusing on static visual stimuli or auditory singularities instead. This may explain enhanced abilities in areas such as spatial memory or pitch sensitivity (Gepner & Féron, 2009). Similarly, repetitive behaviours like switching the lights on and off may be used as coping strategies to slow down the world (cited in Gepner & Féron, 2009). In support, deliberate slowing down of stimuli increased levels of performance in severely affected children with ASD on measures such as face and emotion recognition, voluntary imitation and sentence comprehension (Gepner & Féron, 2009).

In sum, Gepner and Féron (2009) concluded that the environment may be too fast for people with ASD. They support this notion using quotes by able autistic people such as Donna Williams who explained that: "the constant change of most things never seemed to give [her] any chance to prepare [herself] for them." The following subsection addresses brain alterations as a possible underlying cause of cognitive timing problems in ASD.

#### *Neural deviations may underlie timing anomalies in ASD*

Timing anomalies in ASD may be due to neural deviations. For example, cerebellar damage and loss of Purkinje cells causes problems with rapid attention shifting. Attrition in both of these structures may be responsible for social and communication deficits in ASD (Courchesne et al., 1994).

The cerebellum is described to act as a 'master computational system' (p. 861; Courchesne et al., 1994). Purkinje cells connect the cerebellum to other areas in the brain. Together they support brain structures involved in motoric, attentional, arousal, sensory,

memory systems to produce timely, accurate and appropriate responses. Without the cerebellum's support these systems still function but sub-optimally.

In support of this idea, Courchesne and colleagues (1994) found that the impairment is limited to rapid attentional shifts, specifically those under 2.5 seconds. At slower speeds, performance of children with ASD was comparable to age-matched controls (Courchesne et al., 1994). Slowed attention shifting can interfere with social functioning. For example, if a child is unable to adequately shift his focus between rapidly incoming information from gestures, verbalisations, postural, tactile and facial cues, important information may be missed. In response to information overload, the child might withdraw from the interaction (Courchesne, 2004). In short, there is evidence that cerebellar damage hinders processing of rapidly incoming sensory information, thus negatively affecting fast paced interactions.

In addition, structural differences in the inferior olive of individuals with ASD may disrupt its role in the brain, resulting in impairments of processing and reacting to rapid stimulus sequences (Welsh et al., 2005). The authors present evidence for both the inferior olive's role, and why this might affect language development in early childhood. According to Welsh, the infant's brain needs to develop a processing speed that allows him to adapt to the fast communication speed of adult language in order to have fluid conversations.

First 'conversations' between infant and caregiver are slow, and the adult typically follows the infant's lead. As the infant matures, the speed of conversational flow increases and influence becomes mutual (Feldman, 2007b). A global decrease of motor and cognitive speed would thus hinder early communication, with profound consequences for language acquisition (Welsh et al., 2005). This idea appears closely linked with the impaired rapid attention shifting deficit that Courchesne et al. (1994) attributed to cerebellar damage. In fact, the inferior olive is a major input hub to the cerebellum (Xu, Liu, Ashe & Bushara, 2006).

It is possible that both structures are impaired jointly or separately, in both cases causing similar symptoms. In sum, it is conceivable that neural alterations underlie cognitive changes in ASD, which manifest in temporal deficits. However, neural explanations of ASD do not address where structural brain differences stem from. Genetics research suggests answers that may reveal the underlying cause of structural and cognitive anomalies in ASD.

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### *Genetics-the ultimate cause?*

Researchers have hypothesised that social timing may have a genetic basis (Wimpory et al., 2002). Evidence for this comes from fruit fly studies but equivalents were found in humans and mice (Konopka & Benzer, 1971; Sun et al., 1997). The genes that regulate timing are known as 'clock genes'. They are responsible for circadian timing and thereby regulate metabolic function. Clock genes are thought to influence other aspects of timing and social timing, such as emotional and contextual memory and communication, for example, courtship patterns. Circadian timing may play a part in social interaction by supplying 'timekeeping cues' (Barnard & Nolan, 2008).

Dysfunctional circadian timing has been linked to ASD where it may manifest through sleep disturbances (Barnard & Nolan, 2008; Cortesi, Giannotti, Ivanenko, & Johnson, 2010). In ASD, sleeping problems and social problems appear closely linked (Richdale & Prior, 1995). In sum, timing appears to be influenced by processes involving specialised genes.

Genetic anomalies in clock genes and methylation changes that are specific to ASD may cause social timing deficits (Wimpory et al., 2002). Methylation status of a gene decides whether it is expressed or not. In ASD there is reasonable evidence to suspect that methylation status is anomalous (Wimpory et al., 2002). Two genes in particular (*per1* and *npas2*) appear to be significantly<sup>17</sup> associated with ASD (Nicholas et al., 2007). *Per1* is implicated in lack of cerebellar Purkinje cells. *Npas2*, a clock-related gene, is thought to affect sleep-wake cycles, and possibly plays a role in memory formation (Barnard & Nolan, 2008). Both genes are linked to the cerebellum, forebrain and limbic system. Given the role the cerebellum and Purkinje cells play in timing, alterations within those structures may be responsible for timing, contextual and memory anomalies in ASD. In sum, neural anomalies in ASD may be based on genetic differences (albeit indirectly). Further, the affected neural structures play a role in functions that support social and communication. Thus, anomalies in these brain structures plausibly lead to problems in social timing, which may manifest early in parent-infant interactions (Nicholas et al., 2007).

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17 The authors note that correction for multiple testing would render results non-significant, due to the small sample ( $N = 90$ ) and effect sizes (Wimpory et al., 2002).



### 2.4.3 Timing in ASD

The following section examines evidence of differential timing in ASD. Various research domains are considered, including cognition, circadian rhythm, motor timing, and neurology.

#### *Interval timing*

Interval timing in ASD may be attenuated compared to TD controls, however findings are mixed (Jones, 2017). Amongst time estimation studies, two reported that timing was intact in ASD (Mostofsky, Goldberg, Landa, & Denckla, 2000; Wallace & Happé, 2008). Two other studies supported this, but found that the ASD group was less sensitive at estimating time (Allman, DeLeon, & Wearden, 2011; Falter et al., 2012). In contrast, one other study found a clear impairment in time perception (Brodeur, Gordon Green, Flores, & Burack, 2014). Likewise, temporal bisection (Gil, Chambres, Hyvert, Fanget, & Droit-Volet, 2012; Jones, Lambrechts, & Gaigg, 2017) and time production (Wallace & Happé, 2008) appeared intact.

Out of six studies that investigated reproduction of time intervals, four found an impairment (Brenner et al., 2014; Karaminis et al., 2016; Martin, Poirier, & Bowler, 2009; Szelag, Kowalska, & Galkowski, 2004). Mixed findings with equal performance in intermediate intervals and poor performance for intervals at extreme ends were also reported (Maister & Plaisted-Grant, 2011). Only one study reported intact timing abilities with a tendency for superiority in the ASD group (Wallace & Happé, 2008). Most authors observed large variability within the ASD groups. The vast heterogeneity within ASD and methodological differences may account for mixed findings. Attributing a causal role to interval timing deficits may be premature, however, existing research points to the likelihood that timing deficits interact with and modulate symptoms in ASD (Allman & Falter, 2015; Falter & Noreika, 2011).

#### *Temporal processing of multiple inputs and synchrony*

The majority of studies testing multi-sensory integration found a deficit in ASD dependent on stimulus presentation (Foss-Feig et al., 2010; van der Smagt, van Engeland, & Kemner, 2007). Audio-visual integration was intact in youth with ASD, however, ERP analysis revealed differential activation of neural networks in the ASD group, with time windows corresponding to differences in lexical-semantic processing (Megnin et al., 2011). De Boer-Schellekens et al. (2013) observed that people with ASD were less sensitive to asynchrony, but

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performance improved at larger latencies. This supports other evidence showing that performance of timing task improves when timing is slowed down.

Temporal order judgements of aural and visual stimuli revealed no significant differences between children with ASD and a TD control group (Kwakye et al., 2011). Detection of audio-visual synchrony with speech and non-speech stimuli showed no overall group difference, however, results indicated an impaired level of responding in tasks using speech (Bebko et al., 2006). Similarly, judgements of simultaneity and asynchrony of visual stimuli showed that the ASD group had lower synchrony thresholds, suggestive of an impaired ability to integrate stimuli (Falter, Elliot & Bailey, 2012). Finally, synchronised button pressing was done earlier and with greater variability by male adults with Asperger's compared to a matched NT control group (Gowen & Miall, 2005).

#### *Temporal processing of auditory information*

Research into auditory temporal processing points to an overall impairment when using social stimuli (Chevallier, Noveck, Happé, & Wilson, 2011; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Kargas et al., 2016; Lerner, McPartland, & Morris, 2013; Russo, Zecker, Trommer, Chen, & Kraus, 2009) but not when using non-social stimuli (Dawson et al., 1998; Fujikawa-Brooks, Isenberg, Osann, Spence, & Gage, 2010; Jones et al., 2009). Auditory training in children with ASD removed deficits post training (Russo, Hornickel, Nicol, Zecker, & Kraus, 2010).

#### *Temporal processing of visual information*

Several studies in youth and adults with ASD have revealed slowed processing of facial information as indicated by N170 latency (for example McPartland, Dawson, Webb, Panagiotides, & Carver, 2004), including one finding that the ASD group processed objects faster than faces (Webb, Dawson, Bernier, & Panagiotides, 2006). Another ERP study by the same lab tested facial emotion processing in children with ASD using both child and adult face stimuli. While there were no differences for recognising emotions from child faces, significant group differences were found for adult faces, with longer latencies for early perceptual processing, indicated by N170 amplitudes, rather than emotion recognition deficits (Lerner, McPartland, & Morris, 2013). It should be noted that these deficits were behaviourally minor, and that within the ASD groups large variability was found with some individuals performing

very well and others very poorly. In a study looking at spontaneous and voluntary (participants were asked to mimic facial expressions) facial mimicry in response to pictures of happy, sad, angry and neutral faces, the authors found that while children with ASD did mimic facial expressions spontaneously, it took them longer to do so. No difference was found for voluntary mimicry, thus the ASD group performed just as well as TD controls (Oberman, Winkielman & Ramachandran, 2009). The authors propose a potential issue with automatic engagement of sensory-motor mechanisms involved in timing of social interactions, consistent with neuropsychological evidence.

### *Circadian rhythm*

Timing difficulties in ASD are also evident in circadian rhythms. For instance, sleep disturbances are well-recorded in ASD (Cortesi et al., 2010; Elia et al., 2000; Limoges, 2005; Richdale & Prior, 1995). This is further supported by alterations in melatonin patterns (Nir et al., 1995) and evidence from genetic studies (Hu et al., 2009; Nicholas et al., 2007).

### *Motoric timing*

Studies on motoric timing indicated general differences in gait, muscle tone, and balance in ASD (Teitelbaum et al., 2004; Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998). Performance may be normal in simple tasks (tapping as fast as possible) but added complexity revealed differences in speed and execution strategies (Gowen & Miall, 2005).

### *Neural correlates*

Finally, insights from studies on neural correlates add to the evidence that timing is disrupted in ASD. Most notably, the cerebellum appears to be developing differently (Courchesne et al., 2001; Courchesne et al., 2004) with implications for timing processing and motor abnormalities.

In sum, converging evidence shows that a timing deficit is present in ASD. While exceptions exist, performance was almost always found to be diminished in ASD. Timing studies in ASD revealed three overarching themes;

- Processing of social stimuli is impaired while non-social stimuli remain largely intact
- Increased task complexity diminishes performance in ASD more so than in TD people
- Rapid presentation of stimuli further impairs task performance in ASD

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It follows that social interaction, which contains all of these features, must be especially difficult for individuals with ASD. The following subsection addresses this question.

#### 2.4.4 Social timing in ASD

The previous section showed that processing of complex, social and fast stimuli is difficult for people with ASD. Social interaction and communication are all of the above and sensitive to timing disruptions. When timing goes awry, intentions and actions may become uncoupled, resulting in confusion and hindering interaction. Based on findings from timing studies, social timing should be highly challenging for people with ASD.

Section 2.3 illustrated the importance of interactional synchrony for further development, in particular cognitive and social skills. Achieving synchrony requires several skills, for example, coordinating gaze, speech, body language with those of another while engaging in joint attention and turn-taking (Feldman, Golan, Hirschler-Guttenberg, Ostfeld-Etzion, & Zagoory-Sharon, 2014; Srinivasan et al., 2015). The following section presents the result of the literature search on social timing studies in ASD.

##### *Retrieval of studies*

The databases 'Web of Science', 'PubMed' and 'PsycInfo' were searched using the following terms: (autis\* AND interaction) AND (synchrony OR cyclicity OR rhythmicity OR interpersonal timing OR intrapersonal timing OR social timing). Inclusion criteria were experimental or observational studies (including individuals with ASD or at risk for ASD) looking at temporal aspects of coordinating social stimuli or interaction. Furthermore, a study needed to inform about quantitative or qualitative aspects of social timing. Excluded were studies published in a language other than English, comments, editorials and conference papers.

This procedure revealed 16 studies in line with the topic. Additionally, six relevant studies known from previous literature searches and reference lists were included. This resulted in a total of 22 studies. Studies were separated into those that inform about intra- ( $N = 7$ ; see 2.4.5 below) and interpersonal timing ( $N = 15$ ; see 2.4.6 below).

The distinction between intra- and interpersonal timing studies was made based on whether the outcome variable measured both interaction partners' behaviour

(=interpersonal) or just that of the person with ASD (intrapersonal). In other words, a study about interpersonal social timing needed to quantify or qualify social timing for both interaction partners.

### 2.4.5 Intrapersonal timing in ASD

Studies are divided into those that isolated the participant's intrapersonal timing, meaning that their timing was not measured during engaging with another person (see Table 2.5) and those that measured intrapersonal timing during a social task with another person (see Table 2.6).

#### *Isolated intrapersonal timing in ASD*

Emotion recognition and facial mimicry of emotions was investigated by Oberman and colleagues (2009). They found 8- to 12-year-old boys with ASD able to recognise emotions and intact facial response during mimicry. Yet, spontaneous facial mimicry (when people mimic someone else's facial expression without being asked to do so) was delayed, while voluntary facial mimicry (mimicking after being explicitly asked to do so) was intact (Oberman et al., 2009).

Speech-gesture coordination during story telling was desynchronised in a group of adolescents with ASD compared to a TD control group (de Marchena & Eigsti, 2010). This difference was not due to the number of gestures made. Narratives by participants with ASD were also harder to follow, as rated by naive listeners and coincided with symptom severity. The authors concluded that this desynchronisation impacted on story telling quality (de Marchena & Eigsti, 2010).

NT adults synchronised their eye blinks with that of an actor during viewing of video-clips, which distinguished them from adults with ASD who did not even though both groups looked for equal durations towards the actor's mouth and eyes (Nakano, Kato, & Kitazawa, 2011). The higher ASD symptom severity, the lower was eye blink synchronisation, suggesting that this result is due to a social timing impairment (Nakano, Kato, & Kitazawa, 2011).

All of these three studies provided evidence that synchronisation in ASD is delayed or absent.

Table 2.5 Isolated intrapersonal timing studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Oberman et al. 2009	Boys with ASD (age range 8-12; $N=13$ ; $N_{AD}=6$ ; $N_{ASD}=6$ ) vs TD boys (age range 8-12; $N=13$ )	Spontaneous mimicry: classifying images of emotional faces; voluntary mimicry: mimicking and classifying emotions; facial electromyography (EMG) investigated timing and magnitude of mimicry	Intact voluntary but delayed spontaneous mimicry in ASD; no differences for emotion recognition and amplitude of EMG activity	The mirroring system in ASD may only be activated under specific conditions (e.g. stranger vs familiar adult)	Small sample size
de Marchena & Eigsti	Adolescents with ASD ( $N=15$ ; age range 12-17) vs TD adolescents ( $N=15$ ; age range 12-17)	Narrative task from ADOS (Lord et al., 1989): ppts were asked to tell a story based on picture cards subsequently rated by naive listeners and coded for speech and gestural synchrony	Frequency of gestures was equal but those by the ASD group were less synchronised with speech and less communicative resulting in harder to follow narratives	Evidence for impaired intrapersonal synchrony independent of frequency of use of speech and gesture and its effect on communicative quality	No control measure during conversations which prompt people to gesture differently; gesture form not qualified
Nakano et al. 2011	Adults with ASD ( $N=18$ ) vs NT adults ( $N=18$ )	Video of actor with/out focus on eyes (rest of face blurred); eye blink synchronisation	TD ppts synchronised eye blinks with actor, ASD ppts did not; viewing time of speaker's eyes and mouth same for groups; eye blink synchronisation correlated negatively with ASD severity	Evidence for impaired socio-cognitive abilities (incl. face processing) which hindered people with ASD in sharing speech-pauses with speaker	No mutual interaction between listener and speaker, thus results are limited to a non-naturalistic setting

### *Non-isolated intrapersonal timing in ASD*

Synchronised behaviours allow assessment of intrapersonal timing, for example by studying prompted moving together (Fitzpatrick et al., 2013), moving on a rocking chair

(Marsh et al., 2013), and hand-clapping (Fitzpatrick et al., 2017; Romero, Fitzpatrick, Schmidt, & Richardson, 2016).

Prompted synchronisation (performing an action together with the experimenter) was more difficult for 6-year-old children with ASD than TD peers (Fitzpatrick et al., 2013). In a rocking chair paradigm, caregiver and child sit in their own rocking chair in close proximity, while the parent hears a metronome via headphones that he adjusts his rocking to. While TD children engaged in spontaneous rocking along with their parents, 4-year-old children with ASD did not (Marsh et al., 2013). Synchronised object tapping and hand-clapping performance was more robust in 6- to 10-year-old TD children compared to their peers with ASD (Fitzpatrick et al., 2017; Romero et al., 2016).

In sum, all four studies found an impairment in prompted and spontaneous synchronisation in the ASD group when moving together.

Table 2.6 Non-isolated intrapersonal timing studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Fitzpatrick et al. 2013	Children with ASD (age range 5-7 years; $N=11$ ; synchronisation task $N=5$ ) vs TD children (age range 4-8 years; $N=7$ ; synchronisation task $N=3$ )	Ppts randomly assigned to imitation or synchronisation tasks; synchronisation required child to imitate in time with experimenter	Prompted imitation was equal but prompted synchronisation was harder for both groups, even more so in ASD group	Temporal aspect of coordination is more difficult for all children, more so for those with ASD	Task not inherently social in nature, i.e. there is no explicit communicational aspect; small sample size
Marsh et al. 2013	Children with ASD (age range 3-8 years; $N=8$ ) vs TD children (age range 2-8; $N=15$ ) and a parent of each child	Parents heard rhythm (via headphones) to which they adjusted their rocking rhythm in chair; children's spontaneous rocking rhythm was measured	ASD children did not engage in spontaneous, synchronised rocking unlike TD peers	Low-level social-motoric behaviour is deficient in ASD	Small sample size; only one type of synchronisation behaviour measured; attention not measured
Romero et al. 2016	Synchronisation condition: Children with ASD (age range=6-10 years, $N=21$ ) vs	Synchronisation (repeating in time together with experimenter) OR imitation	TD children showed more robust synchronising abilities than ASD children	Movements in ASD are more rigid; social motor coordination may be a	Unclear whether differences may partly be due to the experimenter (who was not blind to the

	TD children (age range=6-10, N=26) Imitation condition: Children with ASD (age range=6-10 years, N=20) vs TD children (age range=6-10, N=21)	(simply repeat after experimenter demonstrated); object tapping and hand-clapping		behavioural bio-marker; differences most obvious during synchronised behaviour	child's group membership)
Fitzpatrick et al. 2017	Children with ASD (age range 6-10; N=45) vs TD children (age range 6-10; N=53)	Interpersonal handclapping; non-social drumming to assess motoric ability	Lower social synchronisation ability in ASD; social synchronisation highest in hand-clapping; drumming of ASD group slower and more variable in spacing and timing	Movements performed differently in ASD, suggesting that motoric abilities impact social interaction; large sample size found strong effect sizes	

## 2.4.6 Interpersonal timing in ASD

Interpersonal timing studies include different approaches and may inform about interpersonal coordination (e.g. vocal synchrony), motoric synchronisation, interactive flow or interactional synchrony. Below follows a review of 14 interpersonal timing studies in ASD. Subsections are divided by approach and accompanied by a table summarising the reviewed studies.

### *Vocal synchrony*

An analysis of prosodic synchrony from mother-infant conversations revealed a different developmental trajectory for dyads at risk for ASD (Quigley, McNally, & Lawson, 2016). TD infants reduced mean pitch between 3 to 18 months of age. This tendency was observed in at risk dyads, but maternal infant-directed speech (used to create synchrony) became more rather than less intense (Quigley et al., 2016). Additionally, pitch synchrony was evident in the



low risk dyads, but absent in the at risk group with the exception of some pitch synchrony at 18 months (Quigley et al., 2016).

Automated analysis of pitch variations of voice recordings showed that levels of vocal arousal synchrony correlated with symptom severity (Bone, Lee, Potamianos, & Narayanan, 2014). Furthermore, more severely affected children tended to lead interactions, while those with milder symptoms followed the psychologist (Bone et al., 2014).

Speech-pause durations in conversations tend to average out between interactive partners as a consequence of synchrony<sup>18</sup> in NT dyads (Feldstein et al., 1982). The speech of dyads with verbal adolescents with high-functioning autism, however, was characterised by longer inter-speech pauses and switching pauses, and synchrony was not achieved (Feldstein et al., 1982). See Table 2.7 below.

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18 Synchrony, or 'interspeaker influence' was defined as correlations of average durations of pauses and switching pauses of Speaker 1 with those of Speaker 2 over all 12 dyads (Feldstein et al., 1982).

Table 2.7 Vocal synchrony studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Feldstein et al. 1982	Adolescent and young adults with HF autism (age range 14-20 years; N=12) and their parents	Dyads were: 1) ppt & parent; 2) ppt & experimenter; 3) parent & experimenter; informal conversations; analysis of speech/ pause durations	Longer switching pauses & pauses with experimenter in ASD; no synchrony in dyads with HFA	Youths with HFA were unable to synchronise their vocalisations and verbalisations with NT adult; interpersonal verbal timing is adversely affected in ASD	Statistical analysis not a time-series analysis, does not account for intercorrelation of data points over time
Bone et al. 2014	Children with ASD (age range 5-15; N=29; N Autism=18, N ASD=5, N ASD cutoffs=6)	Voice recorded from ADOS assessments; vocal signals analysed for pitch variations; cross-correlations to determine synchrony, lead lag relationships	Vocal arousal synchrony related to ASD symptom severity; more severely affected when children lead interactions, those with milder symptoms followed adult	Vocal arousal useful automatic measure for affective synchrony, could be used to discriminate between high and low symptom severity	No control group
Quigley et al. 2016	Mother-infant dyads; at risk for ASD (N=10) vs not at risk (N=9); measurements taken at 3, 12 and 18 months	Mother-infant 'conversations' analysed for prosody synchrony using correlation	Little evidence for synchrony in prosody in the at risk group	Follow-up after 6 months, studying 1-1.5 year olds	Inadequate statistics; at risk study

### *Motoric interpersonal synchronisation*

Social signal processing was examined in a cooperative task in which 7- to 11-year old children with AD or PDD-NOS built figures together with a psychologist (Delaherche et al., 2013). The comparison group was matched by developmental age, and comprised TD children between 4 and 9 years. Group differences emerged as changes to the gestural rhythm of the psychologist, who adapted differentially to the tempo of children with ASD (Delaherche et al., 2013).

Adolescent-parent dyads with ASD further showed impairments during spontaneous and intentional pendulum synchronisation, which was intact in dyads with TD adolescents (Fitzpatrick et al., 2016).

For a cooperative motoric synchronisation task, adults with ASD were paired with a NT adult (Curioni, Minio-Paluello, Sacheli, Candidi, & Aglioti, 2017). Paired participants were seated across from each other and each held a bottle, which they had to grasp as synchronously as possible. Performance was compared to a non-social task, in which participants were not paired, and had to grasp the object in synchrony with a dot displayed on a computer screen. People with ASD did not wait for their partner to join in the movement, which was not due to motor or executive function difficulties (Curioni et al., 2017). Furthermore, higher autistic traits diminished task performance (Curioni et al., 2017). See Table 2.8 below.

Table 2.8 Motoric synchronisation studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Delaherche et al 2013	Children with ASD (age range 7-11, $N=7$ , Autistic Disorder $N=4$ , PDD-NOS $N=3$ ) vs TD children (age range 4-9, $N=14$ )	Automated measures to assess coordination skills of interactive behaviour (including rhythm, turn-taking and synchronised behaviour); children and psychologist built figure either during 'imitation', 'child follows instructions' or 'child gives instructions'	Gestural rhythm of psychologist differed when interacting with ASD vs TD children	Information regarding behaviour of ASD group was found in the way interaction partner adapted to individual with ASD	Small sample size
Fitzpatrick et al. 2016	Adolescents with ASD (age range 12-17 years; $N=9$ ) and NT adolescents (age range 12-16 years; $N=9$ )	Spontaneous and intentional parent-child pendulum synchronisation	ASD group demonstrated disruption of both spontaneous and intentional synchronisation	Spontaneous synchronisation in ASD is diminished in social situations	Possible that findings are specific to parent-child interactions and do not extend to stranger-ppt settings
Curioni et al. 2017	Dyads of adults with ASD and a NT individual (age range <sub>ASD</sub> 18-42; age range <sub>NT</sub> 17-49, $N_{\text{dyads}}=16$ ; ADOS score $M=12$ (5-17))	Joint cooperative task (grasp a bottle-shaped object synchronously with partner vs non-social task where bottle was grasped in synchrony with dot on computer screen)	Higher autistic traits diminished synchrony; ASD ppts did not wait for partner to join; differences not due to motor or executive function difficulties	Synchronisation performance depended on social nature not on motoric abilities	Findings limited to ASD without cognitive disability; relatively small sample size, may not represent ASD heterogeneity

### *Interactive flow*

Analysis of unstructured parent-infant play showed that dyads at risk and dyads not at risk between 6 and 10 months engaged equally in dyadic mutuality. However, the at risk

group's mean was lower, indicating a trend for suboptimal mutuality during face-to-face interaction (Wan et al., 2012).

In a longitudinal study about parent-child interaction styles in TD, one child was later diagnosed with Autistic Disorder and Mental Retardation, and served as the case study (Hedenbro & Tjus, 2007). At 3 months, dyadic synchrony<sup>19</sup> was comparable to that of her TD peers, but triadic synchrony posed more difficulty. At 9 months, previous gains in dyadic synchrony regressed: mother-child synchrony was possible but difficult to achieve, father-child and triadic synchrony were not achieved. At 18 months, no type of synchrony was achieved. At 48 months, dyadic synchrony was still absent but triadic synchrony had slightly improved.

Preschool-aged boys with ASD were randomly assigned to a music therapy intervention followed by toy sessions or vice versa (Kim, Wigram, & Gold, 2009). Emotional synchronicity, defined as sharing of emotional affect between child and adult, was more sustained and of longer duration in music therapy sessions and linked with children's increased initiation of engagement (Kim et al., 2009). Further evidence that treatment can increase interactive flow comes from Hobson's study (2016) that investigated the effects of Relationship Development Intervention (Gutstein, 2009) in children between 2 and 12 years. Autism symptom severity correlated with co-regulation (equality of taking responsibility for interaction coordination) and intersubjective engagement (showing affective responses and interest to one another) before and after intervention. Nevertheless, Relationship Development Intervention increased both these scores significantly post-intervention (Hobson, Tarver, Beurkens, & Hobson, 2016). See Table 2.9 below.

Table 2.9 Interactive flow studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Wan et al. 2002	Infants at risk for ASD (age range 6-10 months; <i>N</i> =45) vs siblings not at risk ( <i>N</i> =47)	Video-analysis using global ratings of unstructured parent-infant interaction	All dyads showed equal levels of dyadic mutuality, but at risk group was lower,	Lower interactive flow in at risk for ASD group	Temporal aspect not measured; outcome relied on subjective, global

<sup>19</sup> Synchrony was defined as emotional engagement and interactive flow between parent and child. For triadic synchrony, this definition further depended on the parents actively inviting each other to participate in the interaction. Synchrony presence was determined subjectively and coded as yes/mostly/partly/no (Hedenbro & Tjus, 2007).

			indicating trend for suboptimal mutuality		ratings of mutuality (including 'interactive flow'), may not be sensitive enough
Hedenbro & Tjus 2007	Girl later diagnosed with ASD vs TD peers ( $N=19$ ), measurements at 3, 9, 18 and 48 months	Longitudinal case study; parent-child interaction; dyadic and triadic interactions	At 3 months, engagement of girl with ASD was higher than in peers, at 9 months, more attention to objects, at 18 months, less eye contact and mutual focus, at 48 months, poor language skills	Longitudinal study gave insight into developmental trajectory; synchrony coded yes/ mostly/ partly/ no; allows nuancing;	Temporal aspect not measured; synchrony was assessed subjectively; case study
Kim et al 2009	Boys with ASD (age range 3-6 years; $N=10$ ); randomly assigned to music therapy (MT) sessions first followed by toy sessions or vice versa	Within-subject comparison design: each child had toy play sessions compared with improvisational MT sessions (30 min) for 12 weeks	Emotional synchronicity more frequent and sustained in MT; closely linked spontaneous 'initiation of engagement' behaviours in children	MT possibly helps in establishing and offering prolonged periods of affective synchrony	Small sample size, low power
Hobson et al 2016	Dyads of parents and ASD children (age range <sub>children</sub> 2-12 years, $N_{dyads}=18$ ) receiving Relationship Development Intervention (Gutstein, 2009)	Coding of video-recorded dyadic parent-child interaction using the Dyadic Coding Scales (Humber & Moss, 2005)	Severity of autism correlated with co-regulation scores and intersubjective engagement scores at baseline and during treatment; post treatment, both scores increased	Treatment increased interactive flow	No comparison group that received alternative treatment; variability in timing of first and second assessment

*Biobehavioural synchrony in ASD*

Biobehavioural synchrony is predictive of cognitive and social outcomes in TD children (Feldman, 2012a; 2012c). In ASD, biobehavioural synchrony is challenged due to autism symptoms, however, achieving attunement despite such challenges may foster development (Feldman, 2012a). Baker and colleagues (2015) conducted the first study to investigate physiological synchrony during parent-child free play with toys in 4- to 10-year children with ASD. Lower ASD symptoms were related to stronger positive covariation of electro-dermal activity (EDA; a measure of sympathetic nervous system arousal), which supports the idea that parent-child biological synchrony might alleviate symptom severity over time (Baker et al., 2015). However, it is not yet known to what extent biological synchrony is heritable or whether social partnering has a greater influence (Baker et al., 2015). Finally, any conclusion also rests on the assumption that biological synchrony plays the same role in children with ASD as it does in TD children (Baker et al., 2015). See Table 2.10 below.

Table 2.10 Biobehavioural synchrony study in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Baker et al. 2015	4-10 years (N=28)	Parent-child free play coded for affective mutuality; electro-dermal activity (EDA) measured	EDA correlated with emotional attunement; symptom severity moderated EDA	First to show physiological synchrony in ASD and how it relates to affective mutuality & symptom severity	Relationship between heritability/partnering and role of EDA unclear

*Interactional synchrony in ASD*

Micro-analysis of home video-recordings of two 11-month-old monozygotic twin sisters revealed differential interactive behaviour by both infants and interacting father (Trevvarthen & Daniel, 2005). For the normally developing Twin B and her father, interaction could be parsed into cycles of interaction, including build up, climax, deceleration and renewed initiation. The dyad attended to one another, interaction was timely, contingent and mutually regulated (Trevvarthen & Daniel, 2005). In contrast, interactions with Twin A, who was later diagnosed with AD, were marked by long periods of non-attention, lack of joint build-up of tension and an absence of cycling interactive behaviour. The father appeared to receive no

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reinforcement from Twin A, which was further detrimental to their interactions (Trevvarthen & Daniel, 2005).

Cyclicity and synchrony during mother-infant interaction in 4-month-old children at low (Sibs-TD) and high risk for ASD (Sibs-A) was assessed during play without toys (Yirmiya et al., 2006). The methodology followed Monadic Phase coding in which synchrony is defined as a match in the direction of change of interaction phases (see 3.4 *Monadic Phases*). Results indicated that the majority of participants achieved synchrony<sup>20</sup>. Coherence<sup>21</sup> was more suboptimal in Sibs-A, indicated by too high and too low levels. Coherence was also lower in Sibs-A when the infant was leading. Low coherence correlated with a language impairment at 14 months. It is remarkable that differences in synchrony were evident at 4 months, considering that most Sibs-A at 14 months were functioning well, and only a small subsample of children showed subtle developmental and language delays (Yirmiya et al., 2006).

The number of episodes of gaze synchrony, touch synchrony and joint attention was assessed in preschoolers with and without ASD during free play with their parent (Feldman et al., 2014). Synchrony in this study was defined as a match. The TD group was found to engage in significantly more synchronous episodes and joint attention than the ASD group (Feldman et al., 2014).

Finally, a recent study investigated emotional and behavioural synchrony in preschoolers with ASD during a music intervention (Venuti et al., 2017). Video-recorded therapist-child play was micro-coded using an adaptation of Monadic Phases to suit this more mature sample. The intervention successfully increased synchrony in these children (Venuti et al., 2017). See Table 2.11 below.

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20 All-or-none synchrony scores were given when time-series were significantly cross-correlated which allowed establishment of lead-lag relationship (Yirmiya et al., 2006).

21 A coherence score indicates the level of synchrony and is calculated based on the shared variance of a dyad's two time-series minus each interaction partner's auto-regulated component (or cyclicity).



Table 2.11 Interactional synchrony studies in ASD

Author/s	Sample	Method	Findings	Value	Limitations
Trevarthen & Daniel 2005	Monozygotic twin sisters (age = 11 months; $N=2$ ), Twin A was subsequently diagnosed with autism	Case study comparing twins using video-analysis of home videos (father playing with each infant)	Twin B's interaction was characterised by timely synchronous exchange with her father, while Twin A's interaction was absent of any interpersonal coordination	TD infants already show synchronous interaction behaviour while the infant with ASD showed a complete lack of synchronous interactive behaviour	Results made on basis of visual examination of plots, hence no statistical analysis was carried out
Yirmiya et al. 2006	Infants at risk (Sibs-A) (age=4 months; $N=21$ ) vs infants not at risk (Sibs-TD) (age=4 months; $N=21$ )	Video-analysis of mother-infant play sessions, using Monadic Phases and TSA	Coherence was lower in Sibs-A; Sibs-A dyads had too low or too high levels of synchrony	Group study with sophisticated method and analysis informing about multiple synchrony parameters	No long-term follow-up; no clinical information about mothers
Feldman et al. 2014	Preschoolers with HF ASD ( $N=40$ ; 3-5 years) were matched with 40 TD controls	Synchrony (=match) during parent-child play; coded gaze to partner & object, avert; joint attention, affect, touch; oxytocin levels measured	More gaze & touch synchrony, joint attention in TD vs ASD group; oxytocin lower in ASD but improved following parent-child contact	Oxytocin levels correlated with gaze and touch synchrony with mother; importance of dyadic interaction & synchrony reflected by physiological markers	No time-series analysis but conditional probabilities (thus synchrony defined as match)
Venuti et al. 2017	Children with ASD (age range 4-6; $N=25$ ; symptom severity: mild:28%, moderate:56%, severe: 16%)	Intervention study; play between child and therapist; micro-coding using an adaptation of MP coding	Intervention increased ability of children to synchronise behaviourally and emotionally with therapist	Improvement over time possibly due to music, possibility that improvements due to therapist	Statistics not comparable to previous MP studies; no non-music control group; interacting adult not parent

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## 2.5 Summary and conclusion

This chapter's objective was to introduce the reader to the role of social timing in early development and to examine existing research evidence about (social) timing in ASD.

### *The role of timing in social interactions*

Temporal perception is necessary to accurately perceive time, rhythm, and make predictions to enable temporally appropriate responding within conversations. Processing and integration of sensory modalities allow individuals to link co-occurring stimuli into meaningful units. Timing of motoric actions plays a role in coordinating an individual's limbs. Timely motoric coordination enables us to use facial expression and body language in communication and are a new-born's first means of communication. In the brain, the cerebellum coordinates movement, executive function, learning and language, thereby connecting areas that depend on timing.

### *Social timing*

Social timing is comprised of intrapersonal and interpersonal timing. Intrapersonal timing refers to the individual's ability to organise expression and comprehension, while interpersonal timing describes the ability of two (or more) individuals to coordinate communication signals between them. Cyclicity can be a quality of intrapersonal timing, describing rhythmical organisation of an individual's own communication modes (e.g. gaze, facial expressions, speech and so on). Interactional synchrony, a quality of interpersonal timing, describes the smooth flow that dynamically unfolds between interaction partners who are able to adjust their timing to one another.

### *Social timing in early childhood*

Parent–infant synchrony unfolds at 3 months as a result of biological and behavioural processes (Feldman, 2007b). The experience of synchrony provides an important foundation for child development, and shapes cognition, symbolic use, self-regulation, and social-emotional development (Feldman, 2007b).

### *Autism Spectrum Disorder*

ASD is a developmental disorder that emerges in early childhood and is characterised by impairments in social interaction, verbal and non-verbal communication and repetitive and restricted behaviours and interests. Social deficits are characterised by decreased interpersonal contact, peer relationships and seeking shared enjoyment. Communication deficits are characterised by difficulties in comprehending non-verbal and verbal communication tools, difficulties with pragmatics, and making gestures. Language may or may not develop and, if it does, is often abnormal. Heterogeneity is large between children for all of these abilities.

### *Timing in ASD*

Growing evidence suggests that a timing deficit may underlie the symptoms seen in ASD, or even be causal to the disorder. Interval timing, perception of synchrony and multi-sensory integration in ASD showed mixed findings, reflecting vast heterogeneity within ASD besides methodological differences of paradigms. Social tasks showed a clear deficit, however, findings for non-social tasks stimuli were inconsistent. Most studies did observe larger variability in task performance and evidence points to alterations in temporal processing which may or may not be impaired.

Sleep disturbances, alterations in melatonin patterns and evidence from genetic studies point to disturbances in circadian rhythm in ASD. Evidence from studies on motoric timing indicated general differences in gait, muscle tone, and balance. Insights from studies on neural correlates consistently showed evidence that the cerebellum develops differently in people with ASD. In sum, converging evidence shows an alteration in timing across modalities, even more so with social stimuli, which lead us to expect impaired social timing abilities in ASD.

### *Social timing in ASD*

A literature review was carried out on 22 social timing studies in ASD, including 7 about intrapersonal timing skills and 15 about interpersonal timing.

It appears as though children tend to develop normally at first with subtle differences between TD children and those later diagnosed with ASD (Hedenbro & Tjus, 2007; Wan et al., 2012; Yirmiya et al., 2006). Studies were too sparse to pinpoint when the differences in social

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timing became more obvious but Hedenbro's study (2007) showed that by 9 months of age differences became more pronounced, and were obvious by 11 months according to Trevarthen and Daniel's study (2005).

In sum, both intrapersonal and interpersonal timing studies lead to overwhelming evidence of impaired or at least abnormal task performance in ASD compared to TD controls, including an impaired ability to synchronise with their interactive partner in people with or at risk for ASD.

### *Conclusion*

It seems plausible that timing deficits can explain many, if not all of the symptoms seen in ASD, as proposed by timing accounts of ASD. However, hypotheses are based on different approaches, and no unifying theory has been put forward yet. The consensus was that more research is required to explain gaps in knowledge in order to advance our understanding of this disorder. A paradigm to study social timing in ASD is required to overcome previous studies' limitations. Therefore, the next chapter will look at existing methods and techniques, evaluating them for their suitability in studying social timing ASD.

## 3 Studying social timing

### 3.1 Introduction

Chapter 2 highlighted that appropriate social timing in early interactions has far-reaching developmental consequences for social skills, communication and cognition. Interruptions to a child's development are linked to long-term adverse effects on social and communication skills. As found, both timing and social timing are impaired in ASD. Impairment severity depends on stimulus complexity and speed of presentation, and is most challenging when social stimuli are used. Knowledge gaps still exist and revealed a need for further investigation of social timing abilities in ASD, which may help to better understand the aetiology of ASD.

To investigate social timing in children with ASD, a research tool and method is needed. This chapter's objective is to select a method that minimises drawbacks while maximising benefits in investigating social timing in preschoolers with ASD.

This chapter begins with a brief overview over social timing methods. Next follows a critical evaluation of existing social timing studies in ASD that examines their merits and limitations. Monadic Phases, a micro-analytic method used with time-series analysis, stands out and is examined in detail. The chapter closes with a summary and conclusion (see Figure 3.1).

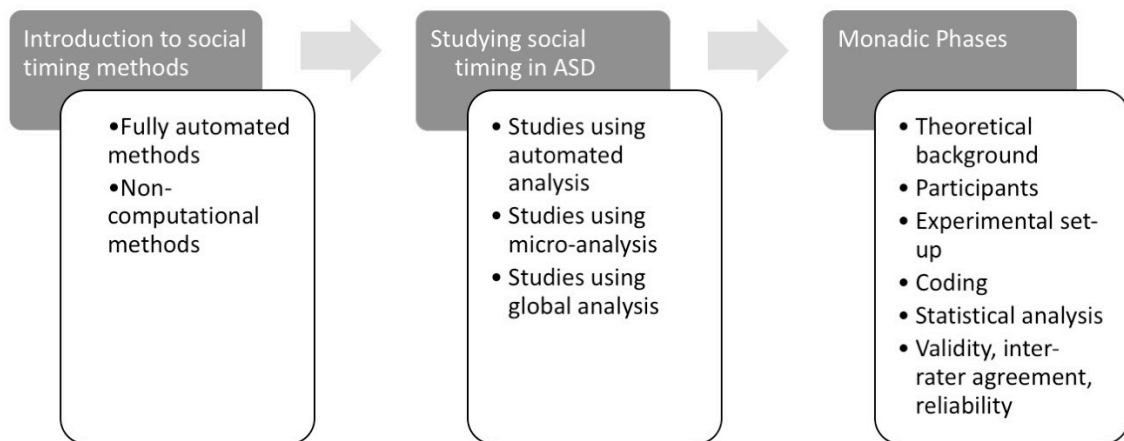


Figure 3.1 Chapter overview

## 3.2 Introduction to social timing methods

Before evaluating existing social timing methods in ASD, a brief overview over methods is supplied. Social timing methods fall into two broad categories: 1) fully automated methods and 2) non-computational techniques (Delaherche et al., 2012; see Table 3.1 below for an overview).

Table 3.1 Overview over social timing methods

Category	Process	Benefits	Drawbacks
Fully automated methods	Uses computer software and automated devices such as motion tracking gadgets and image-processing software	<ul style="list-style-type: none"> <li>• Fast</li> <li>• Efficient</li> <li>• Objective</li> <li>• Rating can be done on a detailed time scale</li> <li>• Interaction partners are coded separately</li> </ul>	<ul style="list-style-type: none"> <li>• Synchrony is measured as a mediating variable or predictor</li> <li>• Requires specialised equipment and software</li> <li>• Requires suitable video recordings (well-lit, both in view etc.)</li> </ul>
Non-computational methods - micro-analysis	Raters manually judge small units of behaviour, which are subsequently distilled into bigger units of behaviour	<ul style="list-style-type: none"> <li>• Synchrony as outcome variable</li> <li>• Allows use of home videos</li> <li>• Ratings on detailed time scale</li> <li>• Interaction partners coded separately</li> </ul>	<ul style="list-style-type: none"> <li>• Less subjective than global analysis</li> <li>• Labour-intensive</li> <li>• Trade-off between accuracy and practicality</li> </ul>
Non-computational methods - global analysis	Raters globally judge qualities such as 'interactive flow'	<ul style="list-style-type: none"> <li>• Synchrony as the outcome variable</li> <li>• Allows use of home video-recordings</li> </ul>	<ul style="list-style-type: none"> <li>• Interaction partners coded jointly</li> <li>• Subjective</li> <li>• Labour-intensive (but less so than in micro-analysis)</li> </ul>

### 3.2.1 Fully automated methods

Fully automated methods do not require raters to manually code behaviour of participants. Instead, computer software and/or specialised equipment is used. Computer software that carries out image-processing techniques designed to make judgements on physical proximity can be used to quantify synchrony. For example, this has been done to

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examine how synchronised two people move in therapy, which requires a video-recording with both people in clear view (Ramseyer & Tschacher, 2011). Software calculates based on differences between frames, to what extent people move together.

These methods lend themselves to study movement synchrony, adaptation in spoken language or turn-taking behaviours (Delaherche et al., 2012). For example, facial image analysis has been applied to mother-infant interaction, which revealed that eye constriction and smiling was loosely linked (Cohn, 2010). In another study with high risk and low risk children mother-infant interaction, including synchrony<sup>22</sup>, was analysed using 3D reconstruction (to overcome the problem of touching), which correlated well with measures of manual coding (Leclère et al., 2016).

In automated designs, synchrony as a variable is not the end goal; instead synchrony is used to predict an outcome variable, or to discriminate between conditions (Delaherche et al., 2012). An automated method may be used to measure the influence of movement synchrony on relationship quality.

### 3.2.2 Non-computational methods

Non-computational methods allow studying of intra- and interpersonal timing as the outcome variables. Such methods require raters to code or annotate while watching a video-recording or observing on-going behaviour. Coding is usually done on a computer, using specialised software such as Interact (Mangold, 2017).

Drawbacks of using non-computational methods are that it is labour intensive because it involves many steps to code videos and train raters (Delaherche et al., 2012). Further, it is not always clear when a behaviour starts and ends, or even which code fits a particular behaviour. Consequently, raters are often required to make a trade-off between accuracy and practicality. Finally, in micro-analysis, interaction partners are coded separately, which may obscure the dynamics that unfold during interaction (Delaherche et al., 2012). One major advantage, however, is that this method lends itself to the use of naturalistic video-recordings, such as home videos for analysis (Saint-Georges et al., 2011).

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<sup>22</sup> Synchrony was defined as the dynamic of partners' head distance and who contributed to changing head distance (Leclère et al., 2016).



Within non-computational methods there are two approaches; global perception and micro-analysis. Global analysis is one way to directly code for synchrony: raters judge simultaneous movements, temporal similarities, coordination and smoothness of interaction all at once. If the study demands closer examination of behavioural units and how they create dynamics during interaction, a micro-analytic approach is more suitable.

Micro-analysis involves coding each interaction partner separately before looking at interpersonal outcomes. Coding can be done on micro-units of behaviour (e.g. speech, body movements, facial expressions), interactive behaviours (e.g. smiling, turning away) or on functional states (e.g. attentiveness to other, body contact; Delaherche et al., 2012). Synchrony may then be deduced from co-varying behaviours.

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## 3.3 Studying social timing in ASD

The previous chapter gave an overview of the current state of knowledge about social timing abilities in ASD. In total, 15 studies were found that addressed social timing in an interactive setting in people with ASD (see 2.4.4 on *Retrieval of studies* for details). Six of these studies examined social timing abilities in parent-child dyadic interaction, which is congruent with the aim of this project.

Three of these studies used at risk for ASD samples (Quigley et al., 2016; Wan et al., 2012; Yirmiya et al., 2006), while two others utilised a case study design (Hedenbro & Tjus, 2007; Trevarthen & Daniel, 2005). Only one study used a group design with adolescents with ASD and a familiar and stranger adult to examine speech-pause timing (Feldstein et al., 1982).

Below these studies are evaluated for their method's values and limitations (see Table 3.2). Studies are divided into automated methods, micro-analysis and global analysis.

### 3.3.1 Studies using automated analysis

Feldstein et al. (1982) looked at speech-pause durations of dyadic naturalistic conversations of young adults with HFA. A computer programme was used to segment recordings into silence (= pauses) and noise (= speech), which were later analysed for their durations and whether interaction partners adapted to one another (i.e. synchronised the durations of speech and pauses). There were three types of dyads: 1) participant with HFA and his/her parent; 2) participant with HFA and experimenter and 3) parent of participant with HFA and experimenter. Each group of participants was compared within each dyad type for the average length of pauses and speech, showing that those dyads with a participant with HFA did not adapt the length of their speech and pauses to that of the other (i.e. they did not synchronise).

Quigley and colleagues (2016) looked at prosody<sup>23</sup> during interaction between mothers and their toddlers, who were at high and low risk for ASD. Naturalistic interactions were recorded for analysis when the infants were 12 and 18 months old. Overlapping and ambient noises were removed manually before automated pitch analysis was employed.

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<sup>23</sup> The pattern of stress and intonation in language.

A valuable contribution of this study is the follow up after 6 months, when the children were 18 months old, thereby showing the developmental trajectory of at risk versus low risk dyads. Drawbacks included that Quigley et al. (2016) did not establish whether any of the participating toddlers were later diagnosed with ASD. Furthermore, this study only focused on a single aspect of interactive behaviour, which limits its overall relevance within social timing studies. Finally, prosodic synchrony was inferred based on correlation of pitch ranges, rather than pitch along a time scale, the latter which would have enabled analysis of the dynamic of pitch behaviour between parent and child.

Table 3.2 Evaluation of social timing studies in ASD

Author(s)	Aspect	Sample	Method; Coding; Data analysis	Value	Limitations
Feldstein et al. 1982	Verbal synchrony	Three types of dyads: 1) Youths with HFA and their parents (age range 14-20 years; N=12) vs 2) youths with HFA and experimenter vs 3) Parents and experimenter (no demographic data given for parents and experimenter)	Speech-pause-analysis of adult-youth dyadic conversations; analysis compared interactions with both familiar and non-familiar adult (experimenter); automated speech-pause analysis	Youths with HFA were unable to synchronise their vocalisations and verbalisations with NT adult; thus, interpersonal verbal timing is adversely affected in ASD	Statistical analysis not a time-series analysis, thus it does not account for the fact that the data points measured over time may contain an autocorrelation that must be accounted for
Trevarthen & Daniel 2005	Pre-verbal synchrony	Monozygotic twin sisters (age = 11 months; N=2), Twin A was subsequently diagnosed with autism at age 18 months	Case study comparing twins using video-analysis of home videos (father playing with each infant); Micro-analysis of overt behaviours; Visual inspection of graphs	Evidence that infant with ASD showed a complete lack of synchronous interactive behaviour	Method unclear, no statistical analysis used

Yirmiya et al. 2006	Pre-verbal synchrony	Infants at risk (Sibs-A) (age=4 months; N=21) vs infants not at risk (Sibs-TD) (age=4 months; N=21)	Video-analysis of mother-infant play sessions, using Monadic Phases and TSA; Micro-analysis: Monadic Phases; Time-series analysis	Group study; sophisticated method and analysis	No long-term follow-up
Hedenbro & Tjus 2007	Emotional engagement and interactive flow	One girl later diagnosed with ASD vs TD peers (N=19), measurements at 3, 9, 18 and 48 months	Longitudinal case study; parent-child interaction; dyadic and triadic interactions; Global rating	Synchrony coded as yes/mostly/partly (allowing for nuances); measurements repeated over time allows following developmental trajectory	Temporal aspect not explicitly measured; synchrony assessed subjectively
Wan et al. 2012	Dyadic mutuality (including interactive flow)	Infants at risk for ASD (age range 6-10 months; N=45) vs siblings not at risk (N=47)	Video-analysis of unstructured parent-infant interaction; global rating	Strong positive correlation between sensitive, non-directive parenting and mutuality may help with future interventions and parental coaching.	Temporal aspect not explicitly measured; subjective, global ratings; measure may not be sensitive enough and/or groups did not differ enough based at risk status
Quigley et al. 2016	Prosodic synchrony	Mother-infant dyads; at risk for ASD (N=10) vs not at risk (N=9); measurements taken at age 12 and 18 months	Mother-infant 'conversations' analysed for prosody synchrony using correlation; automated analysis of pitch; correlations on pitch range to assess prosodic synchrony	Follow-up after 6 months, studying 1-1.5 year olds	Statistics are basic: pitch not analysed over time but rather correlation of pitch ranges were used to infer prosodic synchrony

### 3.3.2 Studies using micro-analysis

Trevarthen and Daniel (2005) conducted a case study of 11-month-old twins, one of which was later diagnosed with AD (Twin A). Home-videos of the twin's father playing with each twin in turn were analysed. Twin A showed poorer social skills when interacting with her father, wherein lies the greatest value of this study; that social timing difficulties were already present long before diagnosis. The total length of recordings that were analysed were 52 seconds long for Twin A and 65 seconds for Twin B. Tapes were time-coded to a resolution of 0.04 seconds, and analysis was carried out on the number of expressive behaviours over 160 ms, which made up the levels of interaction.

Replication of this study is difficult because the methods are described vaguely in the published paper. No statistical analysis was carried out, as comparisons between the twins were made on the basis of visual inspections of graphed representations.

In Yirmiya's study (2006), mother-infant interaction was analysed in 4-month old children at risk for ASD<sup>24</sup> (based on having a sibling with an ASD diagnosis) compared to children at low risk. Dyads were video-recorded during face-to-face pre-verbal conversations. Three minutes of overt behaviour was coded in 0.25 second time frames. Coded behaviour was averaged over 1 second intervals, and synthesised into interactive phases following the Monadic Phase coding scheme (Tronick et al., 1980; see 3.4.4 Coding of Monadic Phases for details). Time-series analysis was used to determine synchrony parameters, including level of synchrony, whether it was significant, time-lag to synchrony and who was leading the interaction (see 4.4.5 for details). Group comparisons were carried out to test whether there were differences in the presence and levels of synchrony between children at high and low risk for ASD.

The main contribution of this study lies in the strength of the methodology they used, which is clearly described and replicable. The method includes behavioural coding on a time scale, group comparison, and an appropriate statistical analysis.

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24 Yirmiya et al. (2006) reported that one participant was diagnosed with autism both at 24 and 36 months, and his exclusion from the analysis did not alter results. It is unclear, however, if all participants were followed up or not.

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### 3.3.3 Studies using global analysis

Hedenbro and Tjus (2007) followed 19 young children over four years and regularly recorded dyadic and triadic parent-child interaction (at 3, 9, 18 and 48 months). One of the participating girls was later diagnosed with ASD and served as the case study. Synchrony analysis was based on global ratings of emotional engagement and interactive flow ranging from 'yes', 'mostly', 'partly' to 'no'. This study gave valuable insight into the developmental trajectory of a child's dyadic and triadic interaction skills over time compared to her TD peers.

Wan and colleagues (2012) investigated dyadic mutuality in infants at high and low risk for ASD between 6 and 10 months of age. Dyadic mutuality is closely related to interpersonal social timing and includes interactive flow. Global ratings of dyadic mutuality were assigned to video-recordings of unstructured parent-infant interactions. Overall dyadic mutuality did not differ significantly ( $p = 0.85$ ) between the low risk and high risk group but was lower in the high-risk group. Mutuality correlated with sensitive responding and non-directiveness of parents, as well as infant attentiveness and positivity. The value of this study lies in providing information about modifiable factors (such as parental directiveness) that affect the level of dyadic mutuality, which may be useful for designing interventions (Wan et al., 2012).

An inherent drawback to using global ratings is that time is not measured as behaviours occurred. Instead they are merged into one subjective rating of how closely dyads (and triads in Hedenbro's study) followed each other's rhythms.

#### *Conclusion*

All of these studies contributed to the knowledge of interpersonal timing abilities in ASD and fill knowledge gaps about the developmental trajectories of children with or at risk for ASD, from as young as 3 months up to the ages of young adults.

At present, no generally accepted method for assessing timing in ASD during parent-child interaction exists (Delaherche et al., 2012), reflected by the differing approaches used in the above studies. The drawback of not having an established and verified method is that some or all of these paradigms might not have been sensitive enough to clearly distinguish differences in social timing abilities. Studying at risk groups possibly obscures a study's outcome because some participants in the high risk group will not actually be affected by ASD, and vice versa.

The most common limitations of the studies reviewed above, are vaguely described methods, use of inappropriate statistics, use of global ratings, case studies and use of at risk samples without follow-up. One study that did not suffer most of these limitations was carried out by Yirmiya et al. (2006). They used Monadic Phases with time-series analysis, which is described in detail in the following section.

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## 3.4 Monadic Phases

Social timing studies in ASD would benefit from further investigation using a paradigm that overcomes previous limitations. Ideally, this paradigm would allow quantification of cyclicity and synchrony parameters, thus enabling comparisons with previous studies of TD populations. Yirmiya et al. (2006) have done exactly that by using Monadic Phases (MP) and time-series analysis (Gottman, 1979; Tronick et al., 1980).

MP have frequently been used for studying synchrony in infants (Cohn & Tronick, 1987; Feldman, 2007a; Feldman, Greenbaum, Yirmiya, & Mayes, 1996; Field, Healy, & Goldstein, 1990; Lester et al., 1985; Tronick et al., 1980). An adaptation of MP was recently used with a sample of preschool-aged children with ASD (Venuti et al., 2017). Below MP methodology is explored in detail.

### 3.4.1 Theoretical background

Monadic Phases coding enables micro-analysis to examine infant-caregiver face-to-face interactions (Tronick et al., 1980). The word 'monadic' stems from the Greek words 'monad' meaning 'single' and 'unit' (Tronick et al., 1980). A 'monadic phase' is a basic meaningful unit made up of a combination of behaviours, for example, a combination of facial expression, body posture and vocalisation that convey meaning. The focus on behavioural units responds to the finding that single units of behaviour did not capture interaction adequately because individuals can substitute one behaviour for another while achieving the same communicative goal (Bakeman & Brown, 1977).

MP were based on the observation that face-to-face interactions between infants and mothers consisted of repetitive positive and negative cycles of attention and affect (Brazelton et al., 1974; Tronick et al., 1977). Interaction could be segmented into phases of disengagement, initiation, greetings, and play dialogue, which expressed the sequential flow of mother-infant 'conversations' from start to end. These findings suggested that interaction is a structured system regulated by units of meaningful behaviours produced by each interaction partner, and in coordination with her or him (Brazelton et al., 1974).



MP methodology allows researchers to extract the content and timing of interaction as it unfolds. Thereby drawing out the ongoing dynamics between two interaction partners and their contribution towards it. It allows plotting the fluctuations of cycling between positive and negative states, turn-taking and burst-pause rhythms, as well as synchrony analysis. Synchrony in this paradigm is defined as a match in the direction of change rather than a match of state. In other words, it measures to what extent a dyad is moving towards higher or lower involvement in coordination (Feldman, 2007b). If synchrony were defined as a match, it would ignore the subtleties contained within lead-lag structures, which have been shown to differentiate developmental outcomes (Feldman et al., 1999). It further acknowledges that mothers usually follow their infant at 3 months of age (Lester et al., 1985), while mutual synchrony typically develops in the second half of the first year as the child's interaction skills mature (Feldman et al., 1999).

Methods and statistical analysis of MPs have become increasingly sophisticated since they were first developed. MPs were used to analyse interactions of different populations, which is one of the major advantages because it enables straightforward comparisons across studies. The following paragraphs look at methodological aspects from previous MP studies: participants, experimental set-up, coding, statistical analysis, reliability and validity.

### 3.4.2 Participants of MP studies

The first studies of mother-infant dyadic interaction (Brazelton et al., 1974; Cohn & Tronick, 1988) disregarded clinical characteristics of participants, so that the mother's and child's health and developmental status is unknown. Later studies specifically examined interactions in samples with health conditions that may adversely affect development. To date, most empirical attention has been paid to premature infants (e.g. Feldman & Eidelman, 2004; 2007; Lester et al., 1985) and depressed mothers (e.g. Feldman et al., 2009; Field et al., 1990). Other studies explored differences in dyadic interaction with fathers versus mothers in full-term (Feldman, 2003) and pre-term infants (Feldman & Eidelman, 2007). MP coding has also been used to investigate the developmental trajectory of interactional synchrony at 3

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and 9 months (Feldman, 2007a). Most recently, an adaptation<sup>25</sup> of MP was used to investigate social timing in 4 to 6-year-old children with ASD (Venuti et al., 2017).

### 3.4.3 Experimental set-up

Interactions were recorded in a laboratory (Matias, Cohn, & Ross, 1989; Weinberg & Tronick, 1994) or at home (Feldman, 2006), when infants were fed and rested (Feldman et al., 1999). Mother and infant were facing each other; the infant was placed in an infant seat mounted on a table, while the mother was seated on an adjustable chair so that both their faces were at an equal height. A camera was set up for each person, so that both faces were filmed concurrently. The cameras were controlled by a technician in an adjacent room. Afterwards, both videos were combined into a split-screen image so that each face was visible (Cohn & Tronick, 1988; Feldman et al., 1999). Alternatively, a mirror placed strategically behind the child's head was used in a single camera set-up (Feldman, 2003).

Typically, parents were instructed to play with their infant as normal for 5 to 10 minutes. Some parents used toys during interaction and the researchers did not wish to interfere (Feldman, 2003; Feldman et al., 1999). A subsequent analysis did not find differences between interactions with and without toys (Feldman, 2003).

### 3.4.4 Coding of Monadic Phases

MP are appropriately analysed using time-series analysis (see 3.4.5 for details or Appendix C), which requires at least 100 observations (Gottman & Ringland, 1981). Typically two or 3 minutes out of 5 to 10 minutes<sup>26</sup> of recorded interaction are analysed (Feldman, 2007a). Each second of interaction results in one observation, so that two minutes of interaction result in 120 observations, and 3 minutes in 180 observations.

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25 Several minor adaptations were made in previous studies, for example, adult phases were changed to avert, object attend, social attend, object play and social play, and protest was added as an infant phase (Feldman, 2003; Yirmiya et al., 2006).

26 Feldman noted that they first piloted coding entire 10 minute sessions but generally noticed that infants became increasingly fussy and tired after 5 minutes. Thus, minutes 2, 3 and 4 were coded for the entire sample, as they had been previously found to be the period when the child was most engaged (Feldman et al., 1999).

First, expressive behaviours are coded. Each recording is viewed several times, and each time only one category is coded on a 0.25 sec time frame. All categories (except vocalisations) are viewed in slow motion. Vocalisations are viewed at normal speed. The following expressive behaviours are coded:

- vocalisations
- direction of gaze
- head orientation
- facial expression
- specific handling of the infant (adult only)

After coding of expressive behaviours, they are averaged within 1 second time periods. While this may seem gross, studies using this approach have been able to make predictions about long-term outcomes based on minor variations in the synchrony parameters (Feldman et al., 1999).

In the next step, predefined combinations of expressive behaviours are distilled into different phases (see Appendix B). Phases describe the level of engagement during parent-infant interaction. There are six phases describing infant behaviour and seven describing adult behaviour:

- protest (infant)/avoid (adult)
- avert
- monitor
- set
- play
- talk
- elicit (adult only)

As a result, each dyadic partner (i.e. infant and parent) is assigned a phase code for each second of interaction, so that two timelines can be plotted. Statistical analysis is carried out on these timelines of phases plotted against time.

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### 3.4.5 Statistical analysis of Monadic Phases

Time-series analysis (TSA; see Appendix C) was first used to study biological rhythms, like heart rate and sleep (Jebb, Tay, Wang, & Huang, 2015). Before then, behavioural scientists largely neglected the use of TSA (Brazelton et al., 1974; Jaffe et al., 2001). It was Gottman (1979) who applied TSA to social interaction, including mother-infant interaction. He argued that TSA is the appropriate choice to study interactions as it accommodates each person's own behaviour (autocorrelation) as well as each person's reactions to the other's behaviour (cross-correlation), while considering the interrelation between time-points (Gottman, 1979; Gottman & Ringland, 1981). Furthermore, TSA allows examination of lead-lag relationships, which addresses the question of who is leading and who is following the interaction (Gottman, 1979).

There are several methods with time-series analysis, of interest here are spectral analysis and auto-regressive moving averages (ARIMA). Spectral analysis focuses on periodic processes, whereas ARIMA modelling, is theoretically equal yet allows examination of time-series regardless of whether they are periodic or stochastic, thus being superior (Cohn & Tronick, 1988).

### 3.4.6 Validity, inter-rater agreement and reliability

A further advantage of Monadic Phase coding is, that this method has been scrutinised. For example, it was compared to the Maximally Discriminative Facial Movement Coding System (MAX; Izard, 1979), and found to correlate strongly (Matias et al., 1989).

An aspect of MP that has sparked controversy is the scalar nature of the phases. Scales are assumed to be equally spaced, and their use facilitates statistical analysis. Scaling phases was questioned and whether they properly reflect their significance during interaction (Fogel, 1988). Instead of scaling phases, the use of nominal or discrete categories was proposed (Fogel, 1988). Cohn and Tronick (1988) defended their work by arguing that scaling is useful for studying the temporal properties of interaction including cyclicity analysis.

Inter-rater agreement, the agreement of occurrence of a behaviour within a .5 second time window between two raters, estimated by the kappa coefficient was found to be .71 (Matias et al., 1989). Inter-rater reliability assesses both raters scores for the percentage of

time an expression occurred, and lay between .75 and .99 (Matias et al., 1989). Satisfactory reliability of above .80 was also achieved in other studies (Feldman, 2003; 2007a; Yirmiya et al., 2006).

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## 3.5 Summary and conclusion

This chapter's objective was to review social timing methods to select one to study social timing, including interactional synchrony, in preschoolers with ASD. The reader was introduced to the broad categories of social timing studies followed by an evaluation of existing studies that examined interactional synchrony in a dyadic interactive setting. Drawbacks revealed desirable criteria, and Yirmiya's study (2006) positively stood out due to their methodology of Monadic Phase coding and time-series analysis. MP methodology was looked at in detail.

### *Conclusion*

MP coding appears to be a suitable micro-analytic method for a number of reasons. Firstly, its frequent use means that comparison data is available for populations of different ages, health conditions, and sexes (e.g. Cohn & Tronick, 1987; Feldman, 2003; Lester et al., 1985). Secondly, this method was established several decades ago, so that validity, reliability, and statistical analysis have been tried and tested. Its recent use by Venuti and colleagues (2017) attests to it still being relevant and that its use is possible in older children with ASD. Thus, MP is concluded to be the appropriate method to use for the purpose of this study. An adaptation may be necessary. Next follows the methods chapter, which shows why and how MP were adapted and how the method was designed to address this study's research aim.

## 4 Methods

### 4.1 Introduction

Considering the drawbacks of existing social timing studies in ASD, it was decided that Monadic Phase methodology could serve in answering this study's research aim. Monadic Phases were shown to be well-established in the field of parent-child interaction studies. The main advantages of this method are easy replicability and comparability to previous MP studies, use of advanced statistical methods, rigorous testing, and the ability to use a group design.

The objective of this chapter is to report how Monadic Phase was used to study aspects of social timing in preschoolers with ASD. The chapter begins with a methodological discussion justifying the choices that were made regarding sample, research tool and data analysis. Next, comes a description of how Monadic Phases were adapted for this study. Finally, the method used in this study is presented. The chapter ends with a summary, see Figure 4.1.

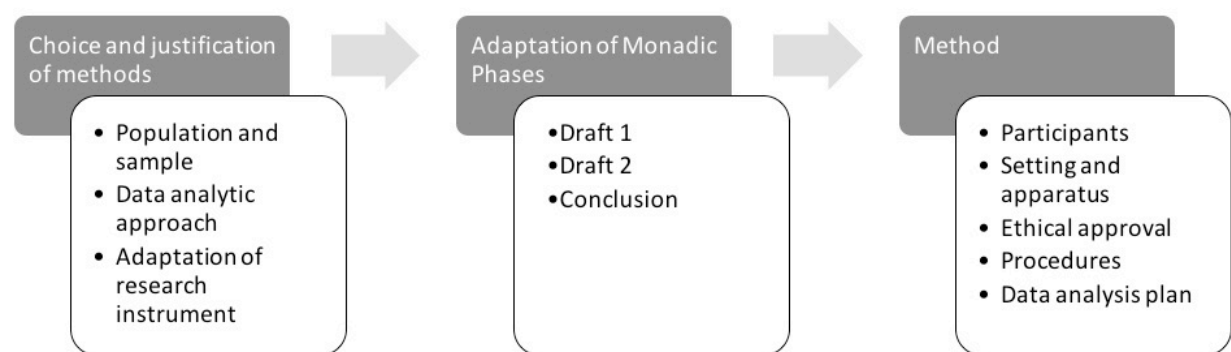


Figure 4.1 Chapter overview

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## 4.2 Choice and justification of methods

The study's aim was to investigate social timing in preschool children with ASD, which meant that many choices had already been made with regards to sample and procedures. Below follows a discussion for each component including alternatives.

### 4.2.1 Population and sample

As part of a larger investigation about timing in ASD conducted by Dr Dawn Wimpory, this study sought to examine social timing in preschoolers with ASD who received Musical Interaction Therapy for which they were regularly filmed (see 4.4.1 and Table 4.6 for details on the participants; Appendix D for details on *Musical Interaction Therapy*). These video-recordings supplied the raw data for this study, meaning that a naturalistic approach with a convenience sample was used. The recordings were produced for clinical monitoring and research purposes, and were readily available when parents consented.

Advantages of using a convenience sample were that minimal burden was placed on participants, and costs were kept to a minimum, while enabling to study a group that has not yet been studied in this way before. Furthermore, for each child there were several recordings to choose from. This allowed choosing recordings in which the child was willing to engage, which was not always the case, for instance when they had had a 'bad day'.

On the other hand, this set-up presented with its own challenges and limitations. Research design variables could not be controlled as tightly as in a laboratory study, and data was likely confounded by intervention effects. The greatest challenge was, that these children differed in a number of ways from those in studies using Monadic Phase coding. They were much older than the infants tested in MP studies, who were typically 3, 4 or 9 months old, whereas the children of this study were between 2 and 8 years old. This means they were not strapped into an infant seat but instead moved around freely and playfully, sometimes running, or jumping, or cuddling their parents. Children at this age and their caregivers have more possibilities regarding their interactive and communicative behaviour.

Furthermore, using recordings made for clinical purposes first, meant that both interaction partners were not always perfectly within camera view, thus contributing to



missing data. Lastly, verbal abilities of these children varied; most were non-verbal or only vocalised, verbalised or offered the occasional echoed utterance.

A final note on the participating caregivers in this study is warranted. The present study included mothers, fathers and, in two cases, teaching assistants. Traditionally, most social timing research has been conducted with mothers, and only a few studies included fathers (e.g. Feldman, 2003). Other familiar caregivers (e.g. grandparents, teaching assistants) have not been studied, yet the literature indicates differences when interacting with a stranger versus familiar interaction partner (Feldstein et al., 1982; Oberman et al., 2009). Thus, caution is warranted when interpreting the results.

#### 4.2.2 Data analytic approach

Different methods to study social timing were introduced in the previous chapter (see 3.2 *Introduction to social timing methods*). Automated analysis was ruled out because it requires a specific set-up and equipment. Out of non-computational methods, micro-analysis was preferred over a global approach because it is less subjective. Monadic Phases were singled out as a well-established method that would allow to fulfil the aim of this thesis (see 3.5 for more details on why it was chosen).

As several recordings were available for each child, recordings were chosen so that interacting adult and length of time between recordings was kept constant if possible. Suitability coding was carried out to choose a clip from each video-recording for micro-analysis, to ensure the child's active social engagement and appropriate visual quality (see 4.4.5 for details and Appendix E for the coding protocol).

Time-series analysis (TSA) has been deemed the appropriate statistical choice for social timing studies using micro-analysis (Gottman, 1979; see Appendix C for details). Within TSA, one approach is to use auto-regressive moving average (ARIMA) modelling, which has more advantages than spectral analysis (Tabachnick & Fidell, 2005; see 3.4.5 for the reasons).

#### 4.2.3 Adaptation of research instrument

Monadic Phases were identified as a suitable method (see 3.4). Due to the differences between sample and study set-up (see section 4.4.4 for *Procedures*; 4.2.1 and 4.4.1 for *Participants*) compared to laboratory studies with infants, an adaptation was needed.

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Through trial and error, an adaptation was drawn up that felt suitable for this project (see 4.3 for details on Adaptation of Monadic Phases).

## 4.3 Adaptation of Monadic Phases

Monadic Phases were chosen for the present study (see 3.4). The necessity of adaptations was justified above (see 4.2.3). Initial changes came about by watching the video-recordings used in this study and observing, together with a second person<sup>27</sup>, what was missing, inappropriate or insufficient. Changes were discussed with Dr Dawn Wimpory (supervisor for this thesis and Principal Investigator in this investigation), who also contributed suggestions to change phase names to reflect their concept more accurately. The following subsections outline the evolution of the adaptations and their two drafts. (see Table 4.1 below for an overview; see Appendix B for the original Monadic Phase coding scheme and Appendix E for the coding protocol).

Table 4.1 Overview over draft changes: Monadic Phases to Mini MP2.0

Original MP	Changes	Draft 1	Changes	Draft 2
Vocalisation	None	Vocalisation	None	Vocalisation
Gaze	None	Gaze	None	Gaze
Head Orientation	None	Head Orientation	Redundant	(deleted)
Facial Expression	None	Facial Expression	Redundant	(deleted)
Body positions	Changed to new category	Actions	None	Actions
Specific handling of the infant (mother only)	Redundant	(deleted)	None	-
Singles codes within each behavioural category	Too many codes; simplified	Codes can be positive, neutral or negative	None	-
'Talk'	Re-named to better reflect concept	'Converse'	None	'Converse'
'Play'	Re-named to better reflect concept	'Playful Interaction'	None	'Playful Interaction'
'Monitor'	None	'Monitor'	None	Monitor
'Elicit' (mother only)	Re-named to better reflect concept; includes now child and adult	'Initiate'	Replaced	'Passive Interaction'
'Avert'	Redundant	(deleted)	None	-
'Avoid'	None	'Avoid'	None	'Avoid'

<sup>27</sup> A former research intern.

### 4.3.1 Draft 1

As a first step, I looked at all existing behaviour codes from the MP coding scheme (Tronick, Als, & Brazelton 1980) and considered whether there were redundant and missing codes based on the interaction behaviour I saw in the video-recordings included in this study (see Table 4.1 above for an overview over all behavioural code changes). For example, due to the nature of this study's set-up and participants, a category describing movement was needed. It was named 'actions' and it includes activities such as running around, reaching for the adult and so on to replace the code 'body positions'.

Secondly, in the original MP coding scheme there are a great number of behaviour codes in each category; 13 alone describe the infant's facial expression. All these single codes for each behavioural category were condensed and coded as either positive, neutral or negative, thereby greatly reducing the cognitive load for the coder. Examples were given to define what constitutes a positive, neutral or negative vocalisation, gaze and so on (see Table 4.2 below).

Table 4.2 Behavioural categories and codes

Behavioural category	Code	Examples
Vocalisation	++	Talk; directed speech, words, babble, repeated positive sounds, singing; must be non-echoed
	+	Laugh; laughter, giggles, coos, squeals
	o	None, isolated sound, word, grunt, non-directed speech, echoed speech
	-	Fuss, cry, scream
Facial expressions	+	Bright, (broad) smile, coo face, kiss face
	o	Puzzled, questioning, thumb-sucking, yawn, eyes closed, tired, plain
	-	Grimace, frown, cry face, angry, upset
Gaze	+	Towards; directed towards face of other or following him/her with gaze
	-	Away; looking away from other, eyes closed or disengaged
Head orientation	+	Towards other; nuzzling, nodding, head frontal, part side or cocked (in relation to other)
	o	Neutral; head complete side
	-	Away; head facing away from other
Actions	+	Active; reaching for the other (e.g. using hand, foot, toy), following, cuddling, tickling, clapping
	o	Sit and wait; passive but observant of the other
	-	Away; disengaged, moving or turning away; or still but clearly disengaged

Thirdly, the number of phases was amended so that there are the same phases for child and adult (see Table 4.3 below). In the original MP, there was an extra category for the adult

('elicit'), which was changed to 'initiate', which applies to child and adult. Likewise, 'avert' and 'avoid' was merged into a single phase: 'avoid'. This was done because the current sample did not show protesting behaviour when disengaging, as is required in 'avert'. Instead, their disengagement behaviour was of a passive nature. 'Monitor' remained the same. 'Set' was deleted because it was unclear what exactly constituted this phase. 'Play' was renamed as 'playful interaction' and includes rough-and-tumble play and cuddling. 'Talk' was renamed to 'converse' and includes non-verbal and verbal play. 'Converse' is conceptualised as more sophisticated than 'playful interaction'.

Table 4.3 Phases

Phases	Vocalisation	Gaze	Action	Facial expression	Head orientation
Converse	++*	+	+ o	+	+
Playful Interaction	+ o	+	+*	+	+
Initiate	(+) o -	+	(+) o	+ o -	+ o
Monitor	o	+*	o	+ o -	+ o
Avoid	o -	-*	-	o -	o -

*Note. \* required; () possible only when no other phase fits*

### 4.3.2 Draft 2: Monadic Phases 2.0

After trialling Monadic Phases 2.0, it was decided that further changes needed to be made to reduce coding time and facilitate the process.

Firstly, the number of behavioural codes was reduced. 'Facial expression' and 'head orientation' were difficult to code on the present data because the video-recordings rarely showed both interaction partner's face clearly enough to code them because interactions were faster and more active. Coding 'head orientation' made sense in the original MP coding scheme because infants were sitting in an infant seat, and their head orientation served as a marker of engagement. However, in this set-up the children moved around freely, engaging in various forms of play, including rough-and-tumble play with the adult, and so that head orientation lost its clarity as a signal. It became apparent, that the crucial information for the

phases was contained in the following behavioural categories: 'vocalisations', 'gaze' and 'actions', see Table 4.4.

Table 4.4 MP2.0: Behavioural categories and codes

Behavioural category	Code	Examples
Vocalisation	++	Directed speech, words, babble, repeated positive sounds, singing; must be non-echoed
	+	Laughter, giggles, coos, squeals
	o	None, isolated sound, word, grunt, non-directed speech, echoed speech
	-	Fuss, cry, scream
Gaze	+	Directed towards face of other or following him/her with gaze
	-	Looking away from other, eyes closed or disengaged
Action	++	Symbolic: gestures (not including touching, children only)
	+	Reaching for the other (e.g. using hand, foot, toy), following, cuddling, tickling, clapping
	o	Passive but observant of the other
	-	Disengaged, moving or turning away; or still but clearly disengaged

The phases were almost all maintained as above and defined based on these three behavioural categories. 'Initiate' was replaced by 'passive interaction'. I reasoned that it is actually difficult to define an initiation based on behavioural elements. It makes more sense to look at a plotted time-series and infer when an initiation happened (i.e. when a person goes from passively observing the other to speaking in order to engage him or her).

'Passive interaction' was borne out of the need to describe frequently observed interactive behaviour that may be specific to children with ASD which is to follow along with the adult. During 'passive interaction' the other neither signals specific communicative intent, nor shows avoidance. For instance, some of the children enjoy walking and holding hands with their parent. This is typically initiated by the parent, and the child may go along with it and enjoy it. Another example is being tickled, which most children seem to enjoy. As soon as they gaze towards their parent's face, it would be coded as 'playful interaction', as they are actively communicating their enjoyment to the parent (unless they appear to be withdrawing from the interaction). For an overview over how behavioural codes are organised into phases, see Table 4.5 below.

Table 4.5 MP2.0: Phases

Phases	Vocalisation	Gaze	Action
Converse	++ (- if communicative)	+ (-)	++, + o (-)
Playful Interaction	+ o	+	+*
Passive Interaction	+ o	-	+
Monitor	+ o (-)	+*	o (-)
Avoid	o - (+)	-*	o -

*Note. \* required; () possible only when no other phase fits*

### 4.3.3 Conclusion on Monadic Phase adaptation

Several adaptations were made to the original Monadic Phases (Tronick et al., 1980) to suit this study's sample. The greatest changes related to accommodating more mature motoric capacities and vocalisations/verbalisation that are expected in preschoolers as opposed to young infants. Further changes were made to adjust to the differing study set-up. The original MP were designed for a controlled laboratory study and video-recordings that captured every single facial expression. In contrast, the present study was naturalistic and observational, showing free play, which often impeded a clear view of the participants' faces. Furthermore, the increased age of the children and their free play meant that the pace of the interaction was accelerated compared to original MP studies. Many of the children enjoy fast-paced activities such as running, which made coding subtle behaviours more difficult. The adaptation therefore needed to serve both fast-paced activities and slower, more intimate interactions.

Amendments also needed to accommodate the specific nature of interaction of children with ASD. For example, 'avert' (avoiding by physically or vocally protesting) was discarded because it was not observed in the data, instead young children with ASD appeared to simply disengage without protest. The observed interactive expressions varied between avoidant passivity, neutral passivity and positive involvement including playful and conversational behaviours. Coding of the data was carried out using Monadic Phases 2.0. The coding protocol can be found in Appendix E.

## 4.4 Method

### 4.4.1 Participants

We recruited 16 dyads, which were children and their caregivers, who received or were receiving Musical Interaction Therapy in, Gwynedd and Anglesey, Wales, UK (see Table 4.6 below). Fourteen children (male  $N = 12$ ) between 2 and 8 years at first analysed video-recording ( $M = 4.27$ ,  $SD = 1.53$ ) and their caregivers participated in this study. Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989) scores for the children<sup>28</sup> ranged from 8-24 ( $M = 17.73$ ,  $SD = 5.27$ ). The interacting caregiver was usually the child's mother ( $N = 10$ ) but fathers ( $N = 2$ ), and teaching assistants ( $N = 2$ ) also participated.

Table 4.6 Demographic data of participants

Ppt	Age (months) at T1	Age (months) at T3	Sex	ADOS	Age at ADOS	Verbal	Learning disability	Adult
1	60	72	m	n/a	n/a	yes	n/a	TA
2	54	76	m	n/a	n/a	no	n/a	M
3	52	70	m	13	3	yes	mild	M, TA
4	99	112	m	n/a	n/a	no	n/a	M
5	46	48	m	21	3	yes	n/a	M
6	46	48	m	23	3	yes	mild	M
7	69	73	m	19	4	yes	moderate	M
8	64	69	m	19	3	yes	no	M
9	53	55	m	8	n/a	yes	no	M
10	29	36	f	15	4	yes	mild	M, F
11	41	60	m	12	n/a	yes	no	F
12	32	35	m	24	2	no	n/a	M
13	35	37	m	17+	2	no	n/a	M
14	38	39	f	24	2	no	mild	M

*Note.* Ppt = participant number; m = male; f = female; TA = teaching assistant; M = mother; F = father.

Inclusion criteria were that participating children received Musical Interaction Therapy (MIT, Wimpory, Chadwick & Nash, 1995; see Appendix D) in North West Wales, UK. Dyads with less than three video-recordings were excluded. A learning disability was not grounds for exclusion. Verbal ability differed between children; some were completely non-verbal, while

<sup>28</sup> Based on 11 available scores.



others were verbal. A small minority was only mildly affected and verbal. This study included both Welsh and English speakers because the intervention took place in North West Wales, where many people speak Welsh.

#### 4.4.2 Setting and apparatus

Each child received MIT (Wimpory et al., 1995) in a local community setting close to their homes, such as a GPs clinic, a school or at home. For example, one setting was a soft play room in a school, consisting of a soft 'playground' with large foam cushions. Normally a child's sessions were all held in the same setting. Video-recordings were carried out by an assistant psychologist, using a small hand-held video camera.

Video-recordings were coded with Interact (Mangold, 2017) used with a Windows computer supplied by Bangor University. That data was analysed with IBM SPSS Statistics for Macintosh, Version 24 (IBM Corp., 2016).

#### 4.4.3 Ethical approval

The study was approved by the Bangor University Ethical Committee and NHS R&D and REC committees as required when studying a patient group through their health care provider. The North Wales Research Ethics Committee - West approved the application for this study on 27 June 2013. Approval from the R&D Internal Review Panel - West was received on 17 July 2013.

#### 4.4.4 Procedures

The following paragraphs inform about the clinical and research procedure and the study design.

##### *Clinical procedure*

Cognitive and ADOS (Lord et al., 1989) assessments were used to diagnose children with ASD. If indicated, patients were placed on a waiting list for Musical Interaction Therapy (MIT, Wimpory et al., 1995; see Appendix D for more detail). Each MIT session took about 30 to 45 minutes and was provided once or twice a week for up to 2 years, with occasional video-recording for clinical supervision and assessments. In addition, up to 10 minutes of

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interaction without music were filmed on the same day periodically for research and clinical monitoring purposes. Video-recording was carried out by the assistant psychologist who regularly supervised MIT sessions.

Data of the length of MIT intervention was not available, however, the length between the first and last analysed session is indicative of time between sessions and ranged from 1 to 22 months ( $M = 8$  months,  $SD = 7.3$  months).

#### *Research procedure*

Parents of children who received MIT were invited by their clinical psychologist to participate in the present study. Participation meant consenting to having their video-recordings analysed for research and to allow the research team access to participant's clinical diagnoses, ADOS scores and session notes. No other assessments were required of participants. Participants did not receive any financial rewards or other benefits for consenting, nor penalties for not consenting. All consent forms and study information sheets were supplied in English and Welsh.

#### *Design*

This was an observational research procedure; data consisted of routine video-recordings made during Musical Interaction Therapy sessions. All children received the same treatment of MIT. To compare interactions with musical support ('Music') versus without, an additional 10 minutes of music were filmed without music ('Interaction'). This was done so that each child could serve as his or her own control. For each child, at least three recordings of Music and Interaction, recorded on the same day, were analysed.

### 4.4.5 Data analysis plan

The following paragraphs report on data selection, application of time-series analysis and subsequent statistical data analysis. Refer to Appendix C for details on TSA theory and application in practice.

#### *Data and clip selection*

For each dyad, there were three or more recordings of Interaction and Music from three different dates. In cases where several recordings were available, recordings were

chosen based on the following criteria: firstly, that the same adult was interacting with the child when possible. Secondly, recordings were chosen so that the time span between them was roughly equal for each dyad.

Each video-recording was between several minutes to 40 minutes long. Micro-analysis of social timing requires both active social engagement and appropriate visual quality (i.e. both dyadic partners must be visible).

Therefore, 2-minute segments<sup>29</sup> were chosen that consisted of appropriate interaction engagement and video-quality. Sequences were chosen by coding each entire video-recording with a 'suitability' code (see coding protocol in Appendix E). Each clip was viewed at 1.5 speed initially, and coded using the following mutually exclusive categories:

- 1 = good interaction (i.e. both were highly engaged) and suitable video quality;
- 2 = suitable (minimum requirement that both child and adult were in view);
- 3 = unsuitable (unable to see either child or adult or both)

The 2-minute sequence that contained the most '1' and the least '3' codes were chosen for micro-analysis.

A second rater coded just over half of all suitability ratings (54%). A Pearson product-moment correlation coefficient was computed to assess the relationship between both raters' agreement on all interaction scores ('good interaction', 'suitable' and 'unsuitable'). For both Interaction and Music, a one-way repeated measures analysis of variance (RM ANOVA) was used to evaluate whether there was change in dyads' interaction scores when measured at Time 1, Time 2 and Time 3. To compare Interaction and Music, a paired t-test was carried out to test whether each participant's suitability score average differed with and without music.

#### *Time-series analysis for cyclicity and synchrony*

- The raw data from the coding programme was adjusted before it could be used with the statistical programme (IBM SPSS Statistics for Macintosh, Version 24, 2016). Every second needs a data entry, resulting in 120 entries for the 2 minutes of coded interaction for each time-series (one for the child and one for the adult). Refer to Appendix C Time-series analysis for details, examples and syntax, see Figure 4.2 below for an overview over TSA procedure.

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29 The length of 2 minutes was deemed appropriate (Cohn & Tronick, 1988).

- Stationarity is an assumption that needs to be met before carrying out TSA. Therefore, the first step ascertained whether each time-series was stationary or not, which was done by visually inspecting the auto-correlation function (ACF) plot for its decay patterns. No decay indicated non-stationarity and required differencing. In the case where the child's time-series was stationary, and the adult's time-series was non-stationary, only the non-stationary time-series was differenced (Tabachnick & Fidell, 2005).
- The partial auto-correlation function (PACF) plot was inspected for cyclicity. The number of significant peaks at the beginning of the plot determined what kind of AR process a time-series is governed by (AR1 = first-order cyclicity, AR2 = second-order cyclicity). If the first peak is significant it is an AR1 process; if the first two peaks are significant it is an AR2 process and so on. The absence of significant peaks means that no cyclicity was present.

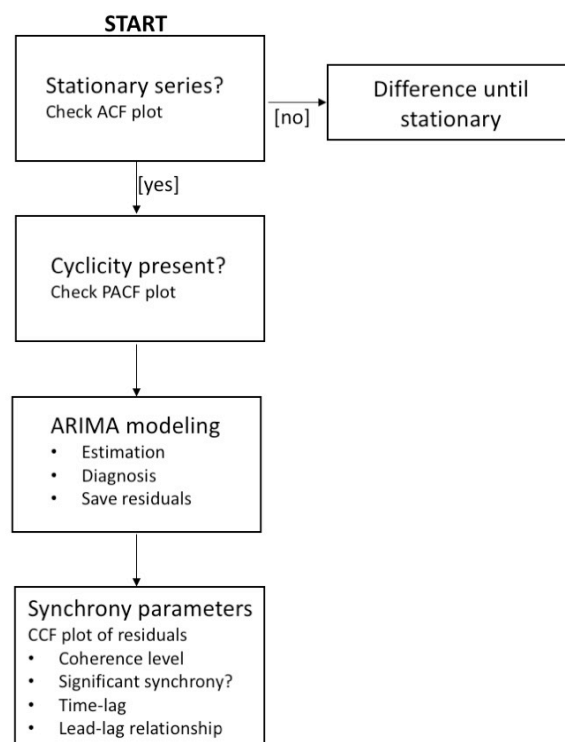


Figure 4.2 Time-series analysis flowchart

- ARIMA modelling was carried out for each time-series (see Appendix C for details). ARIMA parameters were estimated manually and the error residuals saved.
- Synchrony parameters were computed based on the Cross-Correlation Function (CCF) of the error residuals (see Table 4.7 below). Coherence levels were indicated by the

largest peak on the CCF plot. If the largest peak reached significance ( $p < .05$ ), synchrony was present.

- If time-series were significantly synchronous, time-lag to synchrony was identified. It indicates how long a dyad took to achieve synchrony. The first significant peak with the largest cross-correlation equals the time-lag to synchrony.
- In synchronous time-series lead-lag relationships were established based on whether lags were positive, negative or both on the CCF plot.

Table 4.7 Synchrony parameters

Coherence	Time-lag to synchrony	Lead-lag relationships
Indicated by the largest peak on the CCF graph; shows how closely the dyadic interaction matches based on the direction of change of phases.	Indicates how long a dyad took to achieve synchrony. The first significant peak with the largest cross-correlation indicates the time-lag to synchrony.	Based on whether the significant peaks are positive or negative or both. Positive peaks mean that the child was leading, the adult following. Negative peaks mean that the adult was leading and the child following. The presence of both positive and negative peaks mean that mutual synchrony was present.

#### *Subsequent data analysis*

- Cyclicity: a McNemar test was conducted to determine whether cyclicity was more often present during Music than Interaction.
- Synchrony: for both Interaction and Music, a RM ANOVA was conducted to test whether coherence scores changed over time.
- For both Interaction and Music, it was tested whether suitability scores and coherence values correlated.
- To test whether Music was associated with higher coherence and whether time played a role in this, a two-way repeated measures ANOVA was conducted to compare the main effects of the two independent variables (time, condition) and their interaction effect on dyad's coherence scores. Time consisted of three levels (Time 1, Time 2 and Time 3) and condition included two levels (Music and Interaction).
- To test whether synchrony was more frequently present in Music versus Interaction, a McNemar test was conducted.

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## 4.5 Summary

The objective of this chapter was to justify and present the methodology used for this study. In order to learn more about social timing abilities in young children with ASD, an observational design was chosen that compared interaction with and without music. Readily available video-recordings made for clinical monitoring purposes were used for analysis.

Participants ( $N = 14$ ) were made up of parent-child dyads who received Musical Interaction Therapy in North Wales, UK. Video-recordings of these dyads showing them engaging in free play were micro-analysed using coding software. The coding scheme to quantify interaction behaviour over time was adapted from Monadic Phase coding to suit the present study's population and set-up. Behaviour was coded separately for each dyad, and for each interaction partner. Data was analysed using time-series analysis that allows establishing parameters of intra- and interpersonal timing. The next chapter presents this study's findings.

# 5 Results

## 5.1 Introduction

The previous chapter presented the methods used in this study. Interactions were video-recorded and a 2-minute sequence of good engagement was coded using an adapted version of Monadic Phases to describe the level of involvement of each interaction partner. Time-series analysis was applied to the resulting data followed by paired-group tests and ANOVAs to answer the research questions.

The results are presented in this chapter. Preliminary analyses are presented first and include descriptive statistics of suitability scores and stationarity (an assumption that must be met before conducting time-series analysis). Results pertaining to cyclicity and synchrony performance during interaction with and without music follow. The chapter concludes with a summary. The findings are discussed in the next chapter, see Figure 5.1.

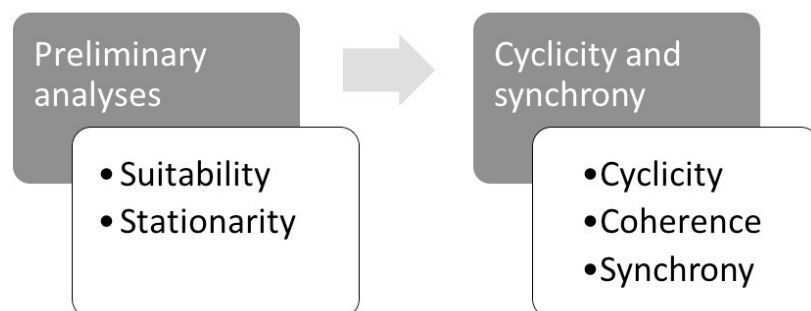


Figure 5.1 Chapter overview

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## 5.2 Preliminary analyses

### 5.2.1 Suitability

Suitability scores served as an indication of the child's willingness to interact and video-quality (i.e. whether both interaction partners were in view). While the latter may seem irrelevant to the former, most of the time video-quality was compromised exactly when the child disengaged, for example, when he withdrew from interaction by running away from his caregiver.

#### *Inter-rater agreement*

A second rater coded half of all suitability ratings (54%). A Pearson product-moment correlation coefficient was computed to assess the relationship between both raters' agreement on all interaction scores ('good interaction', 'suitable' and 'unsuitable'). There was positive agreement for all three scores combined,  $r = .877$ ,  $N = 129$ ,  $p < .01$ . A scatterplot summarizes the results (see Figure 5.2 below).

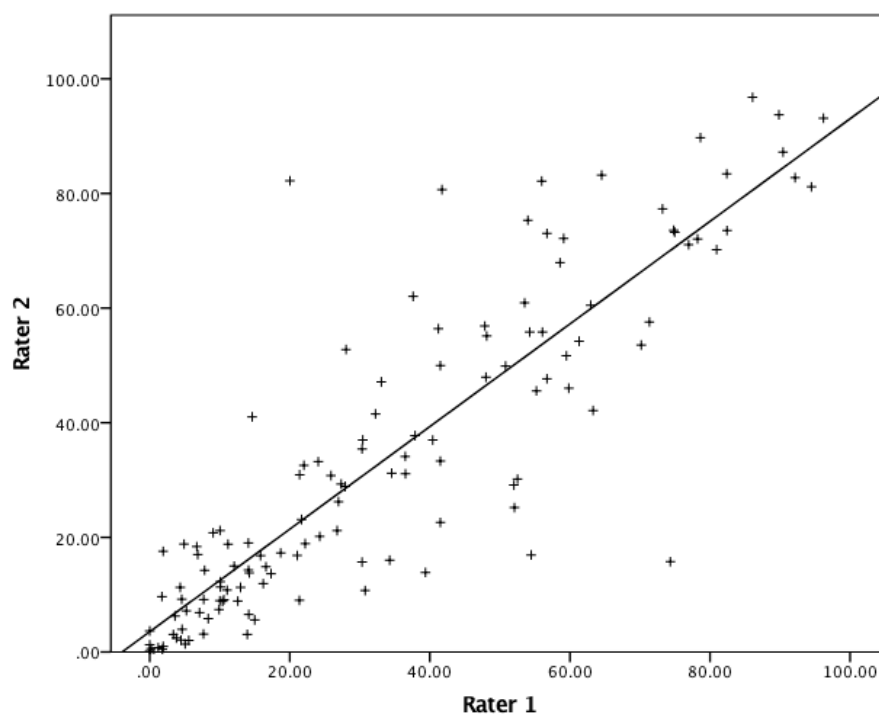


Figure 5.2 Agreement between raters of suitability scores  
The fitted line corresponds to  $r = .877$ ,  $p < .01$ .



A separate analysis was carried out just for 'good interaction' scores to ensure high agreement on this rating. There was also a significant positive agreement between judgements on this category,  $r = .625$ ,  $N = 49$ ,  $p < .01$ . Overall, both tests indicate a strong, positive correlation between both raters' scores on interaction ratings. See Figure 5.3 and Table 5.1 below.

Table 5.1 Summary of suitability scores

Suitability scores	Interaction	Music
Range (Min-Max)	1.75 - 69.85	4.15 - 54.35
$M (SD)$	28.91 (19.94)	24.80 (13.93)
$T_1 M (SD)$	28.06 (20.22)	24.80 (11.85)
$T_2 M (SD)$	22.10 (20.80)	24.89 (13.54)
$T_3 M (SD)$	30.96 (19.71)	22.15 (15.95)

### Interaction

Scores for all dyads and time points<sup>30</sup> ranged from 1.75 to 69.85% ( $M = 28.91$ ,  $SD = 19.94$ ). Based on visual analysis of the graph, roughly half the dyads showed an increase and the other half a decrease in interaction scores over time. A repeated measures analysis of variance (ANOVA) was conducted to evaluate the null hypothesis that there was no change in dyads' interaction scores when measured at  $T_1$ ,  $T_2$  and  $T_3$  ( $N = 12$ <sup>31</sup>). The results of the RM ANOVA indicated a non-significant effect,  $F_{2,10} = 1.39$ ,  $p = .292$ , partial  $\eta^2 = .218$ . Thus, there was not sufficient evidence to reject the null hypothesis, i.e. there was no change over time. Average for means over time were  $T_1 = 28.06$ ,  $T_2 = 22.10$  and  $T_3 = 30.96$ .

<sup>30</sup> Based on 40 scores, as 2 data points were missing.

<sup>31</sup> Dyads #7 and #9 were not taken into account in this analysis due to missing data.

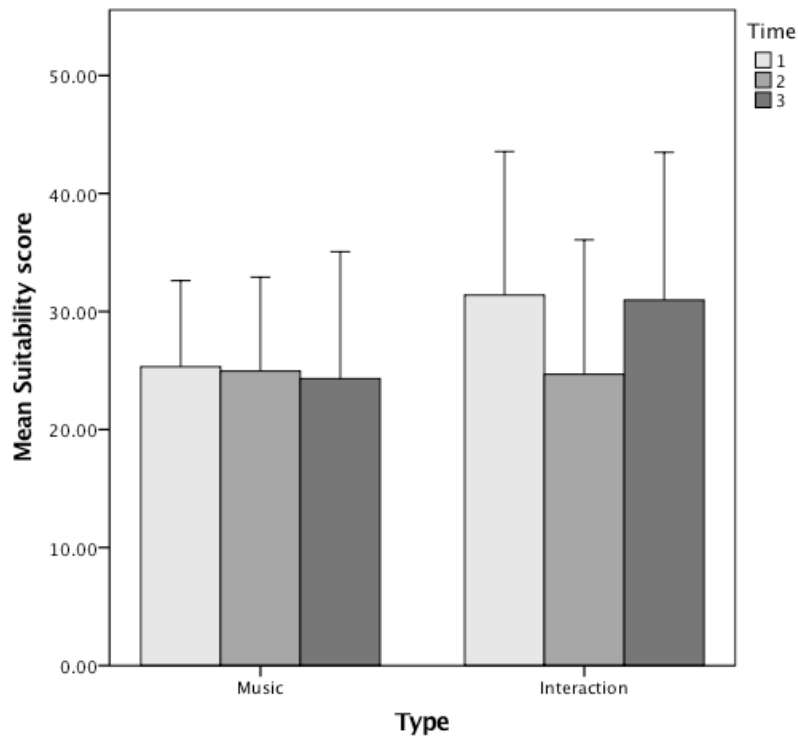


Figure 5.3 Suitability score averages of Music vs Interaction over time

*Note. Error bars represent the 95% Confidence Interval.*

#### Music

Scores for all dyads and time points<sup>32</sup> ranged from 4.15 to 54.35% ( $M = 24.80$ ,  $SD = 13.93$ ). Similarly, to the non-music condition, visual analysis of the plot indicated that about half the dyads showed an increase and the other half a decrease in interaction scores over time. A repeated measures ANOVA was conducted to evaluate the null hypothesis that there was no change over time in dyads' interaction scores when measured at  $T_1$ ,  $T_2$  and  $T_3$  ( $N = 11$ ). The results of the ANOVA indicated a non-significant effect,  $F_{2,9} = .302$ ,  $p = .747$ , partial  $\eta^2 = .063$ . Thus, there was not sufficient evidence to reject the null hypothesis, i.e. there was no change over time. Average for means over time were  $T_1 = 24.80$ ,  $T_2 = 24.89$  and  $T_3 = 22.15$ .

<sup>32</sup> Based on 39 scores, as 3 data points were missing.

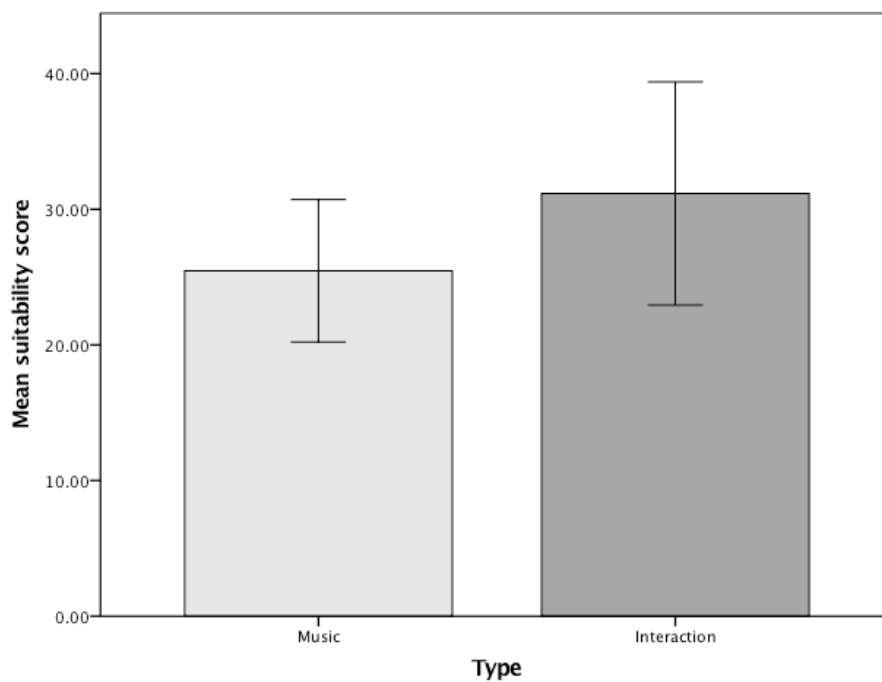


Figure 5.4 Suitability score averages of Music vs Interaction  
*Note. Error bars represent the 95% Confidence Interval.*

#### *Music vs Interaction*

A paired t-test was carried out to test whether each participant's suitability score average differed significantly with and without music. The mean percentage of 'good interaction' during Interaction ( $M = 29.71$ ,  $SD = 15.30$ ) and during Music ( $M = 25.25$ ,  $SD = 9.41$ ) did not differ significantly ( $t = -.148$ ,  $df = 13$ , two-tailed  $p = .162$ ). See Table 5.1 above for an overview and Figure 5.4 above for a visual representation.

### 5.2.2 Stationarity

Stationarity is indicated by rapidly decaying variables on the ACF plot (see Appendix C for details on *Time-series analysis*). If plotted variables decay slowly or not at all, the time-series must be differenced. A total of 168 time-series were analysed. These were derived from 14 dyads (each interaction partner's behaviour was coded separately), three sessions for Music and Interaction. See Table 5.2 below for an overview.

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### *Interaction*

Over half of the children's time-series were stationary ( $N = 25$ ; 60%), as were most adults' time-series ( $N = 30$ ; 71%), thus not requiring differencing. Those that were not stationary were differenced once, which sufficed to make them stationary.

Table 5.2 Summary stationarity results

Stationarity	Interaction Children	Interaction Adults	Music Children	Music Adults
Stationary time-series, N (%)	25 (60)	30 (71)	29 (69)	37 (88)
Stationary after differencing once, N (%)	17 (40)	12 (29)	13 (31)	5 (12)

### *Music*

Most children's time-series were stationary ( $N = 29$ ; 69%), as were most adults' time-series ( $N = 37$ ; 88%), thus not requiring differencing. Those that were not stationary were differenced once, which sufficed to make them stationary.

## 5.3 Cyclicity and synchrony

### 5.3.1 Cyclicity

Cyclicity analysis looks at whether someone's own interactive behaviour is rhythmic. Therefore, children's and adult's behaviour was analysed separately for each time point. Cyclicity was examined based on the number of significant peaks on the PACF plots of the normal or, if non-stationary, differenced series. Significant peaks indicated the presence of cyclicity (auto-correlations) in that person's time-series. If no lags were significant, it was concluded that cyclicity was absent in that time-series. See Table 5.3 below and Figure 5.5 below.

Table 5.3 Summary cyclicity

Cyclicity	Interaction Children	Interaction Adults	Music Children	Music Adults
Cyclic time-series, N (%)	33 (76.2)	38 (90.5)	38 (90.5)	40 (96.2)
AR1 time-series, N (%)	24 (61.0)	26 (63.4)	30 (71.4)	33 (78.6)
AR2 time-series, N (%)	6 (22.0)	8 (19.5)	6 (14.3)	6 (14.3)
Ppts showing cyclicity at least once, N (%)	13 (92.9)	14 (100)	14 (100)	14 (100)
Ppts showing cyclicity at least twice, N (%)	11 (78.6)	14 (100)	14 (100)	14 (100)
Ppts showing cyclicity consistently, N (%)	8 (57.1)	10 (71.4)	10 (71.4)	12 (85.7)

*Note. AR1 = first-order cyclicity; AR2 = second-order cyclicity; Ppt = participant*

#### *Interaction*

All children except one ( $N = 13$ ) showed cyclical interaction behaviour in at least one out of three sessions. Eleven out of 14 children showed cyclicity in two out of three sessions and eight showed cyclicity consistently in every single session. The majority of cyclic processes were AR1 (59.5%) and AR2 (14.3%), meaning that either the first or first two lags were significant. Out of all three time points for each child, there was some consistency with regards to the cyclicity shown; with either the same AR process shown, or one of the three time points exhibited a process one step above or below the others.

Like the children, most adults' time-series showed an AR1 (61.9%) or AR2 (21.4%) process. Out of all 42 adults' time-series 4 showed no cyclicity ( $N = 38$ ). Most adults showed a

consistent response, however, some adult's cyclicity varied more than one step above or below between time points.

### Music

All children ( $N = 14$ ) showed cyclical interaction behaviour in at least two out of three sessions. Ten out of 14 children showed cyclicity consistently in every single session. Most processes were AR1 (71.4%) and AR2 (14.3%). Like in the non-music condition, there appeared to be some consistency with regards to the cyclicity shown, with either the same AR process or one step above or below the others for each child across time.

Like the children, most adults' time-series showed an AR1 (78.6%) or AR2 (14.3%) process. Out of all 42 adults' time-series only two showed no cyclicity. Cyclicity in the adult's time-series was highly consistent in the Music condition.

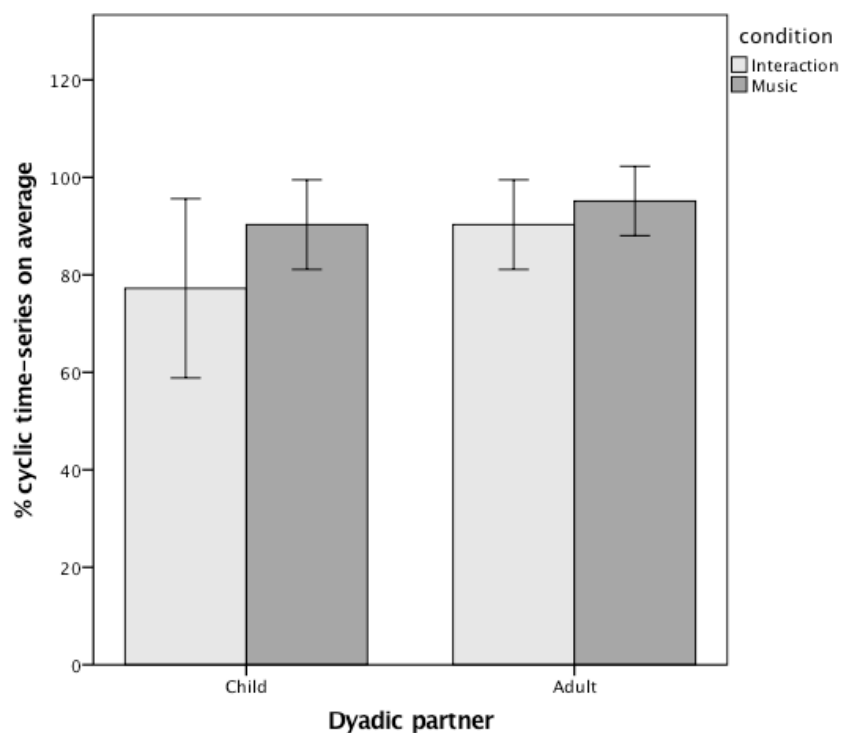


Figure 5.5 Percentage of cyclic time-series on average by dyadic partner and condition

*Note. Error bars represent the 95% Confidence Interval.*

### Music versus Interaction

Cyclicity was present in 90.5% of children's time-series with Music and in 76.2% of time-series without Music. For the adults, cyclicity was present in 96.2% of Music time-series and

90.5% of non-Music time-series. To determine whether differences in cyclicity presence during Music and Interaction were significant, a McNemar test was conducted. According to the corrected McNemar test statistic, there was no significant difference between cyclicity in Music compared to Interaction time-series ( $\chi^2 = 2.5$ ,  $df = 1$ ,  $p = .109$ ). However, The Yate's correction used by SPSS has been judged as too stringent (Hitchcock, 2009), and the uncorrected test revealed borderline significant differences ( $\chi^2 = 3.6$ ,  $df = 1$ ,  $p = .0578$ ). In conclusion, cyclicity was not significantly more present in Music compared to Interaction, however, the results suggest that there was a trend for more cyclical interaction during Music.

### 5.3.2 Coherence

The shared variance (i.e. how much of the time-series' variance is due to synchrony) of a dyad's two time-series after removing the auto-correlated component (or cyclicity) results in a coherence value for each dyad, which indicates the level of synchrony. This measure can take on values between 0 (no shared variance) and 1 (complete shared variance). Coherence was estimated for each dyad. See Table 5.4 below and Figure 5.6 below.

Table 5.4 Summary synchrony coherence

Coherence	Interaction	Music
Range, Min-Max	.075-.331	.084-.393
<i>M (SD)</i>	.184 (.061)	.207 (.071)
<i>T<sub>1</sub>, M (SD)</i>	.197 (.060)	.211 (.102)
<i>T<sub>2</sub>, M (SD)</i>	.168 (.061)	.200 (.059)
<i>T<sub>3</sub>, M (SD)</i>	.185 (.062)	.210 (.043)

#### *Interaction*

Coherence values for this sample (including all three sessions) ranged from .075-.331 ( $M = .184$ ,  $SD = .061$ ), following a roughly normal distribution. A repeated measures ANOVA confirmed that coherence scores did not change over time ( $F_{1,13} = .931$ ,  $p = .407$ , partial  $\eta^2 = .067$ ). The means for each time point were as follows:  $T_1 = .197$ , for  $T_2 = .168$  and for  $T_3 = .185$ . There was no statistically significant correlation between suitability scores and coherence values ( $r = .05$ ,  $p = .762$ ).

## Music

Coherence values for Music (all three sessions) ranged from .084-.393 ( $M = .207$ ,  $SD = .071$ ), and were roughly normally distributed. A repeated measures ANOVA confirmed that coherence scores did not change significantly over time ( $F_{1,13} = .133$ ,  $p = .877$ , partial  $\eta^2 = .022$ ). The means for each time point were:  $T_1 = .211$ ,  $T_2 = .200$  and  $T_3 = .210$ . There was no statistically significant correlation between suitability scores and coherence values ( $r = .07$ ,  $p = .670$ ).

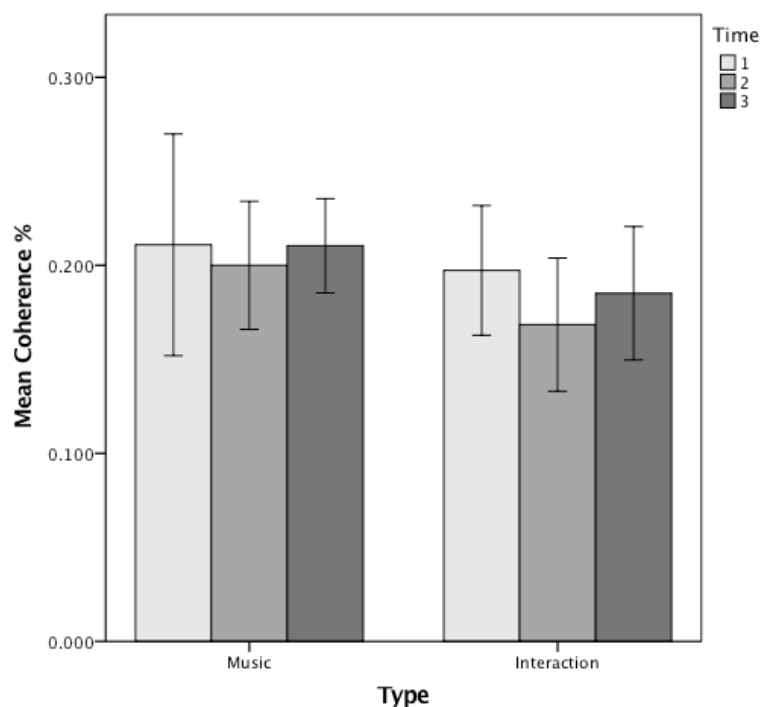


Figure 5.6 Synchrony coherence averages over time Music vs Interaction  
*Note. Error bars represent the 95% Confidence Interval.*

## Music vs Interaction

A two-way repeated measures ANOVA was conducted to compare the main effects of the two independent variables (time, condition) and their interaction effect on dyad's coherence scores. Time consisted of three levels ( $T_1$ ,  $T_2$  and  $T_3$ ) and condition included two levels (Music and Interaction). Time was non-significant ( $F_{2,26} = 1.005$ ,  $p = .380$ , partial  $\eta^2 = .072$ ), as was condition ( $F_{1,13} = 4.128$ ,  $p = .063$ , partial  $\eta^2 = .24$ ) and their interaction ( $F_{2,26} = .103$ ,  $p = .903$ , partial  $\eta^2 = .008$ ). Even though none of the effects were statistically significant



at the .05 significance level, condition was nearly significant, indicating a trend for increased coherence values in the Music condition. See Table 5.5 below for a summary and Figure 5.7 below for a graphic representation of the results.

Table 5.5 Summary two-way repeated measures ANOVA

Source of variation	Sums of squares	Degrees of freedom	Mean square	F-ratio	Probability
Time	.006	2	.003	1.005	.380
Error (Time)	.074	26	.003		
Condition	.012	1	.012	4.128	.063
Error (Condition)	.036	13	.003		
Time x Condition	.001	2	.001	.103	.103
Error (Time x Condition)	.148	26	.007		

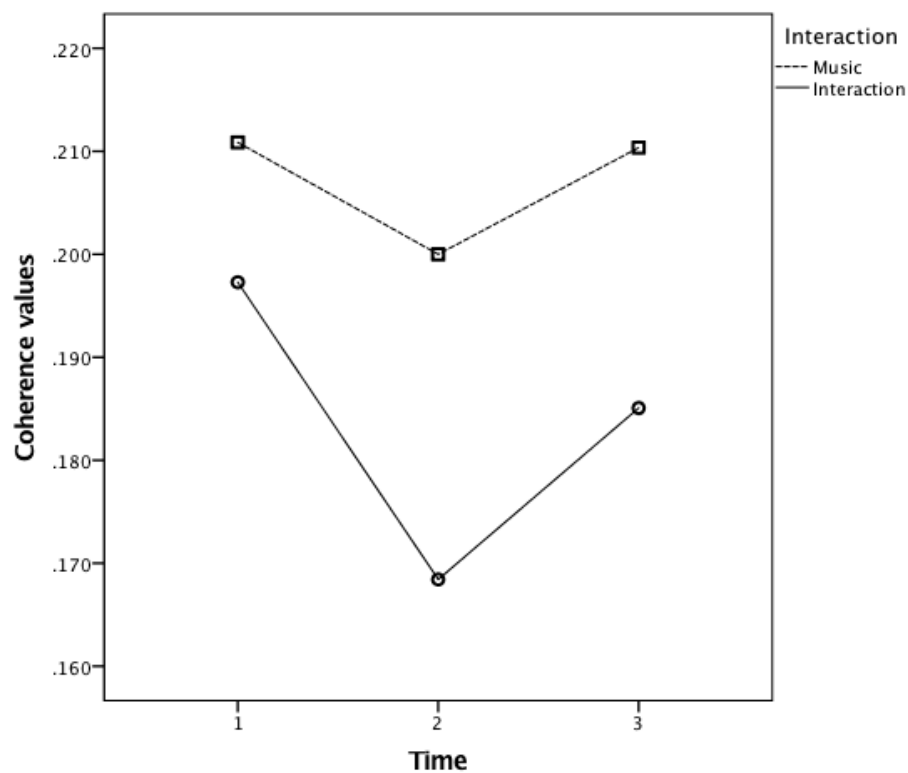


Figure 5.7 Mean coherence values for time (Time1, Time2 and Time3) and condition (Music and Interaction).

### 5.3.3 Synchrony

The presence of (significant) synchrony in a time-series is indicated by the presence of significant peaks on the CCF plot. See Table 5.6 and Figure 5.9 for an overview. Binary logistic regression analysis was employed to test whether interaction score could predict the presence of synchrony. The model was not significant ( $\chi^2=.015$ ,  $p = .901$ ). Thus, interaction score was not predictive of synchrony outcome.

Table 5.6 Summary synchrony

Synchrony	Interaction	Music
Synchronous time-series, $N$ (%)	8 (19.0)	25 (60)
Dyads showing S at least once, $N$ (%)	8 (57.1)	13 (93)
Dyads showing S at least twice, $N$ (%)	0 (0)	9 (64)
Dyads showing S consistently, $N$ (%)	0 (0)	3 (21)
Coherence range, Min-Max	.204-.349	.193-.393
Coherence, $M$ ( $SD$ )	.244 (.050)	.250 (.052)
Time-lag range, Min-Max	1-4 sec	0-5 sec
Time-lag, $M$ ( $SD$ )	1.87 (1.25)	1.36 (1.73)
Mutual synchrony $N$ (%)	2 (5)	0
Child-lead $N$ (%)	5 (12)	25 (100)
Adult-lead $N$ (%)	1 (2)	0

#### *Interaction*

Out of 42 dyadic time-series, 8 contained synchrony. Each dyad that showed significant synchrony did so on one out of three occasions. For this subgroup, the degree of synchrony (based on the cross-correlation of significant peaks) ranged from .204-.349 ( $M = .244$ ,  $SD = .05$ ). Synchrony was only achieved in dyads where both interaction partners showed cyclicity. The time required to achieve synchrony was between 1 and 4 seconds ( $M = 1.87$ ,  $SD = 1.246$ ). In five out of eight dyads, synchrony was achieved within one second. Five dyads were child-led, one was adult-lead and two showed mutual regulation.

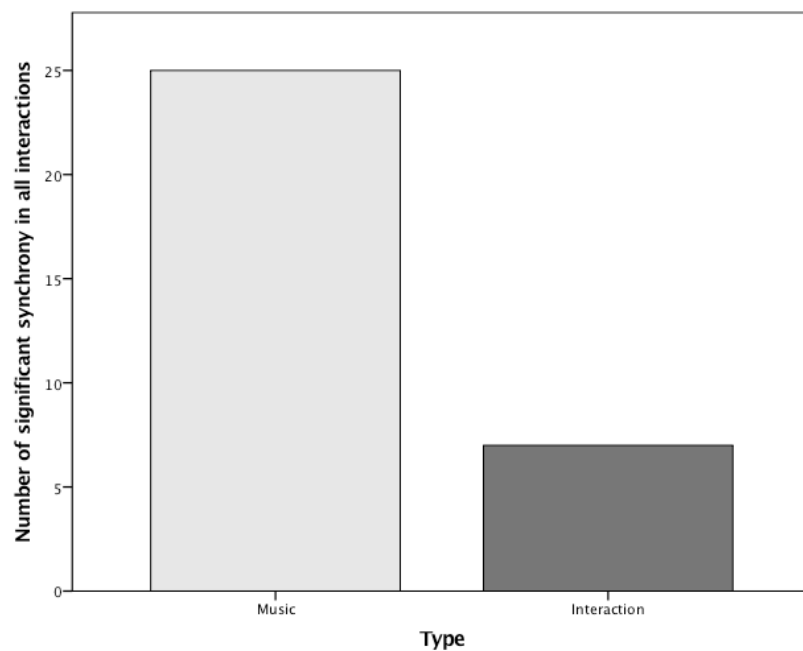


Figure 5.8 Number of interactions with significant synchrony comparing Music and Interaction

### *Music*

Out of 42 dyadic time-series, 25 showed the presence of synchrony. Every dyad, except for one, achieved synchrony during Music at least once out of three occasions. Three dyads achieved synchrony consistently on all three occasions, six dyads achieved it in two out of three sessions and the remaining four achieved it once. Synchrony was only achieved in dyads where both interaction partners showed cyclicity. In all instances of synchrony, the interaction was child-led.

For the time-series during which synchrony was achieved, the degree of synchrony (based on the cross-correlation of significant peaks) ranged from .193-.393 ( $M = .250$ ,  $SD = .052$ ). The time required to achieve synchrony was between 0-5 seconds ( $M = 1.36$ ,  $SD = 1.729$ ). In 18 out of 25 dyads, synchrony was achieved within one second or less.

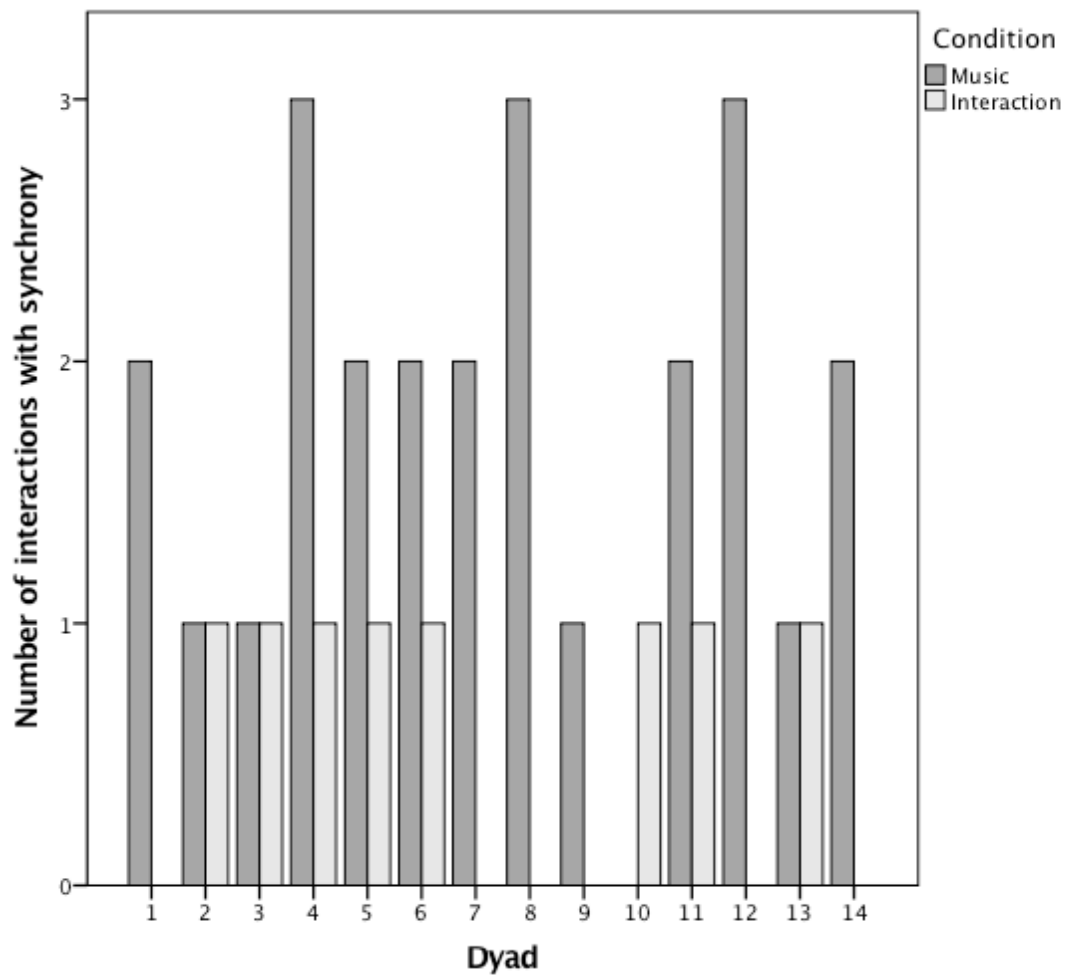


Figure 5.9 Number of interactions with synchrony during Music vs Interaction per dyad

#### *Music vs Interaction*

A McNemar test was conducted to determine whether there were more instances of significant synchrony during Music compared to Interaction. According to the corrected McNemar test statistic, synchrony was significantly more frequent in Music compared to Interaction ( $\chi^2 = 14.82$ ,  $df = 1$ ,  $p < .000$ ; 95% CI for the difference -65.43-28.56%). See Figure 5.8 above.

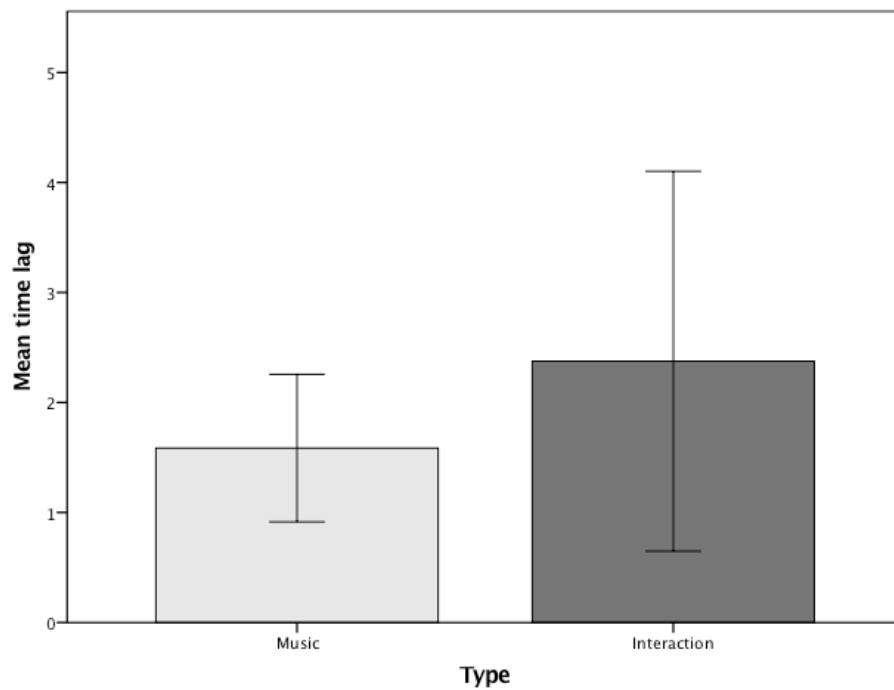


Figure 5.10 Mean time-lag to synchrony in Music vs Interaction

*Note. Error bars represent the 95% Confidence Interval.*

A one-way ANOVA was conducted to test whether time-lag to synchrony differed significantly between Music and Interaction. There was no significant effect of condition on time-lag ( $F_{1,35} = 0.040$ ,  $p = .842$ ). See Figure 5.10 above.

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## 5.4 Summary

This chapter presented the results and was split into preliminary analyses and those targeted at answering the research questions regarding cyclicity and synchrony performance in young children with ASD.

Preliminary analyses included an analysis of suitability scores and stationarity. Suitability scores were coded by two raters and showed good positive agreement. There was no indication of change over time for suitability scores during Music or Interaction. Furthermore, there was no difference between suitability scores during Music and Interaction. Stationarity was present in most adult's and children's time-series, in both Music and Interaction. Non-stationary series were differenced once, after which they were stationary.

Cyclicity was present in most children's and adult's time-series, which was true for both Music and Interaction. There was a trend for cyclicity to be more consistently present in Music. Coherence did not change over time and was not correlated with interaction scores. A positive trend indicated increased coherence in Music. Synchrony was present in both conditions, yet significantly more frequent in Music. Finally, time needed to achieve synchrony was the same in Music and Interaction.

## 6 Discussion

### 6.1 Introduction

Key findings in the previous chapter related to the presence of cyclicity and synchrony in dyadic interactions between a child with ASD and his caregiver. Furthermore, Music<sup>33</sup> was associated with enhanced social timing, especially synchrony.

This chapter discusses these findings in the context of the literature and considers how successfully this study responded to the research problem formulated in Chapter 1 of this thesis. To do this, the chapter is split into three parts, beginning with a discussion about research findings. Next, unexpected findings are discussed more thoroughly. Finally, this study's methodology is evaluated, see Figure 6.1. The chapter closes with a summary. The next and final chapter is dedicated to the conclusion of the thesis.

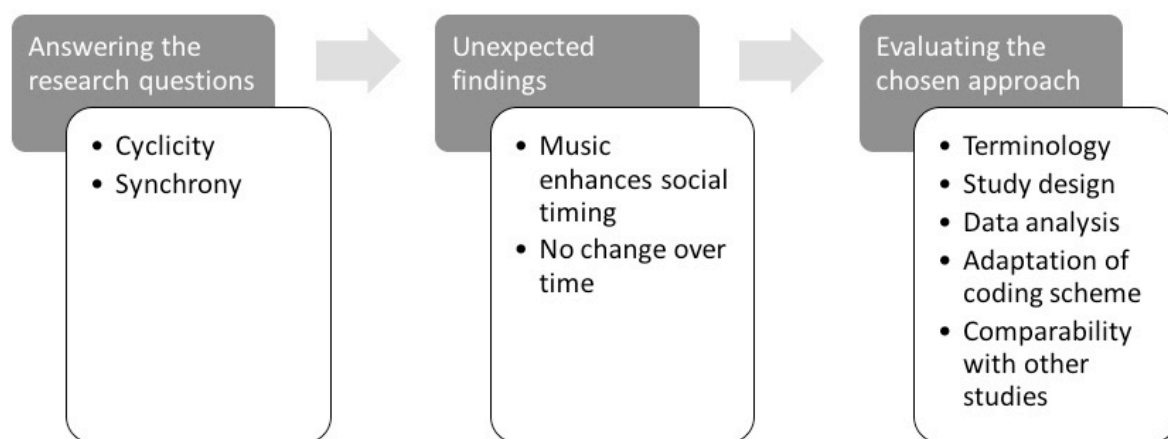


Figure 6.1 Chapter overview

<sup>33</sup> 'Music' is capitalised and refers to 'Interaction with music' within the MIT setting and to distinguish it from music as part of music therapy.

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## 6.2 Answering the research questions

The research aim was to add to existing knowledge of social timing in children with ASD. The research questions asked whether preschoolers with ASD can engage in cyclical and synchronous dyadic interaction with and without Music. Below, each will be answered in turn.

### 6.2.1 Cyclicity

Do children with ASD show cyclicity? Is cyclicity more consistently present in Music versus Interaction? Children with ASD are able to engage in rhythmic interaction behaviour as shown by the presence of cyclicity in their analysed interaction sequences. The Music condition appeared to enhance the presence of cyclicity.

For each child, three interaction sequences were analysed and while cyclicity was not present in all three sessions in all children, half of them showed it consistently without Music. In contrast, most children showed cyclicity consistently in every single session with Music, and all children showed cyclicity in at least two sessions. The adults showed cyclicity consistently regardless of condition.

Based on the literature review of social timing in ASD it was expected that children with ASD are impaired in their ability to engage in intrapersonal timing (see 2.4.5). Social timing behaviour may be more or less present depending on the individual's symptom severity, and other factors.

The cyclicity results confirm this; all children showed the ability to engage in cyclical interaction, even more severely affected children. Moreover, Music enhanced cyclicity, as shown by the greater presence of cyclicity in interactions supported by Music (see 6.3.1 for an in-depth discussion).

From a methodological viewpoint, it is important to mention that if only one session had been analysed rather than three, the conclusion would be that children with ASD rarely show the ability to engage in rhythmic timing. This inconsistency may be explained by the large variations seen in the children's willingness to engage, which varied from session to session and appeared to depend on a multitude extraneous and intraneous factors (see 6.3.2 and 6.4 for a deeper discussion).



In this sample, most time-series included a significant auto-correlated component defined by either an AR1 (or a first order autocorrelation<sup>34</sup>, i.e. behaviour is predicted from the immediately preceding event) or an AR2 (or a second order autocorrelation<sup>35</sup>, i.e. behaviour shows a stochastic–cyclic pattern) structure (Feldman et al., 1999). These findings are consistent with previous research in TD infants (Cohn & Tronick, 1988; Feldman et al., 1996) and adults (Warner, 1992).

Overall cyclicity in this sample was impaired compared with healthy, full-term infants. In Feldman’s study (1996), first-order correlation cyclicity was achieved by 61% of 3-month olds and 63% of 9-month olds (Feldman et al., 1996). In the present study, cyclicity achievement was lower in both the Music and non-Music condition for both first- and second-order cyclicity, with the exception of first-order cyclicity with Music (see Table 6.1 below). Second-order correlation cyclicity was achieved by 44% of 3-month olds and by 43% of 9-month olds (Feldman et al., 1996), whereas in our sample none (stringent criteria, i.e. in all three sessions) achieved it with and without Music respectively.

Table 6.1 Cyclicity comparison data

Study	Sample/Condition	AR1	AR2
Present study	Interaction (%)	57*	7*
		92^	29^
	Music (%)	71*	0*
		100^	50^
Feldman et al. 1996	Healthy, full-term infants at 3 months (%)	61	44
	Healthy, full-term infants at 6 months (%)	63	43

*Note. AR1 = first-order cyclicity; AR2 - second-order cyclicity; \* denotes stringent criteria (i.e. cyclicity achieved in all three sessions); ^ denotes lenient criteria (i.e. cyclicity achieved in at least one session).*

In sum, it appears that most children with ASD have the potential for rhythmicity in social timing, yet it is impaired compared to TD infants. Firstly, the children from Feldman’s study (1996) were 3- and 9-months old, whereas this study’s children were between 2 and 8 years old. Secondly, more children from Feldman’s study (1996) achieved second-order cyclicity.

34 Feldman (1999) referred to it as 'stochastic processes' and defined it as including both AR1 and AR2 processes. In her 1999 paper, she referred to it as first-order correlation instead, presumably because any AR2 processes usually contain AR1 processes as well.

35 Alternatively referred to as stochastic cyclicity. Assumes a stationary AR2 process and a major peak over a broad band of frequencies.

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## 6.2.2 Synchrony

Can children with ASD synchronise with their dyadic partner? Is Music associated with increased coherence and more synchrony? Based on the outcome of the micro-analysis it can be concluded that children with ASD can synchronise with their caregiver during playful interaction. The presence of Music positively impacted on their ability to do so, which was evident in both coherence (i.e. level of synchrony), synchrony and time-lag to synchrony (see 6.3.1 for an in-depth discussion).

### *Coherence*

In both the Music and Interaction condition, coherence values were similar to those found in previous literature (see Table 6.2 below). Coherence values did not change significantly over time. Sessions with Music showed higher coherence values than those without Music.

In a previous study, coherence values of premature high-risk infants averaged .13 ( $SD = .07$ ), those of premature low risk infants .15 ( $SD = .08$ ) and those of full-term infants .18 ( $SD = .10$ ; Feldman, 2006). Differences between parent sex and infant sex in synchrony levels were demonstrated by Feldman (2003), who found that dyads with fathers had higher coherence levels ( $M = .20$  for sons and  $M = .17$  for daughters) than dyads with mothers ( $M = .18$  for daughters and  $M = .16$  for sons). In the at risk studies of siblings with and without ASD, values for at risk children were .13 ( $SD = .07$ ) and for TD controls .15 ( $SD = .07$ ) on average.

Thus, coherence values of the sample with ASD were higher than values found in at risk and healthy 3 and 9-month-old infants (Feldman, 2003; 2006; Yirmiya et al., 2006). A result that may be surprising if we assume that more is better, yet this is inconsistent with the assumption of pervasive social deficits in ASD.

What could be responsible for these higher coherence values? Increased age might have to do with it, or deviance from typical development, which is arguably greater than in at risk children. If the latter is the case, one must question what it means to have higher rather than lower coherence values, and at what level synchrony is optimal.

Early social interaction researchers assumed that the more synchronous interaction is, the more positive the experience of it will be. It was reasoned that the higher the synchrony, the lower uncertainty, resulting in less awkward pauses and interruptions (Chapple, 1970).

Along those lines, early developmental researchers assumed that the level of parent-infant synchrony represents an index of parental sensitivity, with higher levels indicating higher sensitivity (Field, 1985). Mothers who scored high on sensitivity demonstrated moderate levels of vocal congruence (Hane et al., 2003).

Extreme levels of predictability possibly indicate loss of adaptability and even psychopathology (Gottman, 1979). Similarly, Lomax (1982 as cited by De Jaegher, 2006) suggested that very high levels of rhythmicity in speech may actually obscure complex semantic meaning. Following further research on social-interaction in various domains, it was concluded that both very high and very low levels of synchrony are maladaptive, and that moderate levels may be optimal (Warner et al., 1987). Support for this notion came from Jaffe et al. (2001), who extensively studied vocal rhythm synchrony, and found that moderate levels best predicted dyads who were securely attached later on.

In order to examine coherence levels, Yirmiya et al. (2006) used the mean and standard deviation of all participants in their study, forming categories of low (1 SD below the mean), mid-range and high (1 SD above the mean) levels of coherence. Those in the at risk for ASD group showed lower levels of coherence whereas TD dyads achieved mid-range and high levels (Yirmiya et al., 2006).

A modulating factor may be the degree of familiarity between the interaction partners. The more familiar interaction partners are, the more they can deviate to introduce novelty, however strangers benefit from a more closely matched rhythm (Warner, 2002). In interactions with populations with ASD, a familiar dyadic partner seems to be necessary to facilitate social timing (Feldstein et al., 1982; Oberman et al., 2009).

Observed coherence levels may also depend on the paradigm used. Monadic Phases examines direction of change rather than state match, which may allow for higher levels of synchrony to still be regarded as optimal.

In sum, it appears that moderate levels seen in TD children are more optimal in general. However, one can speculate that the higher levels seen in ASD may be adaptive so that children and parents can benefit from a more predictable rhythm.

Table 6.2 Synchrony comparison data

Study	Sample/Condition	Coherence <i>M (SD)</i>	Synchrony	Time-lag in sec <i>M (SD)</i>
Present study	Interaction	.18 (.06)	0%* / 57%^	1.87 (1.25)
	Music	.21 (.07)	21%* / 93%^	1.36 (1.73)
Feldman et al. 1999	Healthy, full-term infants at 3 months	.20	42%	2.82 (1.30)
	Healthy, full-term infants at 9 months	.23	69% (MS)	2.60 (1.50)
Yirmiya et al. 2006	Siblings at low (SIBS-TD) risk for ASD at 4 months	.18 (n/a)	67% (B-M: 57.1%; M-B: 23.8%; MS: 14.3%)	$M_{BM} = 1.14 (1.56)$ ; $M_{MB} = .62 (1.43)$
	Siblings at high risk (SIBS-A) for ASD at 4 months	.13 (.12)	62% (B-M: 38%; M-B: 28.6%; MS: 4.8%)	$M_{BM} = 1.05 (1.53)$ ; $M_{MB} = 1.14 (2.20)$
Feldman 2006	Premature infants at high risk at 3 months	.13 (.07)	53.5% of all dyads achieved sig. synchrony	3.04 (2.01)
	Premature infants at low risk at 3 months	.15 (.08)		2.77 (1.65)
	Full-term infants at 3 months	.18 (.10)		2.45 (1.18)

*Note.* \* denotes synchrony achievement under stringent criteria (i.e. achievement in all three sessions); ^ denotes lenient criteria (i.e. achievement at least once out of three sessions); B-M = baby leads, mother follows; M-B = mother leads, baby follows; MS: mutual synchrony; SIBS-TD = siblings not at risk for ASD; SIBS-A = siblings at risk for ASD

### Synchrony

Synchrony in Interaction sessions was achieved by half of the children of this sample but only in one out of three sessions by each child, and therefore more elusive than cyclicity. In contrast, synchrony achievement in Music sessions was much higher; all except one dyad achieved synchrony at least once, and the majority of the sample achieved synchrony in at least two out of three sessions. Synchrony was not achieved consistently; each dyad only achieved synchrony in one out of three sessions without Music. Consistency was much higher with Music, three dyads showed synchrony in all three sessions. Music had a positive effect on synchrony; as reflected by a significant difference in the number of synchronous interactions with Music compared to without Music (see 6.3.1 for an in-depth discussion).

Inconsistency of synchrony achievement is similar to cyclicity performance (see 6.2.1) and supports the view that a child's willingness to engage is highly variable in ASD, fluctuating considerably from one time point to the next (see also 6.3.2 and 6.4.2). It seems likely, that most, if not all, children with ASD are able to reach synchrony under the right circumstances,

as demonstrated here. Music appeared to enhance synchronising performance, similarly to cyclicity and coherence. Most distinct was the finding, that almost all dyads were able to synchronise at least once with Music, compared to half the sample when interaction was not supported by Music.

According to Yirmiya et al.'s (2006) study on 4-month-old children at risk for ASD 62% achieved synchrony, while 67% of the control group (at low risk) did. This is similar to sessions with Music if we consider synchrony achievement in dyads that achieved in at least two out of three sessions. Levels comparable to the present study's Music condition were also found in previous studies (Feldman, 2006; Feldman et al., 1999).

Even though Music enhanced synchronising performance in the present study, it cannot be considered equal to that of previous studies because the children from the present study are much older than the 3- to 9-month-old infants, and analysis is based on three recordings, whereas the previous studies only used one recording per dyad.

Synchrony presence was only found in dyads that achieved cyclicity. Thus, it may be necessary for individuals to engage in rhythmical intrapersonal behaviour before they can engage in synchronous interaction (Lester et al., 1985).

In sum, synchronising ability is present but attenuated in preschool aged children with ASD compared to 3- to 9-month-old infants with and without risk factors. Nevertheless, the presence of Music enhanced synchrony considerably.

#### *Time-lag to synchrony*

The dyads in this study that achieved synchrony responded within 1.87 seconds ( $SD = 1.25$ ) during Interaction, while with Music it took 1.36 seconds ( $SD = 1.73$ ).

Dyads with non-depressed mothers responded nearly twice as fast to their 3-month old's vocalisations than depressed mothers (Feldman et al., 1999), suggesting that shorter response times may be better.

In Feldman's study (2003) time-lags were within the range of 1 to 7 seconds. In healthy dyads at 3 months, it took 2.8 sec on average (normally mother follows her infants lead), while at 9 months, when mutual influence generally dominates interaction, it took 2.6 seconds on average (Feldman et al., 1999). In Feldman's study (2006) of premature and full-term infants, no significant differences between time-lag to synchrony were observed, but results indicated that full-term infants achieved synchrony faster ( $M = 2.45$  sec,  $SD = 1.18$ )

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than high-risk ( $M = 3.04$  sec,  $SD = 2.01$ ) and low risk infants ( $M = 2.77$  sec,  $SD = 1.65$ ). Same sex dyads were found to reach synchrony faster (mother-daughter  $M = 2.35$  sec and father-son  $M = 2.52$  sec) than mixed sex dyads (father-daughter  $M = 3.44$  sec and mother-son  $M = 3.05$  sec). Four-month-old infants at risk for ASD took 1.05 sec ( $SD = 1.53$ ) when the child was leading and 1.14 sec ( $SD = 2.20$ ) when mother was leading. In comparison, TD peers took 1.14 sec ( $SD = 1.56$ ) and .62 sec ( $SD = 1.43$ ; Yirmiya et al., 2006).

### *Lead-lag relationships*

Synchronous interactions without Music contained all types of lead-lag relationships: most were child-lead, one was adult-lead and two were mutually regulated. Synchronous interactions with Music were all child-lead. As expected, most parents follow their child's lead. This is most likely due to the fact that parents are coached to follow their child's lead during MIT to maintain their child's focus of attention. Another reason may be that child-leads are more common in the earlier stage of synchrony development, whereas mutual influence dominates interaction in developmentally more mature infants (Feldman, 2007a; Feldman et al., 1999).

Non-Music interactions featured all three types of lead-lag relationships. Conclusions based on such a small subsample are speculative, but it may be that parents do not follow MIT instructions in sessions without Music.

In sum, children with ASD are communicatively less mature than their peers, which was reflected by less mature lead-lag relationships (i.e. non-mutual). Previous studies same sex dyads showed more mutual influence (mother-daughter  $M = 29\%$  and father-son  $M = 26\%$ ) than different sex dyads (mother-son  $M = 24\%$  and father-daughter  $M = 17\%$ ).

## 6.3 Unexpected findings

Two findings deserve an in-depth discussion: 1) music enhanced social timing performance, and 2) no change over time was found for any social timing parameters.

### 6.3.1 Music enhances social timing in ASD

Music was associated with enhanced social timing parameters compared to Interaction. To recap, cyclicity, coherence and synchrony were all improved in sessions with Music. In particular, synchrony was significantly more frequent in the Music condition. All other factors were nearly significant or showed a trend for improved social timing.

These findings are in accord with previous studies that examined the positive effects of music on 1) social synchrony in neurotypicals (Demos, Chaffin, Begosh, Daniels, & Marsh, 2012; Tarr, 2014) and 2) on children with ASD. Meta-analyses of music therapy for individuals with ASD consistently found support in favour of their efficacy (Geretsegger, Elefant, Mössler, & Gold, 2014). In contrast, a recent international randomised controlled trial (RCT) did not support the use of improvisational music therapy for symptom reduction of communication skills in children with ASD (Bieleninik et al., 2017). However, their use of the ADOS as a tool to measure change of symptom severity may not be appropriate (Grzadzinski et al., 2016). Instead, a patient-centred approach that takes parental reports into account may have been more informative (Broder-Fingert, Feinberg, & Silverstein, 2017). Finally, the RCT used improvisational music therapy, which differs in many ways to the way music is used in MIT (Wimpory et al., 1995). However, Broder-Fingert et al. (2017) caution that music therapy in ASD should be intended as a supplement rather than a stand-alone treatment option.

Despite all of this research, it remains unclear how music enhances social timing in ASD. Music can act as a motivator by enhancing joy for children with ASD in an intervention compared to toy-based play with a therapist (Kim et al., 2009). Music has also been found to act like a 'social glue' as it encourages social bonding (Demos et al., 2012). Music possibly works through different ways, such as by increasing motivation and supporting intrapersonal and interpersonal timing concurrently.

The effect of the music may depend on the chosen intervention approach; how it is used and by whom it is played. For example, there are three different music intervention

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approaches for individuals with ASD in which a musician plays the music (Clayton, Sager, & Will, 2004). In one approach a musician supplies a rhythm by playing strictly metered music, whereas the exact opposite is when the music mimics the child or dyad, as in the case of MIT. Finally, calming music may also be used as a relaxer (Clayton et al., 2004). This is in opposition to music interventions in which the child plays music alongside the caregiver (Kim et al., 2009).

It seems that the particular approach might not matter as much. All reviewers of music therapy studies found that they were effective regardless of whether music was live, pre-recorded, played to the child or together with the child (Accordino, Comer, & Heller, 2007; Whipple, 2004; Wigram & Gold, 2006), with the exception of the RCT mentioned above (Bieleninik et al., 2017). The most important contribution of music may lay in fostering interpersonal communication, reciprocity and the development of relationship-building skills, all of which matter for social timing (Geretsegger et al., 2014; Wigram & Gold, 2006). Furthermore, music is thought to structure interaction and make it more predictable (Geretsegger et al., 2014).

While these reviewers agreed on music's efficacy, they also criticised the poor methodologies of existing music therapy studies (Accordino et al., 2007; Broder-Fingert et al., 2017; Whipple, 2004). In particular, the lack of group designs, appropriate statistics and the absence of a control condition without music was objected to (Accordino et al., 2007; Whipple, 2004).

In conclusion, the present study may offer a valuable contribution to the field of music interventions for ASD and the effect of music on social timing. The former may benefit from this study's methodology because it offers the desired features that were lacking in previous social timing studies. The present methodology could even be extended to include other variables of interest, such as initiations or imitations. Regarding the effect of music on social timing, this study adds further support to previous findings with neurotypical individuals that may extend to individuals with ASD. Finally, based on the present finding one may conclude that music is an essential part of MIT, which had been previously questioned (Wimpory et al., 2000).



### 6.3.2 No change over time

No changes over time were observed for suitability score, cyclicity, coherence or synchrony. Supposing that there is change, several reasons may account for this finding.

Firstly, improvements may be undermined by daily variations in engagement willingness. This appears to have played some role in every dyad, yet it is hard to control for and remains a challenge in studying this population. If this was the case, one would expect to see this reflected by higher interaction scores. However, interaction scores did not correlate with coherence (see 5.3.2) and were not predictive of synchrony (see 5.3.3).

Secondly, analysed sessions may not be far apart enough to show improvements, or a longer intervention period is needed for change to occur. However, change was not operationalised in this study as it was not defined as a research question. A brief look at length between the first and last analysed session (indicative of MIT length) and synchrony does not indicate an association. In the following, examples from social timing or music intervention studies that found change are considered.

Twenty weeks of 50-minute long improvisational music therapy sessions, resulted in improved synchrony in 4- to 6-year old children with mild to severe autistic traits (Venuti et al., 2017). Children between 2 and 12 years and their parents, who received Relationship Development Intervention (Gutstein, 2009) for at least 1 year, showed positive changes in interpersonal relatedness, co-regulation and intersubjective engagement (Hobson et al., 2016). A short but intensive treatment of 32 sessions during a 2 month period using rhythm and robot intervention with 5- to 12-year old children also found changes to motor skills (Srinivasan et al., 2015). The RCT used a 5-month period of music therapy and did not find a change, which may be due to use of ADOS assessments as an outcome criterion (Bieleninik et al., 2017). Thus, change was found in interventions as short as 8 weeks (using an intense approach) and 12 weeks (weekly sessions).

Alternatively, it is possible that social timing measures are not appropriate for detecting change. Yet, studies employing social timing measures have been able to find change (Hobson et al., 2016; Kim et al., 2009; Srinivasan et al., 2015; Venuti et al., 2017). It should be noted, however, that all but Venuti (2017) used social timing measures in the wider sense, including global evaluations and motor skills. While Venuti (2017) used an adaptation of Monadic Phases, they chose not to analyse their data using time-series analysis, which means that

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their results are not comparable to the ones from the present study. Thus, social timing measures may well be able to capture change, whether the present method can do so as well remains to be seen.

Finally, social timing may not be amenable to long-term changes on the basis of weekly intervention sessions. However, there are two studies that provided weekly sessions over 12 and 20 weeks that found changes in synchrony/emotional synchronicity (Kim et al., 2009; Venuti et al., 2017).

In sum, the present paradigm failed to record change. Most explanations for why this might be the case could be ruled out using examples from the literature, such as session length and social timing not being amenable to or able to detect change. Thus, the lack of change found in the present study is most likely a result of variations in the children's willingness to engage. The interaction scores, which were supposed to capture this factor may not have done so well enough.

## 6.4 Evaluating the chosen approach

The present study was designed to overcome drawbacks of previous studies and to provide a method to study parameters of social timing adapted to the group of interest. The following section discusses how successfully these objectives were addressed, including problems regarding terminology, study design, data analysis, coding scheme adaptation and comparability with other studies.

### 6.4.1 Terminology

Lack of consensus regarding social timing terminology is problematic, especially regarding the terms synchrony and cyclicity (see 2.2.2 for definitions). While some authors have defined the term synchrony (Delaherche et al., 2012; Feldman, 2007b), not all researchers provide a definition of their understanding of the term (e.g. Trevarthen & Daniel, 2005). The term cyclicity has also caused confusion in the literature; depending on its use as a general social timing term or in relation to intrapersonal timing specifically. In the latter sense, it can be used to imply stochastic or periodic cyclicity (see Appendix A: Who or what drives timing in interaction?). Inconsistent use of terminology impacts on methodologies, which results in studies in stating they study synchrony while actually referring to different concepts.

To address this, disentanglement of varying definition was undertaken by reviewing common elements and delineating them from similar but different concepts (see 2.2.3). That way, a definition of the term interactional synchrony was derived. This definition was then used to specify which studies actually examined interactional synchrony, their merits and limitations, and aided in selecting a suitable method for the present study (see 2.4.4 and 3.3).

### 6.4.2 Study design

One of the drawbacks of existing studies was limited generalisability due to case study designs or at risk for ASD studies. The present study resulted in a method that can be used readily with groups, and findings are about a group of children with ASD, and thus an improvement compared to at risk and case studies. However, there was no control group of

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either TD or DD children, which is a limitation. Instead, children served as their own controls and dyads' interaction behaviour was analysed in two different conditions (with and without Music).

A further noteworthy point is that all reviewed studies used only a single recording of face-to-face interaction with a fixed sequence to micro-analyse. In contrast, the present study has the unique feature of analysing three recordings and choosing a sequence to micro-code when the child was willing to engage. One could argue that using three recordings for each dyad limits comparability with previous studies. However, using three recordings revealed that children with ASD have social timing potential. If a single recording and fixed sequence had been used, a different conclusion might have been reached. Thus, the approach taken in the present study may be seen as a benefit.

Another point worth mentioning is the use of the Music and non-Music comparison in this study. One could argue that this study compares MIT (Wimpory et al., 1995) with a control condition. However, most parents may have used the strategies they learnt within MIT in the recordings that were recorded immediately before or after the MIT recording. It is also possible, that some parents did not use these strategies when there is no Music present. Similarly, carry-over or warm-up effects due to the order of Music and Interaction were not controlled for in the present study due to the small sample size. To investigate to what extent parents used MIT strategies in Music and Interaction, clinical judgements about parental behaviour would have to be made. Likewise, this study does not evaluate efficacy of MIT, as the two conditions of Music and Interactions are too close together.

### 6.4.3 Data analysis

Micro-analysis was favoured over global analysis for the present investigation (see 3.2 and 4.2.2 for a justification). Furthermore, a global measure ('mutual shared attention') was trialled in the very beginning of studying the data, yet despite training efforts, inter-rater reliability was too low to continue and therefore abandoned.

Previous studies did not all use appropriate statistical analyses (see 3.3). The advantage of the present study is that it used time-series analysis to evaluate the data (the advantages of which were listed in section 3.4.5). In brief, time-series analysis is appropriate for assessing dynamic data between interaction partners and allows detailed quantification of social timing

parameters. Additionally, it enables comparison to other studies that used the same approach. Thus, by choosing this type of analysis previous studies' drawbacks were minimised.

Clip selection for analysis was carried out based on interaction scores, a coding scheme devised for this specific purpose (see 4.4.5). It was hoped that interaction scores would serve the dual purpose of selecting a clip based on the child's willingness to engage and appropriate visual quality while providing an indication of the session's overall interaction quality. While it was useful as a selection tool, it did not seem to capture interaction quality.

One would expect that interaction quality and social timing would correlate, however, interaction scores and social timing parameters did not correlate. This may be because there is no correlation between the two, or interaction scores did not capture it.

#### 6.4.4 Adaptation of coding scheme

One of the main challenges in designing the method for this study was adapting the chosen approach to a population of preschool-aged children with ASD (refer to section 4.2 for the reasons; see section 4.3 for details on adaptations and decision-making process). The resulting adaptation of the coding scheme was easily learnt and applied. It saved time during coding, as it was much more condensed than the original MP coding scheme.

A major limitation is that inter-rater reliability was not established due to time constraints, which limits this study's validity. Ideally, a secondary coder would have independently coded a large portion of the data set to be compared with the primary rater's coding. However, as a pilot study, it allowed us to gauge whether this type of methodology could be applied to learn more about social timing in this population. From this point of view, the methodology seems worthy of further evaluation and the present findings provide valuable insight about social timing skills in ASD.

#### 6.4.5 Comparability with other studies

Comparability of the present study with previous MP studies is limited by two factors; firstly, different populations under study; and secondly, the adaptation of the method.

Comparing the social timing ability of children with ASD in this sample with previous studies' findings is complicated by the vast age and population differences. Interpretations

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remain speculative, until such a study is repeated with a control group. However, comparing studies that used micro-analysis with discrete outcome variables is superior to comparing outcomes of subjective global ratings.

The question might be raised whether sensory and motor abnormalities seen in ASD affect findings. For instance, children with ASD might show movements in response to emotional excitement, or generally express themselves differently from TD children. Differences in movement and interactive preferences were noted, however, the absence of a control group makes validation of these difficult. To illustrate, the children in this sample frequently enjoyed walking hand-in-hand with their caregiver, and smiled less than expected of a TD child. Behaviours that might indicate dealing with emotional excitement, such as flapping, were not seen in the recordings, which may be due to the fact that clips for micro-analysis were deliberately chosen so that maximum engagement of the child was shown.

Finally, characteristics of the interacting adult deserve some considerations. The adult caregivers in this study were mothers, fathers and female teaching assistants. In all but two dyadic MP studies the interacting adult was the child's mother (Yirmiya et al., 2006). Two studies that included fathers explicitly compared differences in synchrony outcomes due to parent sex (Feldman, 2003; Feldman & Eidelman, 2007). Same-sex dyads showed more optimal levels of synchrony compared to different-sex dyads (Feldman, 2003). Both full-term and prematurely born children showed higher levels of synchrony with the mother than with the father (Feldman & Eidelman, 2007). It is therefore feasible, that child and parent sex affected the data. Even though most dyads included only the mother ( $N = 10$ ), two included both, mother and father, and both were marked by differences. The analysed sessions from dyad #14 were carried out with mother, which was not ideal because the girl preferred interacting with her father (according to the supervising Assistant Psychologist). In contrast, the girl from dyad #10 preferred interacting with her mother.

Data on the parents' mental health was not collected as part of this study. Parents of children with ASD suffer from additional stress that may manifest as increased difficulties with parenting, anxiety, discomfort and a decreased sense of parental competence (Craig et al., 2016). Similarly, researchers that investigated the effects of maternal depression on interactional synchrony reported less optimal levels of synchrony (Field et al., 1990; Zlochower & Cohn, 2001). In sum, parental mental health appears to affect synchrony levels and not having recorded these in this study is a limitation.

## 6.5 Summary

This chapter's objective was to discuss the findings of this thesis. The chapter was divided into three parts, beginning with answers to the research questions, followed by a discussion of unexpected findings and lastly, an evaluation of the method chosen to address the aim of this study.

Part one answered the questions whether this sample showed cyclicity and synchrony, and whether Music promoted this. The data showed that all children with ASD engaged in rhythmic interaction behaviour, yet not all of them were consistent. Music, on the other hand, increased consistency considerably. Findings were compared with data from previous studies, and confirmed the expectation that children with ASD show lower engagement in rhythmical behaviour than TD children. Children in this sample showed coherence levels similar to samples in previous literature, who are typically between 3- to 9-months old. Synchrony was achieved with and without Music, however, it was much lower compared to TD infants. Music significantly promoted synchrony.

Next, two unexpected findings were discussed in depth; the finding that Music promoted social timing and that no change over time was observed for any of the social timing measures. The present study corroborated previous findings that music is a helpful part of interventions for children with ASD and that it has an immediate positive effect on social timing, which in turn increases social interaction. Taken together, results indicate that music is an essential part of MIT. The methodology of the present study could possibly be used to evaluate music interventions in the future. However, the present study did not show changes over time, and possible reasons were discussed. If the focus of a study were to detect change, an alternative route would be advisable.

Finally, an evaluation of this thesis' methodology followed. The major achievements include defining social timing terms, micro-analysis and use of time-series analysis, adaption of the coding scheme and comparability of data to previous studies. The main limitations of this study are the lack of inter-rater reliability and the absence of a control group. The next chapter provides the conclusions to this work.





# 7 Conclusion

## 7.1 Introduction

The previous chapter discussed the research findings and evaluated the approach used in this study. Findings were interpreted and related to data from previous literature. Achievements and drawbacks were appraised in the final section.

This final chapter of my thesis presents the reader with the major conclusions of this thesis. Its purpose is to assess whether the aim defined in the introduction was achieved, and what impact the outcome may have on future applications. It starts with a brief summary of the key findings and is followed by an evaluation of the usefulness of this study, including its limitations. Finally, recommendations for further research and practice are offered, see Figure 7.1.

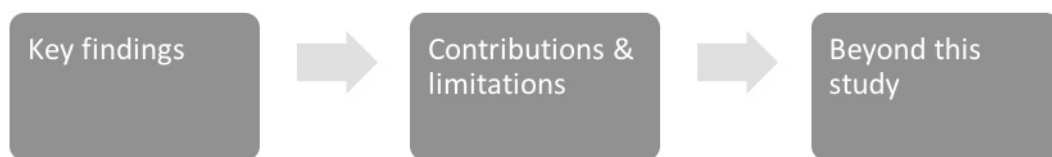


Figure 7.1 Chapter overview

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## 7.2 Key findings

This thesis addressed social timing in children with ASD, with the aim to extend current knowledge of this topic (Chapter 1). Social timing was explored in terms of its relationship with timing and development. Social timing, including interactional synchrony, emerges in the first year of life and both play a key role on concurrent development and long-term outcomes (Chapter 2).

Children with ASD are challenged in their social and communication abilities, which has been attributed to abnormal timing and social timing (Allman, 2011; Amos, 2013; Grossberg & Seidman, 2006; Wimpory et al., 2002). A review of existing social timing studies found overwhelming evidence towards deficits in both intra- and interpersonal timing in ASD. Based on the literature review, it was found that existing research is limited to four studies investigating interactional synchrony suffering methodological limitations. This revealed not only a need for further study, but also finding a method to overcome previous limitations.

To find an improved method, those of existing studies were examined in Chapter 3. The evaluation revealed that only one study of infants at risk for ASD has produced data that quantified social timing parameters (i.e. cyclicity and synchrony) and allowed comparison with previous social timing data in different populations (Yirmiya et al., 2006). This method was adapted to suit the present study's population of interest (Chapter 4).

The main findings of this thesis were that the children in this sample showed cyclicity and synchrony but not consistently (Chapter 5). Remarkably, Music enhanced all social timing measures. It appears that music is a valuable tool in enhancing social timing in general (Demos et al., 2012; Tarr, 2014), but also as an intervention tool for children with ASD (Accordino et al., 2007; Kim et al., 2009; Whipple, 2004; Wigram & Gold, 2006). There was no change over time for either of these variables most likely due to fluctuations in the children's willingness to engage. The methodology and adapted coding scheme born out of this project may possibly serve for future studies investigating both the effect of social timing in the general population and evaluating concurrent social timing effects of music interventions (Chapter 6).

The main conclusions can be summarised as follows:

- Preschoolers with ASD have the potential to engage in rhythmic interactive behaviour and in synchronous exchange with a familiar caregiver
- Social timing abilities in this group are diminished compared to TD infants
- Music enhanced consistency of cyclicity and synchrony
- The method designed for this study served its purpose and may be useful in future studies investigating the concurrent effects of music on social timing

The aim of this investigation has been met, however, a list of further work has been noted throughout (see 7.3 and 7.4)

## 7.3 Contributions and limitations

The findings support previous literature that showed that individuals with ASD have diminished social timing skills. Moreover, findings are extended by arguing that social timing skills are impaired yet fundamentally present and can be enhanced. All children in this sample showed the potential to engage in timely interaction behaviour under favourable conditions. As demonstrated, this potential can be promoted through the use of music.

The present study differs from previous work in several respects. It presents a thorough review of previous social timing studies along with a critical evaluation of their methods. While this exists for music intervention studies in ASD, this was so far lacking in social timing studies. Moreover, this study is the first to my knowledge, to compare intra- and interpersonal timing abilities with and without music when the child was willing to engage. Finally, this study offers a new methodology to study social timing in a group setting and resulting data can be micro-analysed and examined using time-series analysis, thereby overcoming previously criticised shortcomings of case-study designs and inappropriate statistical analyses.

In sum, this study's particular contribution lies in:

- Providing a methodology addressing previous shortcomings
- Quantifying social timing potential in preschoolers with ASD
- Confirming the benefits of music on social timing abilities within the MIT setting

This study was set up as an observational study using readily available recordings made for clinical and research purposes. There were obvious advantages to such a design; minimal

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burden on participants and low costs. However, there are also limiting factors that must be considered:

- Variables were not controlled as tightly as expected of a laboratory study, for example, time between session differed from dyad to dyad.
- The group size was not large enough to test for differences in social timing ability based on symptom severity or verbal abilities
- The absence of a control group limits comparability
- Parental mental health was not recorded and analysed
- Inter-rater reliability was not established due to time constraints
- The present method does not evaluate change, and thus this method might not be suitable to evaluate music interventions over time

## 7.4 Beyond this study

This thesis has shown that social timing in ASD as measured by micro-analysis and time-series analysis is achievable and that music may be an important contributor to promoting social timing in ASD. Evidence that music interventions have favourable long-term outcomes already exists (see 6.3.1). However, there are several important questions that remain unexplored.

### *Theoretical and practical implications*

Using this methodology, at what age do social timing abilities diverge? Could music be used preventatively?

If music affects social timing, what does it mean for who, or what, drives the rhythm in interaction? Does this affect people with ASD in the same way as people without ASD?

How can music be used to boost the impact of existing play-based interventions for children with ASD? Should we encourage parents of affected children to use music at home when engaging with them playfully? What are the limits of using music? And what kind of music is best used, and does it matter how it is delivered (e.g. live or pre-recorded)? Finally, are there children that do not benefit from the use of music?

### *Further research*

The findings of this study provide several avenues for future research. While this study answered the aim, gaps in knowledge still exist due to the limitations of this study. The major drawback, the lack of inter-rater reliability, would need to be addressed first. The following modifications would be recommended if the study were to be replicated:

- Replication with a larger group and more time points to discern which factors promote or hinder synchrony (e.g. symptom severity, dyad sex, parental mental health, parental sensitivity, maturity of child)
- Replication with a control group, such as a group of TD or DD children that are matched by chronological or developmental age

Current findings could be extended by applying the present method to other settings, for example, to test the immediate effect of music on social timing in other populations in dyadic settings, or by including similar music interventions for children with developmental difficulties.

Moreover, the present study leads to new methodological questions that could be addressed in future research, such as how change of social timing pre- and post-intervention could be evaluated and what measure can inform about interaction quality. One could replicate this study with multiple measurements spaced further apart to see if change can be captured, including a baseline and post-intervention measure. An already validated measure of change could be used to verify results. Furthermore, one could investigate what type and delivery of music is most helpful in fostering rhythmical social timing in ASD, which might boost the impact of already existing interventions.

### *A final word*

While it is necessary to understand the theoretical aspects of social timing in ASD, it is also important to generate insights that can be readily applied by clinicians and parents. This thesis has shown what social timing is, as measured by micro-analysis of dyadic interaction, why it is so important in early development and how symptoms in ASD may be due to disruptions of social timing abilities (Chapter 2). It has evaluated existing studies and searched for a method to overcome drawbacks (Chapter 3). These findings informed the design of a method that was applied to a new and as yet uninvestigated sample (Chapter 4). It showed that children in this sample could engage in rhythmic social timing (as defined by Monadic

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Phase methodology), particularly when supported by concurrent MIT (Chapter 5 and 6). In sum, this study added to existing knowledge of social timing in ASD, provided inter-rater reliability is established, and has offered a method that can be used to investigate further: such as social timing abilities of other groups; or the impact of other musical interventions on social timing. It is hoped that this work inspires further investigation of social timing and interventions that may improve the lives of those affected by ASD.

## References

- Accordino, R., Comer, R., & Heller, W. B. (2007). Searching for music's potential: A critical examination of research on music therapy with individuals with autism. *Research in Autism Spectrum Disorders*, 1(1), 101–115. <http://doi.org/10.1016/j.rasd.2006.08.002>
- Allman, M. J. (2011). Deficits in temporal processing associated with autistic disorder. *Frontiers in Integrative Neuroscience*, 5, 2. <http://doi.org/10.3389/fnint.2011.00002>
- Allman, M. J., DeLeon, I. G., & Wearden, J. H. (2011). Psychophysical Assessment of Timing in Individuals with Autism. *American Journal on Intellectual and Developmental Disabilities*, 116(2), 165–178. <http://doi.org/10.1352/1944-7558-116.2.165>
- Allman, M. J., & Falter, C. M. (2015). Timing Processes in autism spectrum disorder. In, A. Vatakis & M. J. Allman (Eds.). *Time Distortions in Mind – Temporal Processing in Clinical Populations*. Leiden, The Netherlands: Brill Academic Publishers.
- Allman, M. J., Pelphrey, K. A., & Meck, W. H. (2012). Developmental neuroscience of time and number: implications for autism and other neurodevelopmental disabilities. *Frontiers in Integrative Neuroscience*, 6, 7. <http://doi.org/10.3389/fnint.2012.00007>
- American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders: DSM-IV-TR*. Washington, DC: American Psychiatric Association.
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Washington, D.C: American Psychiatric Association.
- Amos, P. (2013). Rhythm and timing in autism: learning to dance. *Frontiers in Integrative Neuroscience*, 7, 27. <http://doi.org/10.3389/fnint.2013.00027>
- Bakeman, R., & Adamson, L. B. (1984). Coordinating attention to people and objects in mother-infant and peer-infant interaction. *Child Development*, 55(4), 1278–1289.
- Bakeman, R., & Brown, J. V. (1977). Behavioral dialogues: An approach to the assessment of mother-infant interaction. *Child Development*, 48(1), 195-203.
- Baker, J. K., Fenning, R. M., Howland, M. A., Baucom, B. R., Moffitt, J., & Erath, S. A. (2015). Brief Report: A Pilot Study of Parent–Child Biobehavioral Synchrony in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 45(12), 4140–4146. <http://doi.org/10.1007/s10803-015-2528-0>
- Baranek, G. T. (1999). Autism during infancy: a retrospective video analysis of sensory-motor and social behaviors at 9-12 months of age. *Journal of Autism and Developmental Disorders*, 29(3), 213–224.

- 
- Barnard, A. R., & Nolan, P. M. (2008). When Clocks Go Bad: Neurobehavioural Consequences of Disrupted Circadian Timing. *PLoS Genetics*, 4(5), e1000040–8. <http://doi.org/10.1371/journal.pgen.1000040>
- Bebko, J. M., Weiss, J. A., Demark, J. L., & Gomez, P. (2006). Discrimination of temporal synchrony in intermodal events by children with autism and children with developmental disabilities without autism. *Journal of Child Psychology and Psychiatry*, 47(1), 88–98. <http://doi.org/10.1111/j.1469-7610.2005.01443.x>
- Bernieri, F. J., Davis, J. M., Rosenthal, R., & Knee, C. R. (1994). Interactional Synchrony and Rapport: Measuring Synchrony in Displays Devoid of Sound and Facial Affect. *Personality and Social Psychology Bulletin*, 20(3), 303–311.
- Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain*, 128(Pt 10), 2430–2441. <http://doi.org/10.1093/brain/awh561>
- Bieleninik, L., Geretsegger, M., Mössler, K., Assmus, J., Thompson, G., Gattino, G., et al. (2017). Effects of Improvisational Music Therapy vs Enhanced Standard Care on Symptom Severity Among Children with Autism Spectrum Disorder. *Jama*, 318(6), 525–11. <http://doi.org/10.1001/jama.2017.9478>
- Biscaldi, M., Rauh, R., Müller, C., Irion, L., Saville, C. W. N., Schulz, E., & Klein, C. (2015). Identification of neuromotor deficits common to autism spectrum disorder and attention deficit/hyperactivity disorder, and imitation deficits specific to autism spectrum disorder. *European Child & Adolescent Psychiatry*, 24(12), 1497–1507. <http://doi.org/10.1007/s00787-015-0753-x>
- Blakemore, S.-J., Boyer, P., Pachot-Clouard, M., Meltzoff, A., Segebarth, C., & Decety, J. (2003). The detection of contingency and animacy from simple animations in the human brain. *Cerebral Cortex*, 13(8), 837–844.
- Bone, D., Lee, C. C., Potamianos, A., & Narayanan, S. (2014). An Investigation of Vocal Arousal Dynamics in Child-Psychologist Interactions using Synchrony Measures and a Conversation-based Model. In *Fifteenth Annual Conference of the International Speech Communication Association*.
- Bopp, K. D., Mirenda, P., & Zumbo, B. D. (2009). Behavior predictors of language development over 2 years in children with autism spectrum disorders. *Journal of Speech Language and Hearing Research*, 52(5), 1106–1120. [http://doi.org/10.1044/1092-4388\(2009/07-0262\)](http://doi.org/10.1044/1092-4388(2009/07-0262))
- Brazelton, T. B., Koslowski, B., & Main, M. (1974). The origins of reciprocity: The early mother-infant interaction. In M. Lewis & L. A. Rosenblum, *The effect of the infant on its caregiver*. Oxford, England: Wiley-Interscience.



- Brenner, L. A., Shih, V. H., Colich, N. L., Sugar, C. A., Bearden, C. E., & Dapretto, M. (2014). Time Reproduction Performance Is Associated with Age and Working Memory in High-Functioning Youth with Autism Spectrum Disorder. *Autism Research*, 8(1), 29–37. <http://doi.org/10.1002/aur.1401>
- Brock, J., Brown, C. C., Boucher, J., & Rippon, G. (2002). The temporal binding deficit hypothesis of autism. *Development and Psychopathology*, 14(02), 1–17. <http://doi.org/10.1017/S0954579402002018>
- Broder-Fingert, S., Feinberg, E., & Silverstein, M. (2017). Music Therapy for Children with Autism Spectrum Disorder. *Jama*, 318(6), 523–524. <http://doi.org/10.1001/jama.2017.9478>
- Brodeur, D. A., Gordon Green, C., Flores, H., & Burack, J. A. (2014). Time Estimation Among Low-Functioning Individuals with Autism Spectrum Disorders: Evidence of Poor Sensitivity to Variability of Short Durations. *Autism Research*, 7(2), 237–244. <http://doi.org/10.1002/aur.1364>
- Bruinsma, Y., Koegel, R. L., & Koegel, L. K. (2004). Joint attention and children with autism: A review of the literature. *Mental Retardation and Developmental Disabilities Research Reviews*, 10(3), 169–175. <http://doi.org/10.1002/mrdd.20036>
- Chapple, E. D. (1970). Experimental production of transients in human interaction. *Nature*, 228, 630–633.
- Charman, T. (2003). Why is joint attention a pivotal skill in autism? *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1430), 315–324. <http://doi.org/10.1098/rstb.2002.1199>
- Chevallier, C., Noveck, I., Happé, F., & Wilson, D. (2011). What's in a voice? Prosody as a test case for the Theory of Mind account of autism. *Neuropsychologia*, 49(3), 507–517.
- Chiang, C.-H., Soong, W.-T., Lin, T.-L., & Rogers, S. J. (2008). Nonverbal Communication Skills in Young Children with Autism. *Journal of Autism and Developmental Disorders*, 38(10), 1898–1906. <http://doi.org/10.1007/s10803-008-0586-2>
- Claassen, D. O., Jones, C. R. G., Yu, M., Dirnberger, G., Malone, T., Parkinson, M., et al. (2013). Deciphering the impact of cerebellar and basal ganglia dysfunction in accuracy and variability of motor timing. *Neuropsychologia*, 51(2), 267–274. <http://doi.org/10.1016/j.neuropsychologia.2012.09.018>
- Clayton, M., Sager, R., & Will, U. (2004). In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM Counter Point*, 1, 1–45.
- Cohn, J. F. (2010). Advances in Behavioral Science Using Automated Facial Image Analysis and Synthesis [Social Sciences. *IEEE Signal Processing Magazine*, 1–6. <http://doi.org/10.1109/MSP.2010.938102>

- 
- Cohn, J. F., & Tronick, E. Z. (1987). Mother-infant face-to-face interaction: The sequence of dyadic states at 3, 6, and 9 months. *Developmental Psychology*, 23(1), 68–77. <http://doi.org/10.1037//0012-1649.23.1.68>
- Cohn, J. F., & Tronick, E. Z. (1988). Mother-infant face-to-face interaction: Influence is bidirectional and unrelated to periodic cycles in either partner's behavior. *Developmental Psychology*, 24(3), 386–392.
- Condon, W., & Ogston, W. (1971). Speech and body motion synchrony of the speaker-hearer. In D. Horton and J. Jenkins, eds. *The Perception of Language*, pp. 150–84. Columbus, OH: Charles E. Merrill.
- Condon, W. S., & Sander, L. W. (1974). Synchrony demonstrated between movements of the neonate and adult speech. *Child Development*, 45(2), 456–462.
- Cope, T. E., Grube, M., Singh, B., Burn, D. J., & Griffiths, T. D. (2014). The basal ganglia in perceptual timing\_ Timing performance in Multiple System Atrophy and Huntington's disease. *Neuropsychologia*, 52(C), 73–81. <http://doi.org/10.1016/j.neuropsychologia.2013.09.039>
- Cortesi, F., Giannotti, F., Ivanenko, A., & Johnson, K. (2010). Sleep in children with autistic spectrum disorder. *Sleep Medicine*, 11(7), 659–664. <http://doi.org/10.1016/j.sleep.2010.01.010>
- Courchesne, E., Karns, C. M., Davis, H. R., Ziccardi, R., Carper, R. A., Tigue, Z. D., et al. (2001). Unusual brain growth patterns in early life in patients with autistic disorder: an MRI study. *Neurology*, 57(2), 245–254.
- Courchesne, E., Redcay, E., & Kennedy, D. P. (2004). The autistic brain: birth through adulthood. *Current Opinion in Neurology*, 17(4), 489–496. <http://doi.org/10.1097/01.wco.0000137542.14610.b4>
- Courchesne, E., Townsend, J., Akshoomoff, N. A., Saitoh, O., Yeung-Courchesne, R., Lincoln, A. J., et al. (1994). Impairment in shifting attention in autistic and cerebellar patients. *Behavioral Neuroscience*, 108(5), 848–865.
- Craig, F., Operto, F. F., De Giacomo, A., Margari, L., Froli, A., Conson, M., et al. (2016). Parenting Stress among parents of children with Neurodevelopmental Disorders. *Psychiatry Research*, 1–9. <http://doi.org/10.1016/j.psychres.2016.05.016>
- Curioni, A., Minio-Paluello, I., Sacheli, L. M., Candidi, M., & Aglioti, S. M. (2017). Autistic traits affect interpersonal motor coordination by modulating strategic use of role-based behavior, *Molecular Autism*, 8, 1–13. <http://doi.org/10.1186/s13229-017-0141-0>
- Dawson, G., Meltzoff, A. N., Osterling, J. A., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders*, 28(6), 479–485.

- de Boer-Schellekens, L., Eussen, M., & Vroomen, J. (2013). Diminished sensitivity of audiovisual temporal order in autism spectrum disorder. *Frontiers in Integrative Neuroscience*, 7, 8. <http://doi.org/10.3389/fnint.2013.00008>
- DeCasper, A., & Carstens, A. (1980). Contingencies of Stimulation: Effect on Learning and Emotions in Neonates. *Infant Behaviour and Development*, 4, 19-35.
- DeCasper A.J., & Fifer, W.P. (1980). Of human bonding: Newborns prefer their mother's voices. *Science*, 208, 1174–1176.
- De Jaegher, H. (2006). Social interaction rhythm and participatory sense-making. Unpublished doctoral thesis.
- Delaherche, E., Chetouani, M., Bigouret, F., Xavier, J., Plaza, M., & Cohen, D. (2013). Assessment of the communicative and coordination skills of children with Autism Spectrum Disorders and typically developing children using social signal processing. *Research in Autism Spectrum Disorders*, 7(6), 741–756. <http://doi.org/10.1016/j.rasd.2013.02.003>
- Delaherche, E., Chetouani, M., Mahdhaoui, A., Saint-Georges, C., Viaux, S., & Cohen, D. (2012). Interpersonal Synchrony: A Survey of Evaluation Methods across Disciplines. *IEEE Transactions on Affective Computing*, 3(3), 349–365. <http://doi.org/10.1109/T-AFFC.2012.12>
- Demos, A. P., Chaffin, R., Begosh, K. T., Daniels, J. R., & Marsh, K. L. (2012). Rocking to the beat: Effects of music and partner's movements on spontaneous interpersonal coordination. *Journal of Experimental Psychology*, 141(1), 49–53. <http://doi.org/10.1037/a0023843>
- Dodd, B. (1979). Lip reading in infants: Attention to speech presented in- and out-of-synchrony. *Cognitive Psychology*, 11(4), 478–484. [http://doi.org/10.1016/0010-0285\(79\)90021-5](http://doi.org/10.1016/0010-0285(79)90021-5)
- Dominguez, S., Devouche, E., Apter, G., & Gratier, M. (2016). The Roots of Turn-Taking in the Neonatal Period. *Infant and Child Development*, 25(3), 240–255. <http://doi.org/10.1002/icd.1976>
- Doussard-Roosevelt, J. A., Joe, C. M., Bazhenova, O. V., & Porges, S. W. (2003). Mother-child interaction in autistic and nonautistic children: characteristics of maternal approach behaviors and child social responses. *Development and Psychopathology*, 15(2), 277–295.
- Dreher, J.-C., & Grafman, J. (2002). The roles of the cerebellum and basal ganglia in timing and error prediction. *European Journal of Neuroscience*, 16(8), 1609–1619. <http://doi.org/10.1046/j.1460-9568.2002.02212.x>
- Elia, M., Ferri, R., Musumeci, S. A., Del Gracco, S., Bottitta, M., Scuderi, C., et al. (2000). Sleep in subjects with autistic disorder: a neurophysiological and psychological study. *Brain and Development*, 22(2), 88–92.
- Falter, C. M., Elliott, M. A., & Bailey, A. J. (2012). Enhanced visual temporal resolution in Autism Spectrum Disorders. *PLoS One*, 7(3), 1-6.

- 
- Falter, C. M., & Noreika, V. (2011). Interval timing deficits and abnormal cognitive development. *Frontiers in Integrative Neuroscience*, 5, 26. <http://doi.org/10.3389/fnint.2011.00026>
- Falter, C. M., Noreika, V., Wearden, J. H., & Bailey, A. J. (2012). More consistent, yet less sensitive: Interval timing in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 65(11), 2093–2107. <http://doi.org/10.1080/17470218.2012.690770>
- Feldman, R. (2003). Infant-mother and infant-father synchrony: The coregulation of positive arousal. *Infant Mental Health Journal*, 24(1), 1–23. <http://doi.org/10.1002/imhj.10041>
- Feldman, R. (2006). From biological rhythms to social rhythms: Physiological precursors of mother-infant synchrony. *Developmental Psychology*, 42(1), 175–188. <http://doi.org/10.1037/0012-1649.42.1.175>
- Feldman, R. (2007a). Mother-Infant Synchrony and the Development of Moral Orientation in Childhood and Adolescence: Direct and Indirect Mechanisms of Developmental Continuity. *American Journal of Orthopsychiatry*, 77(4), 582-597.
- Feldman, R. (2007b). Parent-infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry*, 48(3-4), 329–354. <http://doi.org/10.1111/j.1469-7610.2006.01701.x>
- Feldman, R. (2012a). Bio-behavioral Synchrony: A Model for Integrating Biological and Microsocial Behavioral Processes in the Study of Parenting. *Parenting*, 12(2-3), 154–164. <http://doi.org/10.1080/15295192.2012.683342>
- Feldman, R. (2012b). Oxytocin and social affiliation in humans. *Hormones and Behavior*, 61(3), 380–391. <http://doi.org/10.1016/j.yhbeh.2012.01.008>
- Feldman, R. (2012c). Parent–infant synchrony: A biobehavioral model of mutual influences in the formation of affiliative bonds. *Monographs of the Society for Research in Child Development*, 42–51.
- Feldman, R. (2015). Sensitive periods in human social development: New insights from research on oxytocin, synchrony, and high-risk parenting. *Development and Psychopathology*, 27(02), 369–395. <http://doi.org/10.1017/S0954579415000048>
- Feldman, R., & Eidelman, A. I. (2004). Parent-Infant Synchrony and the Social-Emotional Development of Triplets. *Developmental Psychology*, 40(6), 1133–1147. <http://doi.org/10.1037/0012-1649.40.6.1133>
- Feldman, R., & Eidelman, A. I. (2007). Maternal postpartum behavior and the emergence of infant–mother and infant–father synchrony in preterm and full-term infants: The role of neonatal vagal tone. *Developmental Psychobiology*, 49(3), 290–302. <http://doi.org/10.1002/dev.20220>

- Feldman, R., Golan, O., Hirschler-Guttenberg, Y., Ostfeld-Etzion, S., & Zagoory-Sharon, O. (2014). Parent-child interaction and oxytocin production in pre-schoolers with autism spectrum disorder. *The British Journal of Psychiatry*, 205(2), 107–112. <http://doi.org/10.1192/bjp.bp.113.137513>
- Feldman, R., Granat, A., Pariente, C., Kanety, H., Kuint, J., & Gilboa-Schechtman, E. (2009). Maternal Depression and Anxiety Across the Postpartum Year and Infant Social Engagement, Fear Regulation, and Stress Reactivity. *Jaac*, 48(9), 919–927. <http://doi.org/10.1097/CHI.0b013e3181b21651>
- Feldman, R., Greenbaum, C. W., & Yirmiya, N. (1999). Mother-infant affect synchrony as an antecedent of the emergence of self-control. *Developmental Psychology*, 35(1), 223–231.
- Feldman, R., Greenbaum, C. W., Yirmiya, N., & Mayes, L. C. (1996). Relations between cyclicality and regulation in mother-infant interaction at 3 and 9 months and cognition at 2 years. *Journal of Applied Developmental Psychology*, 17, 347–365.
- Feldman, R., Magori-Cohen, R., Galili, G., Singer, M., & Louzoun, Y. (2011). Infant Behavior and Development. *Infant Behavior and Development*, 34(4), 569–577. <http://doi.org/10.1016/j.infbeh.2011.06.008>
- Feldman, R., Weller, A., Zagoory-Sharon, O., & Levine, A. (2007). Evidence for a neuroendocrinological foundation of human affiliation: plasma oxytocin levels across pregnancy and the postpartum period predict mother-infant bonding. *Psychological Science*, 18(11), 965–970. <http://doi.org/10.1111/j.1467-9280.2007.02010.x>
- Feldstein, S., Jaffe, J., Beebe, B., & Crown, C. L. (1993). Coordinated interpersonal timing in adult-infant vocal interactions: A cross-site replication. *Infant Behavior and Development*, 16, 455–470.
- Feldstein, S., Konstantareas, M., Oxman, J., & Webster, C. D. (1982). The chronography of interactions with autistic speakers: an initial report. *Journal of Communication Disorders*, 15(6), 451–460.
- Field, T. M., Healy, B. T., & Goldstein, S. (1990). Behavior-state matching and synchrony in mother-infant interactions of nondepressed versus depressed dyads. *Developmental Psychology*, 26(1), 7–14.
- Fitzpatrick, P., Diorio, R., Richardson, M. J., & Schmidt, R. C. (2013). Dynamical methods for evaluating the time-dependent unfolding of social coordination in children with autism. *Frontiers in Integrative Neuroscience*, 7, 21. <http://doi.org/10.3389/fnint.2013.00021>
- Fitzpatrick, P., Frazier, J. A., Cochran, D. M., Mitchell, T., Coleman, C., & Schmidt, R. C. (2016). Impairments of Social Motor Synchrony Evident in Autism Spectrum Disorder. *Frontiers in Psychology*, 7(510), 469–13. <http://doi.org/10.3389/fpsyg.2016.01323>

- 
- Fitzpatrick, P., Romero, V., Amaral, J. L., Duncan, A., Barnard, H., Richardson, M. J., & Schmidt, R. C. (2017). Evaluating the importance of social motor synchronization and motor skill for understanding autism. *Autism Research*, 9(2), 993–13. <http://doi.org/10.1002/aur.1808>
- Fogel, A. (1988). Cyclicity and stability in mother-infant face-to-face interaction: A comment on Cohn and Tronick (1988), *Developmental Psychology*, 24(3), 393-395.
- Fogel, A. (1993). *Developing through Relationships: Origins of Communication, Self, and Culture*. Chicago, IL: University of Chicago Press.
- Foss-Feig, J. H., Kwakye, L. D., Cascio, C. J., Burnette, C. P., Kadivar, H., Stone, W. L., & Wallace, M. T. (2010). An extended multisensory temporal binding window in autism spectrum disorders. *Experimental Brain Research*, 203(2), 381–389. <http://doi.org/10.1007/s00221-010-2240-4>
- Fujikawa-Brooks, S., Isenberg, A. L., Osann, K., Spence, M. A., & Gage, N. M. (2010). The effect of rate stress on the auditory brainstem response in autism: A preliminary report. *International Journal of Audiology*, 49(2), 129–140. <http://doi.org/10.3109/14992020903289790>
- Gabig, C. S. (2013). Protodeclarative. In F. R. Volkmar (Ed.), *Encyclopedia of Autism Spectrum Disorders* (pp. 2418–2419). New York, NY: Springer New York.
- Gepner, B., & Féron, F. (2009). Autism: A world changing too fast for a mis-wired brain? *Neuroscience and Biobehavioral Reviews*, 33(8), 1227–1242. <http://doi.org/10.1016/j.neubiorev.2009.06.006>
- Geretsegger, M., Elefant, C., Mössler, K. A., & Gold, C. (2014). Music therapy for people with autism spectrum disorder. *The Cochrane Database of Systematic Reviews*, (6), CD004381. <http://doi.org/10.1002/14651858.CD004381.pub3>
- Gil, S., Chambres, P., Hyvert, C., Fanget, M., & Droit-Volet, S. (2012). Children with Autism Spectrum Disorders Have “The Working Raw Material” for Time Perception. *PLoS ONE*, 7(11), e49116–10. <http://doi.org/10.1371/journal.pone.0049116>
- Gordon, I., & Feldman, R. (2008). Synchrony in the triad: a microlevel process model of coparenting and parent-child interactions. *Family Process*, 47(4), 465–479.
- Gottman, J. M. (1979). Detecting cyclicity in social interaction. *Psychological Bulletin*, 86(2), 338-348.
- Gottman, J. M., & Ringland, J. T. (1981). The analysis of dominance and bidirectionality in social development. *Child Development*, 52(2), 393-412.
- Gowen, E., & Miall, R. C. (2005). Behavioural aspects of cerebellar function in adults with Asperger syndrome. *The Cerebellum*, 4(4), 279–289. <http://doi.org/10.1080/14734220500355332>
- Granat, A., Gadassi, R., Gilboa-Schechtman, E., & Feldman, R. (2017). Maternal depression and anxiety, social synchrony, and infant regulation of negative and positive emotions. *Emotion*, 17(1), 11–27. <http://doi.org/10.1037/emo0000204>

- Gratier, M. (2003). Expressive timing and interactional synchrony between mothers and infants: cultural similarities, cultural differences, and the immigration experience. *Cognitive Development*, 18(4), 533–554. <http://doi.org/10.1016/j.cogdev.2003.09.009>
- Green, J., Charman, T., McConachie, H., Aldred, C., Slonims, V., Howlin, P., et al. (2010). Parent-mediated communication-focused treatment in children with autism (PACT): a randomised controlled trial. *Lancet* (London, England), 375(9732), 2152–2160. [http://doi.org/10.1016/S0140-6736\(10\)60587-9](http://doi.org/10.1016/S0140-6736(10)60587-9)
- Greenspan, S. I., & Wieder, S. (1997). Developmental Patterns and Outcomes in Infants and Children with Disorders in Relating and Communicating: A Chart Review of 200 Cases of Children with Autistic Spectrum Diagnoses. *Journal of Developmental and Learning Disorders*, 1(1), 2-38.
- Grossberg, S., & Seidman, D. (2006). Neural Dynamics of Autistic Behaviors: Cognitive, Emotional and Timing Substrates. *Psychological Review*, 1–85.
- Grzadzinski, R., Carr, T., Colombi, C., McGuire, K., Dufek, S., Pickles, A., & Lord, C. (2016). Measuring Changes in Social Communication Behaviors: Preliminary Development of the Brief Observation of Social Communication Change (BOSCC). *Journal of Autism and Developmental Disorders*, 1–16. <http://doi.org/10.1007/s10803-016-2782-9>
- Gutstein, S. E. (2009). Empowering families through Relationship Development Intervention: an important part of the biopsychosocial management of autism spectrum disorders. *Annals of Clinical Psychiatry: Official Journal of the American Academy of Clinical Psychiatrists*, 21(3), 174–182.
- Hane, A. A., Feldstein, S., & Dornetz, V. H. (2003). The relation between coordinated interpersonal timing and maternal sensitivity in four-month-old infants. *Journal of Psycholinguistic Research*, 32(5), 525–539.
- Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 36(1), 5–25.
- Harrist, A. W., & Waugh, R. M. (2002). Dyadic synchrony: Its structure and function in children's development. *Developmental Review*, 22(4), 555–592. [http://doi.org/10.1016/S0273-2297\(02\)00500-2](http://doi.org/10.1016/S0273-2297(02)00500-2)
- Hedenbro, M., & Tjus, T. (2007). A case study of parent child interactions of a child with autistic spectrum disorder (3 48 months) and comparison with typically-developing peers. *Child Language Teaching and Therapy*, 23(2), 201–222. <http://doi.org/10.1177/0265659007076294>
- Hitchcock, David B. (2009). Yates and Contingency Tables: 75 Years Later. Retrieved 4/8/2015 from: University of South Carolina.

- 
- Hobson, J. A., Tarver, L., Beurkens, N., & Hobson, R. P. (2016). The Relation between Severity of Autism and Caregiver-Child Interaction: A Study in the Context of Relationship Development Intervention. *Journal of Abnormal Child Psychology*, 44(4), 745–755. <http://doi.org/10.1007/s10802-015-0067-y>
- Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition*, 27(6), 949-961.
- Hu, V. W., Sarachana, T., Kim, K. S., Nguyen, A., Kulkarni, S., Steinberg, M. E., et al. (2009). Gene expression profiling differentiates autism case-controls and phenotypic variants of autism spectrum disorders: evidence for circadian rhythm dysfunction in severe autism. *Autism Research*, 2(2), 78–97. <http://doi.org/10.1002/aur.73>
- Hudry, K., Aldred, C., Wigham, S., Green, J., Leadbitter, K., Temple, K., et al. (2013). Predictors of parent-child interaction style in dyads with autism. *Research in Developmental Disabilities*, 34(10), 3400–3410. <http://doi.org/10.1016/j.ridd.2013.07.015>
- Humber, N. and Moss, E. (2005), The Relationship of Preschool and Early School Age Attachment to Mother-Child Interaction. *American Journal of Orthopsychiatry*, 75: 128–141. doi:10.1037/0002-9432.75.1.128
- IBM Corp. Released 2016. IBM SPSS Statistics for Macintosh, Version 24.0. Armonk, NY: IBM Corp.
- Isabella, R. A., & Belsky, J. (1991). Interactional synchrony and the origins of infant-mother attachment: a replication study. *Child Development*, 62(2), 373–384.
- Izard, C.E., (1979). *The Maximally Discriminative Facial Movement Coding System (MAX)*. Newark, DE: University of Delaware Instructional Resource Center.
- Jaffe, J., Beebe, B., Feldstein, S., Crown, Jasnow, Rochat, & Stern, D. N. (2001). Rhythms of Dialogue in Infancy: Coordinated Timing in Development, *Monographs of the Society for Research in Child Development*, 66(2), 1–149.
- Jasnow, M., Crown, C. L., Feldstein, S., Taylor, L., & Beebe, B. (1988). Coordinated interpersonal timing of Down-syndrome and nondelayed infants with their mothers: Evidence for a buffered mechanism of social interaction. *The Biological Bulletin*, 175(3), 355-360.
- Jebb, A. T., Tay, L., Wang, W., & Huang, Q. (2015). Time series analysis for psychological research: examining and forecasting change. *Frontiers in Psychology*, 6, 270–24. <http://doi.org/10.3389/fpsyg.2015.00727>
- Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*, 40(1-2), 1–19.



- Jones, C. R. G., Lambrechts, A., & Gaigg, S. B. (2017). Using Time Perception to Explore Implicit Sensitivity to Emotional Stimuli in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 47(7), 2054–2066. <http://doi.org/10.1007/s10803-017-3120-6>
- Jones, C. R. G., Happé, F., Baird, G., Simonoff, E., Marsden, A. J. S., Tregay, J., et al. (2009). Auditory discrimination and auditory sensory behaviours in autism spectrum disorders. *Neuropsychologia*, 47(13), 2850–2858. <http://doi.org/10.1016/j.neuropsychologia.2009.06.015>
- Karaminis, T., Cicchini, G. M., Neil, L., Cappagli, G., Aagten-Murphy, D., Burr, D., & Pellicano, E. (2016). Central tendency effects in time interval reproduction in autism. *Nature Publishing Group*, 1–13. <http://doi.org/10.1038/srep28570>
- Kargas, N., López, B., Morris, P., & Reddy, V. (2016). Relations Among Detection of Syllable Stress, Speech Abnormalities, and Communicative Ability in Adults with Autism Spectrum Disorders. *Journal of Speech Language and Hearing Research*, 59(2), 206–10. [http://doi.org/10.1044/2015\\_JSLHR-S-14-0237](http://doi.org/10.1044/2015_JSLHR-S-14-0237)
- Kaye, K. (1982). *The Mental and Social Life of Babies: How Parents Create Persons*. Chicago, IL: The University of Chicago Press.
- Kim, J., Wigram, T., & Gold, C. (2009). Emotional, motivational and interpersonal responsiveness of children with autism in improvisational music therapy. *Autism*, 13(4), 389–409. <http://doi.org/10.1177/1362361309105660>
- Kjelgaard, M. M., & Tager-Flusberg, H. (2001). An Investigation of Language Impairment in Autism: Implications for Genetic Subgroups. *Language and Cognitive Processes*, 16(2-3), 287–308. <http://doi.org/10.1080/01690960042000058>
- Klin, A. (1991). Young autistic children's listening preferences in regard to speech: a possible characterization of the symptom of social withdrawal. *Journal of Autism and Developmental Disorders*, 21(1), 29-42.
- Koehne, S., Hatri, A., Cacioppo, J. T., & Dziobek, I. (2016). Perceived interpersonal synchrony increases empathy: Insights from autism spectrum disorder. *Cognition*, 146(C), 8–15. <http://doi.org/10.1016/j.cognition.2015.09.007>
- Konopka, R. J., & Benzer, S. (1971). Clock mutants of *Drosophila melanogaster*. *Proceedings of the National Academy of Sciences of the United States of America*, 68(9), 2112–2116.
- Kuhl, P. K., Coffey-Corina, S., Padden, D., & Dawson, G. (2005). Links between social and linguistic processing of speech in preschool children with autism: behavioral and electrophysiological measures. *Developmental Science*, 8(1), F1–F12. <http://doi.org/10.1111/j.1467-7687.2004.00384.x>

- 
- Kwakye, L. D., Foss-Feig, J. H., Cascio, C. J., Stone, W. L., & Wallace, M. T. (2011). Altered Auditory and Multisensory Temporal Processing in Autism Spectrum Disorders. *Frontiers in Integrative Neuroscience*, 4. <http://doi.org/10.3389/fnint.2010.00129>
- Lavelli, M., & Fogel, A. (2005). Developmental Changes in the Relationship Between the Infant's Attention and Emotion During Early Face-to-Face Communication: The 2-Month Transition. *Developmental Psychology*, 41(1), 265–280. <http://doi.org/10.1037/0012-1649.41.1.265>
- Leclère, C., Avril, M., Viaux-Savelon, S., Bodeau, N., Achard, C., Missonnier, S., et al. (2016). Interaction and behaviour imaging: a novel method to measure mother-infant interaction using video 3D reconstruction. *Translational Psychiatry*, 6(5), e816. <http://doi.org/10.1038/tp.2016.82>
- Lerner, M. D., McPartland, J. C., & Morris, J. P. (2013). Multimodal Emotion Processing in ASD: An event-related potential study. *Accident Analysis and Prevention*, 3, 11–21. <http://doi.org/10.1016/j.dcn.2012.08.005>
- Lester, B. M., Hoffman, J., & Brazelton, T. B. (1985). The rhythmic structure of mother-infant interaction in term and preterm infants. *Child Development*, 56(1), 15–27.
- Lewkowicz, D. J. (1996). Perception of auditory-visual temporal synchrony in human infants. *Journal of Experimental Psychology*. Human Perception and Performance, 22(5), 1094–1106.
- Lewkowicz, D. J. (2000). Infants' perception of the audible, visible, and bimodal attributes of multimodal syllables. *Child Development*, 71(5), 1241–1257.
- Limoges, E. (2005). Atypical sleep architecture and the autism phenotype. *Brain*, 128(5), 1049–1061. <http://doi.org/10.1093/brain/awh425>
- Lloyd, M., MacDonald, M., & Lord, C. E. (2011). Motor skills of toddlers with autism spectrum disorders. *Autism*, 17(2), 133–146. <http://doi.org/10.1177/1362361311402230>
- Lord, C., Rutter, M., Goode, S., Heemsbergen, J., Jordan, H., Mawhood, L., & Schopler, E. (1989). Autism diagnostic observation schedule: a standardized observation of communicative and social behavior. *Journal of Autism and Developmental Disorders*, 19(2), 185–212.
- Lorenz, T., Weiss, A., & Hirche, S. (2015). Synchrony and Reciprocity: Key Mechanisms for Social Companion Robots in Therapy and Care. *International Journal of Social Robotics*, 8(1), 125–143. <http://doi.org/10.1007/s12369-015-0325-8>
- Loveland, K. A., & Landry, S. H. (1986). Joint attention and language in autism and developmental language delay. *Journal of Autism and Developmental Disorders*, 16(3), 335–349.
- Lyakso, E., Frolova, O., & Grigorev, A. (2016). A Comparison of Acoustic Features of Speech of Typically Developing Children and Children with Autism Spectrum Disorders. In A. Ronzhin, R. Potapova, & G. Németh (Eds.), *Speech and Computer: 18th International Conference, SPECOM 2016*, Budapest, Hungary, August 23–27, 2016, Proceedings (pp. 43–50). Cham: Springer International Publishing.

- Main, M., Kaplan, N., & Cassidy, J. (1985). Security in infancy, childhood and adulthood. A move to the level of representation. In I. Bretherton & E. Waters (Eds.), *Growing Points of Attachment Theory and Research. Monographs of the Society for Research in Child Development*, 50, No. 1/2 (pp. 66-104).
- Maister, L., & Plaisted-Grant, K. C. (2011). Time perception and its relationship to memory in Autism Spectrum Conditions. *Developmental Science*, 14(6), 1311–1322. <http://doi.org/10.1111/j.1467-7687.2011.01077.x>
- Malloch, S. N. (2000). Mothers and infants and communicative musicality. *Musicae Scientiae*, 3(1), 29-57.
- Mangold (2017): INTERACT User Guide. Mangold International GmbH (Ed.) [www.mangold-international.com](http://www.mangold-international.com)
- Marsh, K. L., Isenhower, R. W., Richardson, M. J., Helt, M., Verbalis, A. D., Schmidt, R. C., & Fein, D. (2013). Autism and social disconnection in interpersonal rocking. *Frontiers in Integrative Neuroscience*, 7, 4. <http://doi.org/10.3389/fnint.2013.00004>
- Martin, J. S., Poirier, M., & Bowler, D. M. (2009). Brief Report: Impaired Temporal Reproduction Performance in Adults with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 40(5), 640–646. <http://doi.org/10.1007/s10803-009-0904-3>
- Matias, R., Cohn, J. F., & Ross, S. (1989). A comparison of two systems that code infant affective expression. *Developmental Psychology*, 25(4), 483-489.
- McEvoy, R. E., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 34(4), 563–578.
- McPartland, J. C., Dawson, G., Webb, S. J., Panagiotides, H., & Carver, L. J. (2004). Event-related brain potentials reveal anomalies in temporal processing of faces in autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, 45(7), 1235–1245. <http://doi.org/10.1111/j.1469-7610.2004.00318.x>
- Meck, W. H. (2005). Neuropsychology of timing and time perception. *Brain and Cognition*, 58(1), 1–8. <http://doi.org/10.1016/j.bandc.2004.09.004>
- Megnin, O., Flitton, A., Jones, C. R. G., de Haan, M., Baldeweg, T., & Charman, T. (2011). Audiovisual speech integration in autism spectrum disorders: ERP evidence for atypicalities in lexical-semantic processing. *Autism Research*, 5(1), 39–48. <http://doi.org/10.1002/aur.231>
- Meindl, J. N., & Cannella-Malone, H. I. (2011). Initiating and responding to joint attention bids in children with autism: A review of the literature. *Research in Developmental Disabilities*, 32(5), 1441–1454. <http://doi.org/10.1016/j.ridd.2011.02.013>

- 
- Mitchell, S., Brian, J., Zwaigenbaum, L., Roberts, W., Szatmari, P., Smith, I., & Bryson, S. (2006). Early language and communication development of infants later diagnosed with autism spectrum disorder. *Journal of Developmental and Behavioral Pediatrics: JDBP*, 27(2 Suppl), S69–78.
- Mostofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: Implications for cerebellar contribution. *Journal of the International Neuropsychological Society*, 1–8.
- Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. *Journal of Autism and Developmental Disorders*, 20(1), 115–128.
- Mundy, P., Sigman, M., Ungerer, J., & Sherman, T. (1986). Defining the social deficits of autism: the contribution of non-verbal communication measures. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 27(5), 657–669.
- Nakai, Y., Takashima, R., Takiguchi, T., & Takada, S. (2014). Speech intonation in children with autism spectrum disorder. *Brain and Development*, 36(6), 516–522. <http://doi.org/10.1016/j.braindev.2013.07.006>
- Nakano, T., Kato, N., & Kitazawa, S. (2011). Lack of eyeblink entrainments in autism spectrum disorders. *Neuropsychologia*, 49(9), 2784–2790. <http://doi.org/10.1016/j.neuropsychologia.2011.06.007>
- Natale, M. (1978). Perceived empathy, warmth and genuineness as affected by interviewer timing of speech in a telephone interview. *Psychotherapy: Theory, Research & Practice*, 15(2), 145–152. <http://dx.doi.org/10.1037/h0085854>
- Nicholas, B., Rudrasingham, V., Nash, S., Kirov, G., Owen, M. J., & Wimpory, D. C. (2007). Association of Per1 and Npas2 with autistic disorder: support for the clock genes/social timing hypothesis. *Molecular Psychiatry*, 12(6), 581–592. <http://doi.org/10.1038/sj.mp.4001953>
- Nichols, K., Gergely, G., & Fonagy, P. (2001). Experimental protocols for investigating relationships among mother-infant interaction, affect regulation, physiological markers of stress responsiveness, and attachment. *Bulletin of the Menninger Clinic*, 65(3), 371–379.
- Nir, I., Meir, D., Zilber, N., Knobler, H., Hadjez, J., & Lerner, Y. (1995). Brief report: circadian melatonin, thyroid-stimulating hormone, prolactin, and cortisol levels in serum of young adults with autism. *Journal of Autism and Developmental Disorders*, 25(6), 641–654.
- Oberman, L. M., Winkielman, P., & Ramachandran, V. S. (2009). Slow echo: facial EMG evidence for the delay of spontaneous, but not voluntary, emotional mimicry in children with autism spectrum disorders. *Developmental Science*, 12(4), 510–520. <http://doi.org/10.1111/j.1467-7687.2008.00796.x>

- Osterling, J. A., & Dawson, G. (1994). Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders*, 24(3), 247-257.
- Petitto, L. A., Holowka, S., Sergio, L. E., & Ostry, D. (2001). Language rhythms in baby hand movements. *Nature*, 413, 35-36.
- Pickles, A., Simonoff, E., Conti-Ramsden, G., Falcato, M., Simkin, Z., Charman, T., et al. (2009). Loss of language in early development of autism and specific language impairment. *Journal of Child Psychology and Psychiatry*, 50(7), 843-852. <http://doi.org/10.1111/j.1469-7610.2008.02032.x>
- Quigley, J., McNally, S., & Lawson, S. (2016). Prosodic Patterns in Interaction of Low-Risk and at-Risk-of-Autism Spectrum Disorders Infants and Their Mothers at 12 and 18 Months. *Language Learning and Development*, 12(3), 295-310. <http://doi.org/10.1080/15475441.2015.1075405>
- Ramseyer, F., & Tschacher, W. (2011). Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology*, 79(3), 284-295. <http://doi.org/10.1037/a0023419>
- Rapin, I., & Dunn, M. (1997). Language disorders in children with autism. *Seminars in Pediatric Neurology*, 4(2), 86-92. [http://doi.org/10.1016/S1071-9091\(97\)80024-1](http://doi.org/10.1016/S1071-9091(97)80024-1)
- Richdale, A., & Prior, M. R. (1995). The sleep/wake rhythm in children with autism. *European Child & Adolescent Psychiatry*, 4(3), 175-186.
- Rogers, S. J., Hepburn, S. L., Stackhouse, T., & Wehner, E. (2003). Imitation performance in toddlers with autism and those with other developmental disorders. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 44(5), 763-781.
- Romero, V., Fitzpatrick, P., Schmidt, R. C., & Richardson, M. J. (2016). Using Cross-Recurrence Quantification Analysis to Understand Social Motor Coordination & Motor Coordination in Children with Autism Spectrum Disorder. In C. L. Webber, C. Ioana, & N. Marwan (Eds.), *Recurrence Plots and Their Quantifications: Expanding Horizons* (Vol. 180, pp. 227-240). Cham: Springer International Publishing. [http://doi.org/10.1007/978-3-319-29922-8\\_12](http://doi.org/10.1007/978-3-319-29922-8_12)
- Russo, N. M., Hornickel, J., Nicol, T., Zecker, S., & Kraus, N. (2010). Biological changes in auditory function following training in children with autism spectrum disorders. *Behavioral and Brain Functions: BBF*, 6(1), 60. <http://doi.org/10.1186/1744-9081-6-60>
- Russo, N., Zecker, S., Trommer, B., Chen, J., & Kraus, N. (2009). Effects of Background Noise on Cortical Encoding of Speech in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, 39(8), 1185-1196. <http://doi.org/10.1007/s10803-009-0737-0>
- Saint-Georges, C., Cassel, R. S., Cohen, D., Chetouani, M., Laznik, M.-C., Maestro, S., & Muratori, F. (2010). What studies of family home movies can teach us about autistic infants: A literature

- 
- review. *Research in Autism Spectrum Disorders*, 4(3), 355–366.  
<http://doi.org/10.1016/j.rasd.2009.10.017>
- Saint-Georges, C., Mahdhaoui, A., Chetouani, M., Cassel, R. S., Laznik, M.-C., Apicella, F., et al. (2011). Do Parents Recognize Autistic Deviant Behavior Long before Diagnosis? Taking into Account Interaction Using Computational Methods. *PLoS ONE*, 6(7), e22393.  
<http://doi.org/10.1371/journal.pone.0022393.t001>
- Schmahmann, J. D., & Sherman, J. C. (1998). The cerebellar cognitive affective syndrome. *Brain*, 121 (Pt 4), 561–579.
- Schmitz, C., Martineau, J., Barthélémy, C., & Assaiante, C. (2003). Motor control and children with autism: deficit of anticipatory function? *Neuroscience Letters*, 348(1), 17–20.  
[http://doi.org/10.1016/S0304-3940\(03\)00644-X](http://doi.org/10.1016/S0304-3940(03)00644-X)
- Sigman, M., Ruskin, E., Arbelle, S., Corona, R., Dissanayake, C., Espinosa, M., Kim, N., Lopez, A., Zierhut, C., Mervis, C. B., & Robinson, B.F. (1999). Continuity and Change in the Social Competence of Children with Autism, Down Syndrome, and Developmental Delays. *Monographs of the Society for Research in Child Development*, 64(1), 1-139. Retrieved from <http://www.jstor.org/stable/3181510>
- Sigman, M., Dijamco, A., Gratier, M., & Rozga, A. (2005). Early detection of core deficits in autism. *Mental Retardation and Developmental Disabilities Research Reviews*, 10(4), 221–233.  
<http://doi.org/10.1002/mrdd.20046>
- Sigman, M., Mundy, P., Sherman, T., & Ungerer, J. (1986). Social interactions of autistic, mentally retarded and normal children and their caregivers. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 27(5), 647–655.
- Siller, M., & Sigman, M. (2008). Modeling longitudinal change in the language abilities of children with autism: Parent behaviors and child characteristics as predictors of change. *Developmental Psychology*, 44(6), 1691–1704. <http://doi.org/10.1037/a0013771>
- Silverman, L.B., Eigsti, I., & Bennetto, L. (2017). I tawt i taw a puddy tat: Gestures in canary row narrations by high-functioning youth with autism spectrum disorder. *Autism research: official journal of the International Society for Autism Research*, 10(8), 1353-1363.
- Spiker, M. A., Lin, C. E., Van Dyke, M., & Wood, J. J. (2012). Restricted interests and anxiety in children with autism. *Autism*, 16(3), 306–320. <http://doi.org/10.1177/1362361311401763>
- Srinivasan, S. M., Kaur, M., Park, I. K., Gifford, T. D., Marsh, K. L., & Bhat, A. N. (2015). The Effects of Rhythm and Robotic Interventions on the Imitation/Praxis, Interpersonal Synchrony, and Motor Performance of Children with Autism Spectrum Disorder (ASD): A Pilot Randomized Controlled Trial. *Autism Research and Treatment*, 2015(1), 1–18. <http://doi.org/10.1155/2015/736516>

- Stern, D. N. (1971). A Micro-analysis of Mother-Infant Interaction: Behavior Regulating Social Contact Between a Mother and her 3 1/2-Month-Old-Twins, *Journal of the American Academy of Child Psychiatry*, 10(3), 501–517. [http://doi.org/10.1016/S0002-7138\(09\)61752-0](http://doi.org/10.1016/S0002-7138(09)61752-0)
- Stern, D. (1977). *The First Relationship*. Cambridge, Massachusetts: Harvard University Press.
- Stern, D. (1985). *The Interpersonal World of the Infant: A View from Psycho-Analysis and Developmental Psychology*. New York, NY: Basic Books.
- Stone, W. L., Ousley, O. Y., & Littleford, C. D. (1997). Motor imitation in young children with autism: what's the object? *Journal of Abnormal Child Psychology*, 25(6), 475–485.
- Sun, Z. S., Albrecht, U., Zhuchenko, O., Bailey, J., Eichele, G., & Lee, C. C. (1997). RIGUI, a putative mammalian ortholog of the Drosophila period gene. *Cell*, 90(6), 1003–1011.
- Szelag, E., Kowalska, J., & Galkowski, T. (2004). Temporal processing deficits in high-functioning children with autism. *British Journal of Psychology*, 95(3), 269-282.
- Tabachnick, B. G., & Fidell, L. S. (2005). Time-Series Analysis. In *Using Multivariate Statistics* (pp. 1–63).
- Tarabulsky, G. M., Tessier, R., & Kappas, A. (1996). Contingency detection and the contingent organization of behavior in interactions: Implications for socioemotional development in infancy. *Psychological Bulletin*, 120, 25–41.
- Tarr, B. (2014). Music and social bonding: “self-other” merging and neurohormonal mechanisms. *Frontiers in Psychology*, 5, 1–10. <http://doi.org/10.3389/fpsyg.2014.01096>
- Teitelbaum, O., Benton, T., Shah, P. K., Prince, A., Kelly, J. L., & Teitelbaum, P. (2004). Eshkol-Wachman movement notation in diagnosis: the early detection of Asperger's syndrome. *Proceedings of the National Academy of Sciences of the United States of America*, 101(32), 11909–11914. <http://doi.org/10.1073/pnas.0403919101>
- Teitelbaum, P., Teitelbaum, O., Nye, J., Fryman, J., & Maurer, R. G. (1998). Movement analysis in infancy may be useful for early diagnosis of autism. *Proceedings of the National Academy of Sciences of the United States of America*, 95(23), 13982–13987.
- Trawick-Smith, J. (2014). *The Physical Play and Motor Development of Young Children: A Review of Literature and Implications for Practice*, 1–53.
- Trevarthen, C. (1974). Conversations with a two-month-old. *New Scientist*, 1–3.
- Trevarthen, C., & Aitken, K. J. (2001). Infant intersubjectivity: research, theory, and clinical applications. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 42(1), 3–48.
- Trevarthen, C., & Daniel, S. (2005). Disorganized rhythm and synchrony: Early signs of autism and Rett syndrome. *Brain and Development*, 27, S25–S34. <http://doi.org/10.1016/j.braindev.2005.03.016>
- Tronick, E. Z., Als, H., & Brazelton, T. B. (1977). Mutuality in mother-infant interaction. *The Journal of Communication*, 27(2), 74–79.

- 
- Tronick, E. Z., Als, H., & Brazelton, T. B. (1980). Monadic phases: A structural descriptive analysis of infant-mother face to face interaction. *Merrill-Palmer Quarterly of Behavior and Development*, 26(1), 3–24.
- Tryfon, A., Foster, N. E., Ouimet, T., Doyle-Thomas, K., Anagnostou, E., Sharda, M., et al. (2017). Auditory-motor rhythm synchronization in children with autism spectrum disorder. *Research in Autism Spectrum Disorders*, 35, 51–61. <http://doi.org/10.1016/j.rasd.2016.12.004>
- van der Smagt, M. J., van Engeland, H., & Kemner, C. (2007). Brief report: can you see what is not there? low-level auditory-visual integration in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 37(10), 2014–2019. <http://doi.org/10.1007/s10803-006-0346-0>
- Van Overwalle, F., Baetens, K., Mariën, P., & Vandekerckhove, M. (2013). Social cognition and the cerebellum: A meta-analysis of over 350 fMRI studies. *NeuroImage*, 1–19. <http://doi.org/10.1016/j.neuroimage.2013.09.033>
- Venuti, P., Bientuto, A., Cainelli, S., Landi, I., Suvini, F., Tancredi, R., et al. (2017). A joint behavioral and emotive analysis of synchrony in music therapy of children with autism spectrum disorders. *Health Psychology Report*, 2, 162–172. <http://doi.org/10.5114/hpr.2017.63985>
- Vivanti, G., Trembath, D., & Dissanayake, C. (2014). Mechanisms of Imitation Impairment in Autism Spectrum Disorder. *Journal of Abnormal Child Psychology*, 42(8), 1395–1405. <http://doi.org/10.1007/s10802-014-9874-9>
- Wallace, G. L., & Happé, F. (2008). Time perception in autism spectrum disorders. *Research in Autism Spectrum Disorders*, 2(3), 447–455. <http://doi.org/10.1016/j.rasd.2007.09.005>
- Wan, M. W., Green, J., Elsabbagh, M., Johnson, M., Charman, T., Plummer, F., & Team1, T. B. (2012). Research in Developmental Disabilities: Parent–infant interaction in infant siblings at risk of autism. *Research in Developmental Disabilities*, 33(3), 924–932. <http://doi.org/10.1016/j.ridd.2011.12.011>
- Warner, R. M. (1992). Sequential-Analysis of Social-Interaction - Assessing Internal versus Social Determinants of Behavior. *Journal of Personality and Social Psychology*, 63(1): 51-60.
- Warner, R. M. (2002). Rhythms of dialogue in infancy: comments on Jaffe, Beebe, Feldstein, Crown, and Jasnow (2001). *Journal of Psycholinguistic Research*, 31(4), 409–420.
- Warner, R. M., Malloy, D., Schneider, K., Knoth, R., & Wilder, B. (1987). Rhythmic organization of social interaction and observer ratings of positive affect and involvement. *Journal of Nonverbal Behavior*, 11(2), 57-74.
- Webb, S. J., Dawson, G., Bernier, R., & Panagiotides, H. (2006). ERP Evidence of Atypical Face Processing in Young Children with Autism. *Journal of Autism and Developmental Disorders*, 36(7), 881–890. <http://doi.org/10.1007/s10803-006-0126-x>



- Weinberg, M. K., & Tronick, E. Z. (1994). Beyond the face: an empirical study of infant affective configurations of facial, vocal, gestural, and regulatory behaviors. *Child Development*, 65(5), 1503–1515.
- Welkowitz J., Feldstein S. (1970). The relation of experimentally manipulated interpersonal perception and psychological differentiation to the temporal patterning of conversation. *Proceedings of the 78th Annual Convention of the American Psychological Association*, 5, 387–388.
- Welsh, J. P., Ahn, E. S., & Placantonakis, D. G. (2005). Is autism due to brain desynchronization? *International Journal of Developmental Neuroscience*, 23(2-3), 253–263. <http://doi.org/10.1016/j.ijdevneu.2004.09.002>
- Whipple, J. (2004). Music in Intervention for Children and Adolescents with Autism: A Meta-Analysis, *Journal of Music Therapy*, 41(2), 90–106.
- Wigram, T., & Gold, C. (2006). Music therapy in the assessment and treatment of autistic spectrum disorder: clinical application and research evidence. *Child: Care, Health and Development*, 32(5), 535–542. <http://doi.org/10.1111/j.1365-2214.2006.00615.x>
- Williams, J. H., Whiten, A., Suddendorf, T., & Perrett, D. I. (2001). Imitation, mirror neurons and autism. *Neuroscience and Biobehavioral Reviews*, 25(4), 287–295.
- Wimpory, D. C., Hobson, R. P., Williams, J. M., & Nash, S. (2000). Are infants with autism socially engaged? A study of recent retrospective parental reports. *Journal of Autism and Developmental Disorders*, 30(6), 525–536.
- Wimpory, D. C., Nicholas, B., & Nash, S. (2002). Social timing, clock genes and autism: a new hypothesis. *Journal of Intellectual Disability Research: JIDR*, 46(Pt 4), 352–358.
- Xu, D., Liu, T., Ashe, J., & Bushara, K. O. (2006). Role of the olivo-cerebellar system in timing. *Journal of Neuroscience*, 26(22), 5990–5995. <http://doi.org/10.1523/JNEUROSCI.0038-06.2006>
- Yale, M., Messinger, D., Cobo-Lewis, A., & Delgado, C. (2003). The temporal coordination of early infant communication. *Developmental Psychology*, 39(5), 815–824. doi:10.1037/0012-1649.39.5.815
- Yirmiya, N., Gamliel, I., Pilowsky, T., Feldman, R., Baron-Cohen, S., & Sigman, M. (2006). The development of siblings of children with autism at 4 and 14 months: social engagement, communication, and cognition. *Journal of Child Psychology and Psychiatry*, 47(5), 511–523. <http://doi.org/10.1111/j.1469-7610.2005.01528.x>
- Zlochower, A. J., & Cohn, J. F. (2001). Vocal Timing in Face-to-Face Interaction of Clinically Depressed and Nondepressed Mothers and their 4-Month-Old Infants, *Infant Behavior and Development*, 19, 371–374.

---

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*, 23(2-3), 143–152. <http://doi.org/10.1016/j.ijdevneu.2004.05.001>

## Appendix A: What or who drives timing in interaction?

Historically, the question was whether the infant could even assert any influence during interaction. Those in favour of a bidirectional approach argued positively in response to this question (Condon & Sander, 1974; Brazelton, Koslowski, & Main, 1974; Lester, Hoffman, & Brazelton, 1985), while others argued that during early interactions, parents mainly contribute to interaction rhythms (e.g. Kaye, 1982). This question was resolved by time-series analysis, which showed that early interactions can be bidirectional (Cohn & Tronick, 1988; Jaffe et al., 2001). In addition, analysis of lead-lag relationships has shown that initially, mothers tend to follow their child at around 3 months. Over time, child-lead synchrony shifts towards mutual regulation at around 9 months (Cohn & Tronick, 1988; Feldman, 2007b). However, adult interactions do not necessarily always show bidirectionality, which may be due to added complexity and symbolic use (Jaffe et al., 2011).

The next question concerned the organisation of social timing, which implied the question of what drives it; is it the internal clock or the interaction partner? Two hypotheses have sought to answer this question; periodicity and stochasticity.

Periodicity posits that events cycle periodically at regular intervals, thereby allowing accurate prediction of the timing of future events. It allows predictions about event's frequency, phase and amplitude, which are assumed to be stable over time (Cohn & Tronick, 1988). For example, if humans are governed by periodicity, features of the interactive style will be highly predictable, such as how often and when people smile. The bidirectional, or mutual entrainment, hypothesis is built on this assumption: the timing of interaction between a mother and her infant depend on their own internal clocks. In this view, mother and infant cycles may synchronise during interaction through a process of mutual entrainment (Condon & Sander, 1974; Brazelton, Koslowski, & Main, 1974; Lester, Hoffman, & Brazelton, 1985).

However, Cohn and Tronick (1988) pointed out that periodicity was simply assumed by Lester et al. (1985), yet visual inspection of their plots suggested that there was no periodicity. Gottman (1981) observed that "researchers have tended to be frustrated in summarising their data, and instead they have relied on metaphors that create a veneer of time-series language" (p. 400), which suggests unintentional use of the terms.

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In opposition to periodicity, stands the view that events are organised stochastically, meaning that events are auto-correlated over short intervals. Stochasticity allows for cyclicity but not periodicity (Cohn & Tronick, 1988). For interaction, this means that expressive behaviours are auto-correlated and contingent on (cross-correlated) with the preceding behaviour of the interaction partner (Cohn & Tronick, 1987). Cohn and Tronick (1988) argued that those who supported the notion of periodicity actually used unsuitable analyses. They repeated those analyses with appropriate statistics, and their results supported the assumption that cyclicity is organised stochastically. Cohn and Tronick (1988) further proposed that the mutual entrainment hypothesis is not mutually exclusive with stochasticity, and that both could influence the timing of behaviour.

Feldman (2007b) reviewed evidence showing that biological rhythms as well as the interaction partner influence social timing. For instance, a stressful event that increases heart rate, may lead to the speaker talking faster. In turn, this may affect the listener. This approach, that takes the coordination between ongoing bodily and behavioural processes into account, is referred to as biobehavioural synchrony (Feldman, 2012a). Thus, internal clocks may follow a periodic rhythm, however, biological processes may be disrupted and respond to the environment. Biological processes may initially provide a rhythm for interaction, but subsequent events during interaction can feed back into them. For example, it has been demonstrated that heart rhythms of mother and child could be synchronised following episodes of affect and vocal synchrony (Feldman et al., 2011). In conclusion, Feldman (2007b) suggested that the interactional time-series does not follow a predetermined regularity, however, within rhythmicity, preceding events can reliably predict the events that follow.

## Appendix B: Monadic Phases

Monadic Phases following (Tronick et al., 1980)

Behavioural Codes Infant	Behavioural Codes Adult
<u>Vocalisation</u>	<u>Vocalisation</u>
1. None	1. Abrupt shout
2. Isolated sound	2. Stern, adult narrative
3. Grunt	3. Rapid tense voice
4. Coo	4. Whispering
5. Cry	5. Little or no vocalizing
6. Fuss	6. Rhythmic sounds with little modulation
7. Laugh	7. Burst-pause talking
8. Repeated positive sounds	8. Single bursts in rapid succession with wide pitch range
	9. Burst of sound that peaks with much change of modulation and pitch
<u>Direction of Gaze</u>	<u>Direction of Gaze</u>
1. Towards mother's face	1. Toward infant's face
2. Away from mother's face	2. Towards infant's body
3. Follows mother	3. Away from infant but related to interaction
4. Looking at toy or hand mother is using as part of interaction	4. Away from infant and not related to interaction
<u>Head Orientation</u>	<u>Head Orientation</u>
1. Head towards, nose level	1. Towards and down
2. Head towards, nose down	2. Towards and up
3. Head towards, nose up	3. Towards and level
4. Head part side, nose level	4. Part side and down
5. Head part side, nose down	5. Part side and up
6. Head part side, nose up	6. Part side and level
7. Head complete side, nose level	7. Head complete side. Nose level
8. Head complete side, nose down	8. Head complete side, nose down
9. Head complete side, nose up	9. Head complete side, nose up
	10. Thrusting
	11. Nodding
	12. Nuzzling
	13. Cocked head
<u>Facial Expression</u>	<u>Facial Expression</u>
1. Cry face	1. Angry
2. Grimace	2. Frown
3. Pout	3. Serious, sad, sober
4. Wary/sober	4. Lidded
5. Lidding	5. Neutral flat
6. Yawn	6. Bright
7. Neutral	7. Animated
8. Sneeze	8. Simple smile
9. Softening	9. Imitative play face
10. Bright	10. Kisses
11. Simple smile	11. Exaggerated

12. Coo face	12. Broad full smile
13. Broad smile	13. 'ooo' face
<u>Body Position</u>	<u>Body Position</u>
1. Doubled over or complete away	1. Turns body full away
2. Arching	2. Sits back and still
3. Slumped	3. Slumping
4. Off to one side	4. Neutral-slight forward
5. Neutral or being adjusted	5. Sideways shift
6. Up into vertical	6. Slight rocking
7. Up and off backrest	7. Large sideways shifts into line of vision
8. Body vertical and extended	8. Medium close forward
9. Leaning forward with back straight	9. Going close and staying close
	10. Large shifts forward and back
	<u>Specific Handling of the Infant</u>
	1. Abrupt shift of baby's position
	2. Abrupt but no shift
	3. Jerky movement of limbs
	4. No contact
	5. Gentle containing
	6. Small rhythmic patting
	7. Rhythmic movements of limbs
	8. Intensive movement, fast rhythm

Phases Infant	Gaze	Head Orientation	Body Orientation	Facial Expression	Voice
Avoid	Away* (2)	Away (7, 8, 9)	Away (1-4)	Negative to neutral (1-7)	Cry and others (1, 3, 5, 6)
Avert	Away* (2)	Partially away (5, 6, 7)	Partially away (3, 4)	Negative to neutral (2-7)	Negative to neutral (1, 3, 6)
Monitor	Toward* (1)	Toward (1-6)	Toward (5-9)	Negative to bright (2-10)	Negative to neutral (1, 3, 6)
Set	Toward* (1)	Toward (1-6)	Toward (5-9)	Neutral to positive (7, 9, 10)	Neutral (1, 3)
Play	Toward (1)	Toward (1-6)	Toward (5-9)	Positive (11, 12, 13)	None, Single laugh (1, 2, 7)
Talk	Toward (1)	Toward (1-6)	Toward (5-9)	Positive (11, 12, 13)	Repeated and Coo (8, 4)

Phases Adult	Gaze	Head Orientation	Body Orientation	Facial Expression	Voice	Specific Handling
Avoid	Away* (4)	Away (7, 8, 9)	Away (1-4)	Negative to none (1-5)	Negative (1, 2, 3, 5)	None or negative (2, 3, 4)
Avert	Away* (4)	Partially away (4, 5, 6)	Away (1-4)	Negative to none (1-5)	Negative Adult (1, 2, 3, 5)	Varied (2, 3, 4)
Monitor	Toward* (1)	Toward (1-6)	Toward (4, 8)	Negative to none (3-6)	Little Infantalisation (4, 5, 6)	Varied (4, 5, 6)
Elicit	Towards* (1)	Toward/ Moving (1-6, 10, 11, 13)	Toward/ Moving (4-10)	Varied (2-9, 11, 12)	Rapid/none (3, 5)	Abrupt/ Touching (1, 2, 4, 8)
Set	Toward (1)	Toward (1-6)	Toward (4, 8)	Neutral to positive (5, 6, 7)	Infantalised (5, 6, 7)	Varied (4-7)
Play	Toward (1)	Toward/ Moving (1-6, 11-13)	Toward (4, 6, 8, 9, 10)	Positive (8-13)	Infantalised (5, 6, 8, 9))	Varied (2, 4-7)
Talk	Toward (1)	Toward/ Moving (1-6, 10, 11, 13)	Toward (4, 6, 8)	Positive (8-13)	Burst-Pause (7)	Varied (2, 4-7)

## Appendix C: Time-series analysis - Theory and practice

### 1. Data preparation

- TSA requires the data to be in a certain format: SECOND\_ (starting at zero, one entry for each second); a variable for each interaction partner that contains behaviour code

#### In practice

The raw data consisted of three important columns: 'ENTRY' (beginning when the sequence started during the 10-min recording), 'PERSON' (1=Child; 2=Adult) and 'PHASE' (one of the four phase codes).

SECOND\_ was computed:

```
compute SECOND_ = ENTRY-time.hms(x,y,z)
```

(x, y, z) was replaced by the starting time of each time-series (e.g. 0,1,32 if it started at 1 min and 32 sec)

IBM SPSS automatically creates the DATE\_ variable when carrying out a time-series analysis.

The diagram illustrates the transformation of raw data into a transformed data set. The 'Raw data set' table on the right contains columns for Entry, MiniMP2.0, Person, and Phases. The 'Transformed data set' table on the left contains columns for adult, child, SECOND\_, and DATE\_. An arrow points from the 'Raw data set' to the 'Transformed data set', indicating the transformation process.

	adult	child	SECOND_	DATE_
1	3	0	0	0
2	1	0	1	1
3	4	0	2	2
4	3	0	3	3
5	1	0	4	4
6	1	0	5	5
7	3	0	6	6
8	3	0	7	7
9	1	2	8	8
10	1	3	9	9
11	1	3	10	10
12	2	2	11	11

	Entry	MiniMP2.0	Person	Phases
1	0:13:20.00	Play	1	3
2	0:13:20.00	Avoid	2	0
3	0:13:21.09	Monitor	1	1
4	0:13:22.14	Talk	1	4
5	0:13:22.14	Talk	1	4
6	0:13:23.11	Play	1	3
7	0:13:24.06	Monitor	1	1
8	0:13:26.12	Play	1	3
9	0:13:26.18	Monitor	2	1
10	0:13:27.03	Avoid	2	0
11	0:13:28.01	PassiveInter	2	2
12	0:13:28.04	Monitor	1	1

For each second of the time-series, a phase entry for CHILD and ADULT was created. Manually, a code was assigned to each second, one for the child and one for the adult.



					Entry	MiniMP2.0	Person	Phases
1					0:13:20.00	Play	1	3
2					0:13:20.00	Avoid	2	0
3					0:13:21.09	Monitor	1	1
4					0:13:22.14	Talk	1	4
5					0:13:22.17	Play	1	4
6					0:13:23.11	Play	1	3
7					0:13:24.06	Monitor	1	1
8					0:13:26.12	Play	1	3
9					0:13:26.18	Monitor	2	1
10					0:13:27.03	Avoid	2	0
11					0:13:28.01	PassiveInter	2	2
12					0:13:28.04	Monitor	1	1

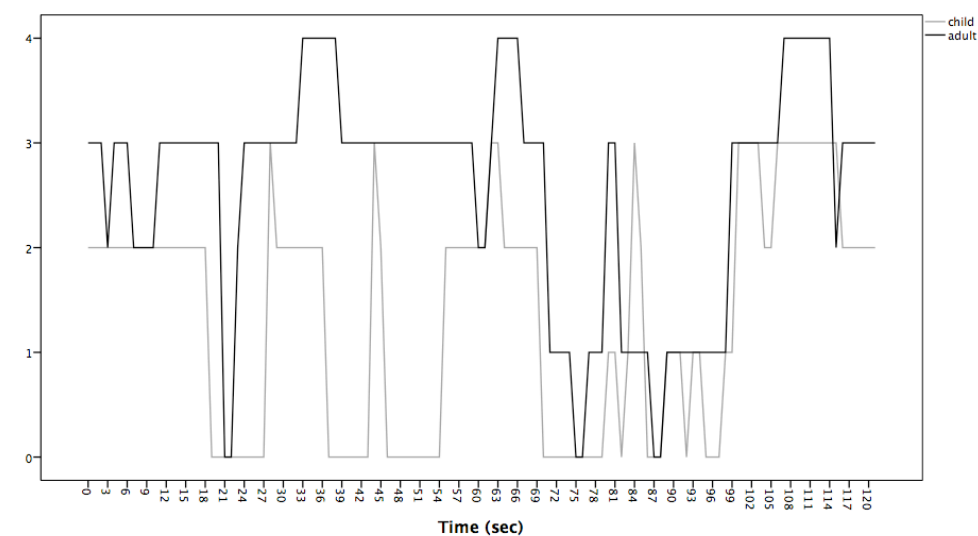
	adult	child	SECOND_	DATE_
1	3	0	0	0
2	1	0	1	1
3	4	0	2	2
4	3	0	3	3
5	1	0	4	4
6	1	0	5	5
7	3	0	6	6
8	3	0	7	7
9	1	2	8	8
10	1	3	9	9
11	1	3	10	10
12	3	2	11	11

## 2. Visual inspection of the time-series

### In practice

Each dyad's time-series can be plotted using the following syntax:

```
TSPLIT VARIABLES = CHILD ADULT
/ID = DATE_
/NOLOG
/FORMAT NOFILL NOREFERENCE
```



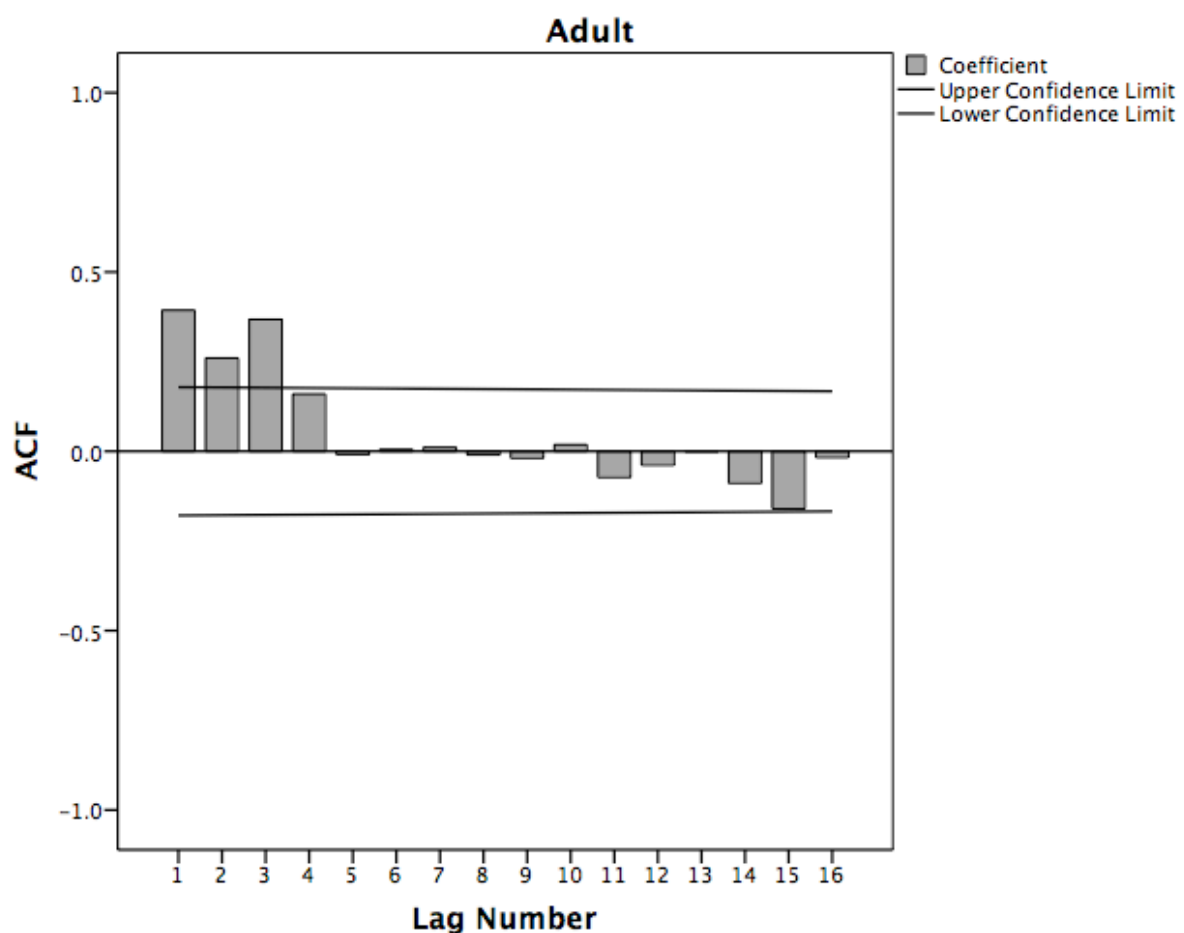
### 3. Stationarity assumption

- Stationarity: mean and variance are constant, no trends or change over time
- Informs the integrated (I) parameter of the ARIMA model
- On ACF plot, stationarity is indicated by a rapidly decaying ACF plot
- On the PACF plot, a cut off at lag 1 or 2 is expected
- If non-stationary, the TS must be differenced
- After differencing once: ARIMA (p, 1, q); if differenced twice: ARIMA (p, 2, q)
- After differencing, stationarity must be re-tested
- Over-differencing may introduce dependence when none exists (Jebb et al., 2015)

#### In practice

For each ADULT and CHILD, an ACF plot was created:

Analyse → Forecasting → Autocorrelations



Differencing of non-stationary time-series:

Transform → Create Time Series... [Enter the variables that need differencing (CHILD and/or ADULT)]. Choose Function: Differencing Order: 1.

This created a new variable, e.g. CHILD\_1 or ADULT\_1.

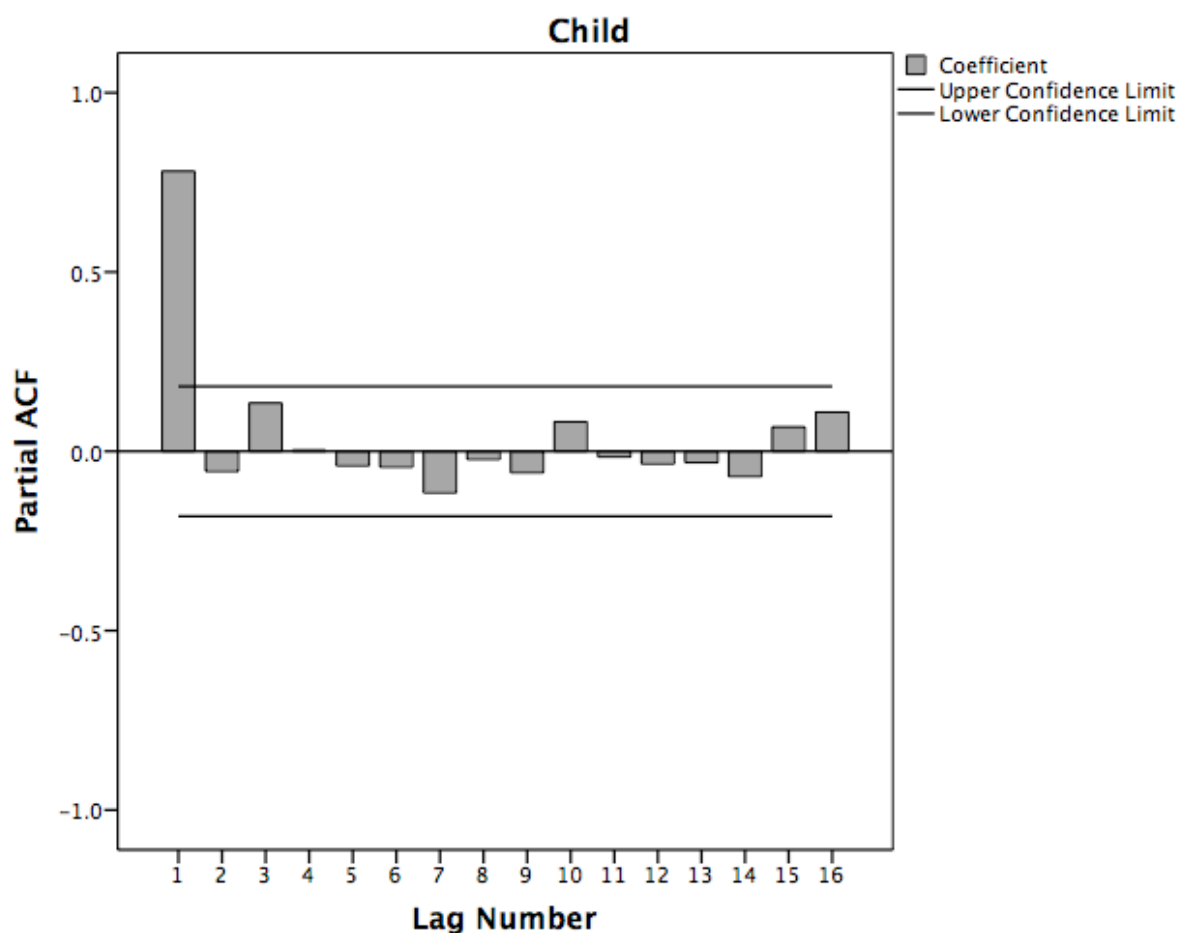
## 4. Cyclicality

- Informs the auto-regressive (AR) parameter of the ARIMA model
- Cyclicality is based on the PACF plot, which is a visual representation of the auto-correlation matrix at different time points (or lags)
- Estimates how much the behaviour at time point 1 is related to the behaviour at time point 2 and so on
- The presence of significant peaks in the first few lags means that cyclicality can be assumed
- The absence of significant peaks means that the series is not auto-correlated and there is no cyclicality

### In practice

For adult and child variable an PACF plot each was created:

Analyse → Forecasting → Autocorrelations checking the Partial Autocorrelations box



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## 5. ARIMA Modelling

- An ARIMA model ( $p, d, q$ ) is estimated for each time-series
- The integrated part (I), denoted by  $d$ , indicates whether the series was differenced (see above) ( $d=1$ ) or not ( $d=0$ )
- The autoregressive part (AR), denoted by  $p$ , indicates whether the series contained cyclicity (see above), for example, an AR1 ( $p=1$ ), AR2 process ( $p=2$ ) or none ( $p=0$ )
- The moving average (MA), denoted by  $q$ , is informed by significant spikes on the ACF plot

### In practice

Models were estimated based on visual examination of the ACF and PACF plots. The model was estimated separately for CHILD and ADULT using the parameters specified using the ACF and PACF plots:

Analyse → Forecasting → Create Models. Chose Method → ARIMA [inputting the parameters specified above; saving the residual]

## 6. ARIMA diagnostics

- The model should be stationary and parsimonious, with significant coefficients and good fit
- Normality of the residuals can be verified visually by looking at a histogram of the residuals or QQ plot
- A non-significant Box-Ljung Q statistic indicates random distributed of error residuals
- Goodness of fit is reflected by the AIC and BIC statistic (the lower, the better)
- AIC and BIC reflect the trade-off between model fit and model complexity

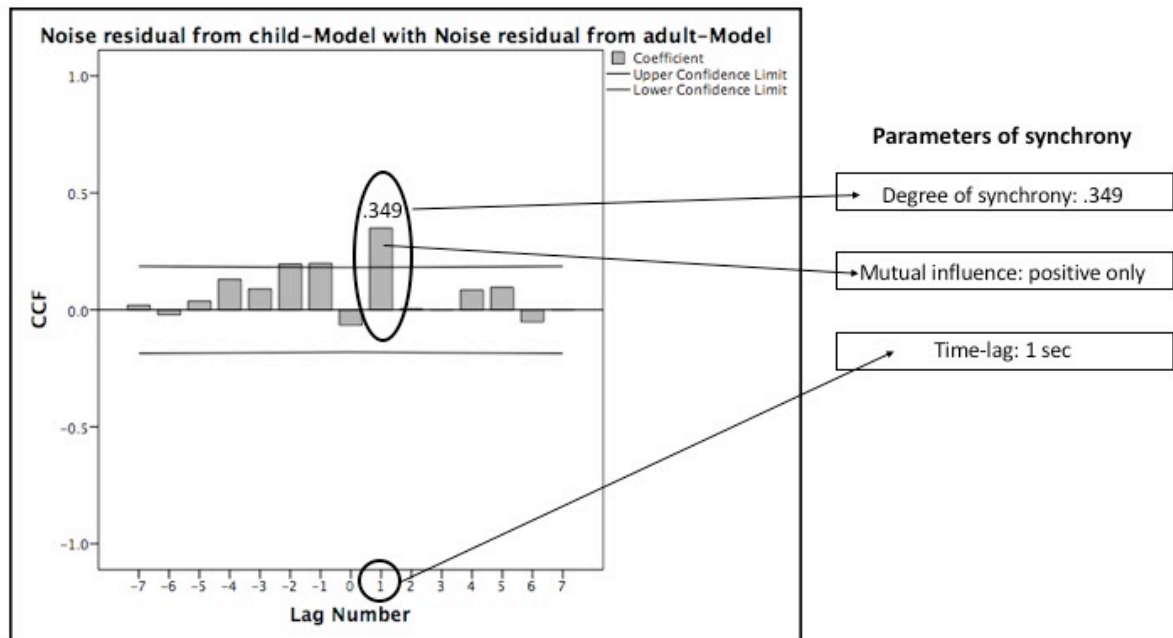
## 7. Synchrony Parameters

- Synchrony parameters are established based on the residuals of the ARIMA models (one for each interaction partner)
- *Coherence* measures the strength of lagged associations between two individuals; the CCF plot's largest coefficient indexes coherence and can range from 0 (no association) to 1 (perfect match)
- *Significant synchrony* is indicated by significant peaks on the CCF plot
- When significant synchrony was present, *time-lag to synchrony* is established based on the lag on which the first significant peak lay (e.g. If on lag 2, then time taken to achieve synchrony was 2 seconds); synchrony can occur at multiple lags but generally, the lag in which the largest cross-correlation (positive or negative) is observed, is considered the first one

## In practice

Inputting the CHILD and ADULT ERROR RESIDUALS, a cross-correlation function (CCF) was computed:

Go to Analyse → Forecasting → Cross-correlations



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## Appendix D: Musical Interaction Therapy

Musical Interaction Therapy (MIT) is a play-based parent-child intervention with live musical accompaniment (Wimpory, Chadwick & Nash, 1995; Wimpory & Nash, 1999). MIT was designed for children with ASD who struggle with pre-verbal interaction, interpersonal contact, joint attention, understanding as well as spontaneity (Wimpory et al., 1995). MIT addresses social timing difficulties in ASD by offering 'enhanced and prolonged experience of pre-verbal interaction play patterns supported by a musician' (Wimpory et al., 1995, pp. 17-18).

Despite its longstanding popularity with parents and children, MIT is only applied in two areas in the United Kingdom, partly due to limited scientific support. While it has been evaluated previously on a case study basis (Wimpory et al., 1995), a larger evidence base is still lacking.

### *An early intervention approach*

In typical development, young children naturally engage with their parents in interactive play, such as nursery rhymes, rough-and-tumble play and repetitive games. What comes naturally to most parents and children is often challenged in those with ASD. MIT was designed to facilitate early interactions by providing several strategies to the caregiver (see Wimpory & Nash, 1999 for more detail) as well as through musical support (see below).

### *The role of music*

MIT takes advantage of the observation that children with ASD respond well to music (Wigram & Gold, 2006). In MIT, the music is played by a Music Therapist, that resembles an accompanying pianist's role in a silent film whose music reflects the movements, speed and mood of the interaction.

For children, the music may be motivating and enhance the child's social timing; not only his own intrapersonal timing but also his perception of the caregiver's behaviour (Newson, 1984; Prevezer, 1998 as cited in Wimpory & Nash, 1999). In other words, music may 'add both interest and meaning to social situations where they would otherwise be lacking' (Jordan & Libby, 1997, pp. 32-33 as cited in Wimpory & Nash, 1999).

The music also appears to have a positive effect on the parents: Especially, those parents that find it hard to engage their child appreciate the music for its supportive ability. The music appears to help the parents relax and may inspire activities (H. Horton, former NHS Assistant Psychologist, personal communications, 2014).

In sum, it appears that there is something about the music that 'works', even though Wimpory and Nash (1999) stated that it had not yet been identified as an essential component of MIT.

#### *MIT sessions*

Ideally MIT takes place in a quiet room with few distractions (e.g. other people, toys, noise). A parent or other familiar caregiver, such as a support worker or teaching assistant, engages the child in playful interaction. The Music Therapist provides the music on his or her instrument, typically a piano or a harp. Sessions last about 45 minutes, depending on the child's mood and capacity. MIT is indicated for pre-verbal autistic children between the ages of 2 to 9 years. Playful interaction may include repetitive games, nursery rhymes, cuddling or rough-and-tumble play. MIT aims at making use of each child's preferences and skills while encouraging him or her to engage in areas of interaction or on interactive skills that need more practice.

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## Appendix E: Coding protocol

### 1. Suitability Code

Establish the 2-minute sequence to be micro-analysed in Step 2. Watch the entire video clip at 1.5 speed and code the following:

Code	Descriptor	Explanation
a	good engagement & suitable	cuddling, conversing, highly engaged by both parties
s	suitable	both dyadic partners are visible in the frame, and if it's a music video, music is playing
d	unsuitable	unable to see one or both dyadic partners

Subsequently, identify the 'best' sequence, preferring those with the least **d** and the most **a**-codes. Note section to code on MIT list, in minutes and seconds and save the coded data in the 'suitability' file in the CodeArchive.

### 2. Micro-analysis coding

Code separately for child and adult the 2-minute sequence identified in step 1. Code at normal speed, using headphones.

Code each behavioural code (gaze, action, vocalisation, see below) separately. Use the appropriate coding keys (i.e. MiniMP2.0\_child.ikey for the child and likewise MiniMP2.0\_mother.ikey for the adult).



Behavioural category	Code	Examples
Vocalisation	++	Directed speech, words, babble, repeated positive sounds, singing; must be non-echoed
	+	Laughter, giggles, coos, squeals
	o	None, isolated sound, word, grunt, non-directed speech, echoed speech
	-	Fuss, cry, scream
Gaze	+	Directed towards face of other or following him/her with gaze
	-	Looking away from other, eyes closed or disengaged
Action	++	Symbolic: gestures (not including touching, children only)
	+	Reaching for the other (e.g. using hand, foot, toy), following, cuddling, tickling, clapping
	o	Passive but observant of the other
	-	Disengaged, moving or turning away; or still but clearly disengaged

All of these behavioural codes are coded in relation to the interaction partner, i.e. only parent or child. Every engagement with musician or psychologist assistant counts as '-' (avoid).

After coding, ensure that the timeline shows no gaps in codes.

To do this:

Open the [Analysis Wizard](#), click [Statistics & Chart \(all data\)](#)

And set the beginning and end time of each coding string so that you have the exact same 2-minute sequence for both child and adult. Every file should contain the child and adult behaviour codes (three each) as well as their phases (see Step 3). Save the data with name of participant, date of interaction, interaction type and initials of coder in the appropriate folder in the CodeArchive in the folder "Mini MP2.0".

### 3. Phase Conversion

The coded behaviours now need to be converted into phases (**Converse**<sup>36</sup>, **Playful Interaction**, **Passive Interaction**, **Monitor**, and **Avoid**).

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<sup>36</sup> Converse may be pre-verbal or verbal.

To do this:

Open the Analysis Wizard, click Statistics & Chart (all data). Go to Analysis, and select Co-occurrence Filter

A window will open.

Check the relevant boxes for each phase.

Phases	Vocalisation	Gaze	Action
Converse	++ (- if communicative)	+ (-)	++, + o (-)
Playful Interaction	+ o	+	+*
Passive Interaction	+ o	-	+
Monitor	+ o (-)	+*	o (-)
Avoid	o - (+)	-*	o -

*Note. \* required, () possible if no other phase fits.*

For example, to create Passive Interaction (Child), check the following: child\_vocalisation=o, child\_gaze=-, child\_action=+

The class for all child phases is called: MiniMP2.0 (and for all adult phases: MiniMP2.0\_adult).

This must be done for all possible combinations and for all Phases. It is possible that an interaction partner does not use all of these, in this case, the rater need to use his own judgement.

After creating all phases, close and re-open the Time Line Chart and check for gaps in the Phase codes. Identify the combination of behaviour codes, assign a suitable code and add it in the Co-occurrence Filter.

Do the same for the adult.

Save.

#### 4. Export Data for further Analysis

Go to

File→ Export data → Raw coding data

Specify the following to be exported: Entry, Code. Time in Seconds.