Interpersonal Synchrony and Affiliation in Typically Developing Children and Children with Emerging Emotional and Behavioural Difficulties

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Summary of thesis

Interpersonal synchrony (IS) is the temporal co-ordination of behaviour during social interactions. For typically developing (TD) children, IS has important social consequences, promoting affiliation and prosocial behaviour between social partners, and informing children's understanding of the relationships of others. However, little is known about the factors that contribute to the affiliative effects of IS; whether IS holds social significance for atypically developing children; and what factors account for variation in social sensitivity to IS.

This thesis explored how IS influenced the social judgements of typically and atypically developing children. In Chapter 2, findings from a novel experimental paradigm indicated that both simultaneity and temporal regularity contributed to the affiliative effects of IS when TD children witnessed IS, with this effect mediated by their perceptions of partners' 'togetherness'. However, when children experienced IS in a limited social context, no affiliative effects were observed, suggesting that positive social effects arise from experienced IS only when social presence/partner engagement is sufficiently salient. The same tasks were then used to investigate the social effects of IS in children with emerging emotional and behavioural difficulties (EE&BDs) (Chapter 3), finding limited evidence that IS was socially relevant for this group. Chapter 4 profiled two fundamental synchrony-related processes in children with EE&BDs: synchrony perception and motor synchrony. Abilities in both domains varied considerably in the sample, with performance increasing with age. To investigate the processes that might contribute to reduced social sensitivity to IS in children with EE&BDs, Chapter 5 brought together the evidence from Chapter 3 and 4, finding that social sensitivity to IS in children with EE&BDs (Chapter 3) was not related to perceptual and motor synchrony abilities (Chapter 4), or to theory of mind (ToM).

Overall, the social judgements of TD children were reliably guided by IS when witnessing IS, but IS had limited social significance for children with EE&BDs. IS likely plays a role in the diverging social experiences of typically and atypically developing children, contributing to differences in social communication commonly observed in atypical development.

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List of abbreviations

2IFC	Two interval forced choice
ADHD	Attention deficit hyperactivity disorder
ANOVA	Analysis of variance
APA	American Psychological Association
AQ-Child	Autism Spectrum Quotient (Children's Version)
DAWBA(AAS)	Development And Well-Being Assessment (Attention and Activity Section)
DCD	Developmental co-ordination disorder
DSM-5	Diagnostic and Statistical Manual (5th ed.)
EE&BDs	Emerging emotional and behavioural difficulties
GLMM	Generalised linear mixed model
IRI	Inter response interval
IS	Interpersonal synchrony
ISI	Inter stimulus interval
ITI	Inter trial interval
LMM	Linear mixed model
MCAR	Missing completely at random
ms	Milliseconds
NDAU	Neurodevelopmental assessment unit
PCA	Principal Components Analysis
PF	Psychometric function
RDoC	Research domain criteria
SDQ	Strengths and Difficulties Questionnaire
SJ	Simultaneity judgement
SMT	Spontaneous motor tempo
SOA	Stimulus onset asynchrony
TD	Typically developing
ToJ	Temporal order judgement
ToM	Theory of mind

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Impact of Thesis

Chapters in this thesis are based on work published in peer-reviewed articles and presented at a national conference.

Chapter 1:

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Bowsher-Murray, C., Jones, C. R., & von dem Hagen, E. (2023). Beyond simultaneity: Temporal interdependence of behavior is key to affiliative effects of interpersonal synchrony in children. Journal of Experimental Child Psychology, 232, 105669.

Chapter 2:

Bowsher-Murray, C., Jones, C. R., & von dem Hagen, E. (2023). Beyond simultaneity: Temporal interdependence of behavior is key to affiliative effects of interpersonal synchrony in children. Journal of Experimental Child Psychology, 232, 105669.

Interpersonal Synchrony: How the Temporal Properties of Interactions Influence Children's Social Judgements. *Poster Presentation, British Psychological Society (Developmental Section) Annual Conference*, September 2022.

Chapter 1

General Introduction

1.1 Overview

Interpersonal synchrony (IS) refers to the temporal co-ordination of behaviour during social interactions (Bernieri et al., 1988; Delaherche et al., 2012; Feldman, 2007b). IS may arise via posture; gross motor movements; gaze; gestures; facial expressions; speech; and vocalizations (Bernieri et al., 1988; Cross et al., 2019; Cuadros et al., 2020; Nguyen et al., 2022). It may be the product of conscious effort, e.g. dancing or shaking hands, but may also arise spontaneously: social partners might fall into step (Zivotofsky & Hausdorff, 2007), align their postural positions (Gaziv et al., 2017; Shockley et al., 2003), or entrain their head movements (Hadar et al., 1984) or facial expressions (Louwerse et al., 2012). Spontaneous IS may also arise across multiple body parts at once (Koul et al., 2023). IS may display rhythmical properties (e.g., walking in step; nodding), but equally may be less structured in nature (e.g., sporadic gestures, postural adjustment). IS is related to, but distinct from, other aspects of interpersonal co-ordination (Bernieri et al., 1988; Mayo & Gordon, 2020; Rauchbauer & Grosbras, 2020). For example, mimicry refers to the automatic imitation of a social partner's gestures, posture, movement etc (Chartrand & Lakin, 2013). As such, mimicry, like IS, involves the unconscious co-ordination of social behaviour. However, mimicry necessarily concerns behaviour matched in form, and the precise timing of behaviour is not critical. By contrast, IS is concerned with the extent to which behaviour is co-ordinated in time, irrespective of whether it is matched in form (Hu et al., 2022; Kragness & Cirelli, 2021; Mayo & Gordon, 2020). A further related concept is joint action, in which partners consciously co-ordinate complimentary behaviour to achieve a shared goal (Meyer & Hunnius, 2020; Sebanz et al., 2006). While such goal-directed behaviour may be closely co-ordinated in time, IS may also arise without conscious effort and in the absence of an end goal (Ayache et al., 2021; Gallotti et al., 2017; Oullier et al., 2008), and thus is relevant to a broader range of social interactions.

IS is developmentally significant: infant-caregiver IS believed to promote a range of positive outcomes including self-regulation, empathy and secure attachment (Evans & Porter, 2009; Feldman, 2007c; Harrist & Waugh, 2002). IS is also a mechanism through which social bonds are built and understood (Hoehl et al., 2021; Rauchbauer & Grosbras, 2020). In particular, there is evidence that IS promotes both partner affiliation (Rabinowitch et al., 2015; Tarr et al., 2015) and partner-directed prosocial behaviour (Rabinowitch & Meltzoff, 2017a; Rabinowitch & Meltzoff, 2017b; Tunçgenç & Cohen, 2018) in children and adults (Cross et al., 2019; Mogan et al., 2017; Rennung & Göritz, 2016). Positive social effects of IS have been observed in infants as young as 12 months (Cirelli et al., 2014; Cirelli et al., 2018; Fawcett & Tunçgenç, 2017; Tunçgenç et al., 2015).

While IS has been found to play a positive role in neurotypical social functioning, challenges with social communication and social relationships are frequently observed in atypical development (see e.g. Mikami et al., 2019). Researchers have therefore considered whether IS may operate differently in neurodivergent individuals, and whether any differences relate to social difficulties they may experience. Lower levels of IS have been observed in autistic children and adults (Chen et al., 2022; Fitzpatrick et al., 2017a; Kruppa et al., 2021; Marsh et al., 2013; Zampella et al., 2020) and adults with other conditions (Dean et al., 2021; Problovski et al., 2021), relative to neurotypical comparators. There is also some evidence that the social effects of IS are reduced in autistic compared to neurotypical adults (Au & Lo, 2020; Koehne, Hatri, et al., 2016). However, the factors that contribute to the social effects of IS are not well understood (Bowsher-Murray et al., 2023; Michael et al., 2020). Further, it is largely unknown whether IS has social effects in atypically developing populations.

A range of perceptual, social and motoric processes contribute to IS (Delaherche et al., 2012; Konvalinka et al., 2010; McNaughton & Redcay, 2020; Mills et al., 2019), each of which may operate differently in atypical development (see e.g. Bora & Pantelis, 2016; Hudry et al., 2020; Casassus et al., 2019; Lense et al., 2021; Falter & Noreika, 2014). As such, a range of factors potentially contribute to variation in the experience of IS, and therefore to its social relevance (Bloch et al., 2019; Cirelli, 2018). A better understanding of the social significance of IS across typical and atypical development would enhance understanding of differences in social communication across neurotypes, and potentially of the associated challenges experienced by neurodivergent individuals. To that end, this thesis investigates the properties of IS that contribute to its affiliative effects in typically developing (TD) children; the social significance of IS for children with emerging emotional and behavioural difficulties (EE&BDs) ; and the component processes that may contribute to variation in its social effects.

This Chapter gives an account of the emergence of IS in typical development, describes the developmental and social significance of IS, then discusses the factors potentially underpinning its social effects. Evidence of IS in atypical populations is presented, followed by a discussion of factors that may contribute to variation in the social effects of IS in these populations. Finally, the value of a transdiagnostic approach to the examination of IS in atypical development is discussed.

1.2 Emergence of IS in typical development

Sensitivity to social timing begins to emerge from the earliest days of life. Infant behaviour has been shown to correspond with caregiver cues (Cuadros et al., 2020; Markova et al., 2019) via their limb movements (Condon & Sander, 1974), facial expressions (Tronick & Cohn, 1989) and vocalisations (Dominguez et al., 2016). From the second month of life, infants begin to engage in proto-conversations with caregivers, characterised by smooth turn-taking in vocalisations (Gratier et al., 2015; Nguyen et al., 2022). Around the same age, infants display distress in response to substantial disruptions in interactional timing (Murray & Trevarthen, 1985; Nadel et al., 1999), suggesting that timing is significant even in early social experiences (Hoehl et al., 2021).

However, infant-caregiver interactions are more frequently characterised by periods of discoordination than periods of IS (Tronick & Cohn, 1989), with early instances of IS believed emerge via temporal scaffolding by the adult partner (Gratier et al., 2015; Harrist & Waugh, 2002; Markova et al., 2019; Meyer & Hunnius, 2020). In line with the development of infants' motor skills (Trainor & Cirelli, 2015), infant-caregiver IS becomes increasingly temporally accurate and somewhat less reliant on adult facilitation during the first year of life (Evans & Porter, 2009; Feldman, 2012; Feldman et al., 1999; Hilbrink et al., 2015). Evidence suggests that adult facilitation of IS nevertheless continues to be important in early childhood. For example, mothers were primarily responsible for maintaining IS with mobile 13- to 19-month-old infants as they explored a playroom (Hoch et al., 2021). Relatedly, children aged 2.5 years were able to synchronise the tempo of their drumming with an adult partner (Kirschner & Tomasello, 2009; Yu & Myowa, 2021), but spontaneous co-ordination of drumming with a peer was not observed until four years of age (Endedijk et al., 2015). In another drumming task, 5-year-old children synchronised more accurately with an adult than with another child (Kleinspehn-Ammerlahn et al., 2011). Accuracy of IS continues to increase over the course of later childhood. For example, in children and adolescents aged 6 to 19 years, accuracy of movement synchronisation with a virtual tightrope walker was positively associated with age (Xavier et al., 2018). Adolescents achieved higher levels of IS than children during co-ordinated walking and mirroring tasks (Bar Yehuda & Bauminger-Zviely, 2022). Similarly, when carrying out a tidying-up activity, dyads of 10- and 11-year-old children displayed lower levels of spontaneous IS than adult dyads (Su et al., 2020). In sum, sensitivity to social timing is present from early on in development. IS initially emerges via adult facilitation, which continues to contribute to IS throughout the first years of life. Children's involvement and accuracy in co-creating IS increases with age (Rauchbauer & Grosbras, 2020; Trainor & Cirelli, 2015).

1.3 Developmental and social relevance of IS

1.3.1 IS and developmental outcomes

IS plays a significant role in children's developmental outcomes (Feldman, 2007c; Harrist & Waugh, 2002). For example, infant-caregiver IS is believed to support the development of secure attachment relationships, with longitudinal evidence that higher levels of infant-caregiver IS positively predict secure attachment relationships in infancy (Evans & Porter, 2009; Isabella et al., 1989; Lundy, 2003) and in later childhood and adolescence (Feldman, 2007a; Leclère et al., 2014). Further, higher levels of mother-infant synchrony predicted enhanced emotional regulation (Feldman, 2012; Feldman et al., 1999) and self-control

(Lindsey et al., 2009) in later childhood. Relatedly, disrupted mother-infant synchrony mediated the link between maternal post-partum and disrupted emotional regulation (Granat et al., 2017). Higher levels of infant-caregiver IS have also been associated with increased empathy (Feldman, 2012; Feldman et al., 1999) and social competence (Atzil & Gendron, 2017; Leclère et al., 2014) in childhood and adolescence.

1.3.2 IS and social relationships

IS is an important aspect of social interactions beyond the infant-caregiver dyad. A range of studies have experimentally manipulated the level of IS between partners, finding evidence that IS promotes affiliation throughout the lifespan (Cirelli, 2018; Cross et al., 2019; Mogan et al., 2017; Rauchbauer & Grosbras, 2020; Rennung & Göritz, 2016). For example, infants aged 12 months preferred to reach for teddies with whom they had been rocked synchronously, over teddies who had rocked asynchronously (Tunçgenç et al., 2015). Children, adolescents and adults who moved with a live partner during a silent disco (Tarr et al., 2015; Tarr et al., 2016; Tunçgenç & Cohen, 2016) reported greater liking and/or feelings of similarity towards synchronous than asynchronous partners, as did adults who made limb movements with a partner who appeared via video link (Lang et al., 2017). IS occurring via more isolated movements such as finger or hand tapping (Hove & Risen, 2009; Howard et al., 2021; Rabinowitch et al., 2015; Valdesolo & Desteno, 2011) similarly led to increased partner affiliation in both children and adults. Comparable effects on affiliation have been observed during virtual, computer-based interactions in which the partner is neither present nor visible, with their movement conveyed only via auditory signals (Cacioppo et al., 2014; Koehne, Hatri, et al., 2016; Launay et al., 2013), suggesting that the temporal qualities of an interaction are socially relevant, even in the absence of other social information.

IS also induces prosocial behaviour. For example, 12-month old infants bounced either synchronously or asynchronously with a researcher were subsequently more helpful towards synchronous than asynchronous partners (Cirelli et al., 2014; Cirelli et al., 2016). Four-year-old children who were swung with a peer in a swing set displayed more sharing (Rabinowitch & Meltzoff, 2017a) and higher levels of co-operation (Rabinowitch & Meltzoff, 2017b) towards synchronous peers. Synchronous clapping (Tunçgenç & Cohen, 2018) induced increased helping behaviour between 4- to 6-year old peers. In adults, IS occurring via actions including walking (Wiltermuth & Heath, 2009), drumming (Kokal et al., 2011) and finger tapping (Launay et al., 2013) similarly led to increased prosocial behaviour between partners (for reviews see Cross et al., 2019; Mogan et al., 2017, Rennung & Göritz, 2016).

As well influencing first-person experiences of social interaction, IS informs the social interpretation of interactions between others, from an equally early point in development. Twelve- to 14-month-old infants expected synchronous but not asynchronous human partners to demonstrate friendly behaviour towards each other (Cirelli et al., 2018), and 15-month-olds – although not 12-month-olds – were more likely to expect affiliative behaviour between teddies who bounced synchronously relative to those who bounced asynchronously (Fawcett & Tunçgenç, 2017). Relatedly, children aged 9 to 11 years rated synchronously interacting adult-child dyads as higher in affiliation than asynchronous dyads (Abraham et al., 2022). Adults were similarly influenced by IS when assessing partner rapport (Edelman & Harring, 2014; Lakens & Stel, 2011; Miles et al., 2009), similarity (Hartmann et al., 2019), closeness (Lee et al., 2020) and social cohesion (Wilson & Gos, 2019). Such effects have been observed both when IS is presented via highly controlled stimuli such as stick-figure animations (e.g. Miles et al., 2009) and via more naturalistic social interactions such as partners walking in step (Edelman & Harring, 2014), dancing (Hartmann et al., 2019; Lee et al., 2020), and taking part in a painting activity (Abraham et al., 2022).

In addition to evidence that IS affects social outcomes, there is also evidence of the opposite causative relation, that is, social factors can influence levels of IS. Individuals synchronise more accurately (Honisch et al., 2021; Howard et al., 2021) and at an earlier stage of development (Kirschner & Tomasello, 2009) when interacting with a social partner as opposed to a non-social stimulus, suggesting that the existence of a social context may in itself motivate synchronisation (Kirschner & Tomasello, 2009; Yu & Myowa, 2021). Further, factors *within* the social context influence IS. Higher levels of IS emerged between friends than between strangers (Latif et al., 2014), and individuals synchronised more with partners to whom they were positively disposed, such as those they believed to be punctual (Miles et al., 2010), honest (Brambilla et al., 2016), and attractive (Zhao et al., 2015), relative to partners they believed to be tardy, dishonest, and unattractive, respectively. Relatedly, higher levels of IS have been observed in interactions with affiliative goals compared to those in argumentative settings (Paxton & Dale, 2013; Tschacher et al., 2014) and in closeness-generating interactions, relative to 'small talk' (Asher et al., 2020).

In sum, complementary lines of research indicate both that IS arises from positive social antecedents and that it has positive social consequences (Tschacher et al., 2014), suggesting that the relation between IS and social rapport is bidirectional and mutually reinforcing (Gvirts & Perlmutter, 2020; Hoehl et al., 2021). Consequently, researchers have characterised IS as arising from the need or desire to make social connections with others (Gvirts & Perlmutter, 2020; Hoehl et al., 2021; Lumsden et al., 2014) and a means of co-constructing a social space (Carlos et al., 2017).

1.3.3 Factors underpinning affiliative effects

Although the social significance of IS is well documented, much less is known about *how* its positive social effects come about (Cirelli, 2018; Hu et al., 2022; Rabinowitch, 2020; Wan & Zhu, 2022). Two different theoretical accounts have proposed that specific temporal properties of an interaction are responsible. The first proposal is that contiguity (i.e. the extent to which behaviours co-occur in time) is critical (Dignath et al., 2018; Rauchbauer & Grosbras, 2020). The second proposal is that IS drives affiliation because it creates conditions of temporal contingency (i.e. partners' actions predict one another) (Cirelli et al., 2014; Tunçgenç et al., 2015; Wan & Fu, 2019).

The first proposal (contiguity) therefore suggests that the affiliative effects of IS depend on simultaneity of partner action. Indeed, much of the existing literature has assumed that simultaneity of action is an essential property of IS (e.g. Hove & Risen, 2009; Tarr et al., 2016; Howard et al., 2021). It has been proposed that IS generates affiliative effects by creating an impression of similarity between partners (see e.g. Valdesolo & Desteno, 2011; Dignath et al., 2018; Hu et al., 2022). By contrast, the second proposal (contingency) takes a broader view of the temporal relations that generate affiliative effects. In addition to simultaneity, temporal regularity – whereby partners' actions occur at a constant (but non-zero) temporal interval – would also create temporal contingency between partners. Under the second proposal, therefore, simultaneity and regularity would each lead to affiliative effects, because they each provide a shared temporal framework (Demos et al., 2012; Kirschner & Tomasello, 2010; Wan & Zhu, 2022). This interpretation aligns with proposals that IS generates affiliative effects because it conveys a sense of co-operation and shared intentionality between interacting partners (Kirschner & Tomasello, 2010; Reddish et al., 2013; Wan & Fu, 2019; Wan & Zhu, 2022). A further possibility is that the effects of simultaneity and regularity are cumulative, such that affiliation is greatest when both are present.

Previous empirical research has not clearly delineated the relative importance of simultaneity and regularity, as studies have not typically manipulated simultaneity and regularity independently. Rather, they have contrasted a 'synchronous' condition, in which partners' interactions displayed both simultaneity and regularity, with an 'asynchronous' condition, in which partners acted neither simultaneously nor at regular intervals from each other (e.g. Lang et al., 2017; Tarr et al., 2018; Tunçgenç et al., 2015; Rabinowtich & Meltzoff, 2017; Fawcett & Tunçgenç, 2017). Some studies have manipulated temporal proximity between partners during regular interactions, but have given rise to conflicting findings on whether simultaneity influences social outcomes when temporal regularity is present (Cirelli et al., 2014; Cross et al., 2016; Dignath et al., 2018; Lakens & Stel, 2011; Miles et al., 2009; Wiltermuth, 2012). The two studies that manipulated both simultaneity and regularity independently (Cacioppo et al., 2014; Cirelli et al., 2014) each used different samples (adults vs infants) and outcome measures (self-reported perceived affiliation vs helping behaviour). Findings from these studies were mixed: in adults, both simultaneity and regularity significantly influenced affiliation (Cacioppo et al., 2014), whereas in infants only simultaneity had such an effect (Cirelli et al., 2014). Thus, the relative importance of temporal regularity and simultaneity in generating positive social effects, particularly in children, remains unclear.

A further, related question concerns the factors that mediate the relation between the objective temporal properties of an interaction and the social judgements to which they give rise. In adults, there is evidence to suggest that subjective perceptions of IS play a role. For example, adult participants' subjective perception of the extent to which they were synchronized in a tapping game was significantly associated with how much they reported liking their partner (Launay et al., 2014), and with the level of trust they displayed towards each other (Launay et al., 2013). There is also some evidence that subjectively perceived synchrony mediated the relationship between objective levels of IS and corresponding social judgements in adults (Hagen & Bryant, 2003; Lakens, 2010). By contrast, previous studies of the effects of IS in children have focused exclusively on the relation between objective levels of IS and affiliation. There is no evidence of how children subjectively perceive IS, or how such perceptions relate to their assessments of affiliation between interacting partners.

1.4 Individual differences in IS in typical populations

The studies described above almost all employed between-subjects designs and established group level effects. Much less attention has been given to variation in the tendency to synchronise at an individual level, and still less to individual differences in sensitivity to the social effects of IS. Considerable heterogeneity in levels of IS was reported among adult participants in one study: even among those exposed to the same experimental conditions, the proportion of an interaction spent synchronising ranged between 4 and 97% (Lumsden et al., 2012; Miles et al., 2010). However, no other studies have reported on variation in levels of IS at the individual level, and there are no known studies that report on within-group variation in the affiliative or behavioural effects of IS. There is some evidence that two individual level factors, namely, personality traits and gender, may influence the incidence and social effects of IS.

1.4.1 Personality traits

Personality-related traits may modulate individuals' tendency to synchronise. Lumsden et al. (2012) assessed participants' trait-level propensity towards co-operation and sociality, according to which participants were classified either as 'prosocial' or 'proself.' Prosocial participants spontaneously synchronised with a partner to a significantly greater extent than pro-self participants, when carrying out an arm movement activity. In naturalistic interactions, extroverts synchronised more than introverts (Arellano-Véliz et al., 2023), as did those with greater openness to experience and fewer narcissistic interpersonal traits (Tschacher et al., 2018). Thus, different personality dimensions may be relevant to the tendency to display IS. However, it is not known whether personality traits influence the extent to which individuals are sensitive to the affiliative or prosocial effects of IS.

1.4.2 Gender

A small number of studies have investigated gender differences in IS. In neurotypical adults (Cheng et al., 2017; Fujiwara et al., 2019) and autistic children aged 2 to 7 years (Paolizzi et al., 2022), females displayed higher levels of IS than males during naturalistic or semi-structured interactions, although another study observed the reverse, with adult male dyads displaying more extended periods of IS than female dyads (Tschacher et al., 2018).

Evidence of gender differences in the social outcomes of IS is also both limited and mixed. The relation between the degree of IS experienced and partner ratings of affect was significantly stronger in female dyads than male dyads (Tschacher et al., 2014), suggesting higher sensitivity to the social effects of IS in females than males. Relatedly, when participants took part in two six-minute conversations separated by a short unrelated task, levels of IS in the first conversation predicted levels of IS in the second task for females but not for males (Fujiwara et al., 2019). Interpreting levels of IS in the second conversation as a marker of partner affiliation established during the first conversation, the researchers therefore concluded that males were less socially sensitive to IS than females. By contrast, no gender differences were found in the extent to which a synchronous musical interaction promoted helping behaviour in 4-year-old children (Kirschner & Tomasello, 2010), or in the influence of a synchronous tapping interaction on self-reported partner affiliation in adults (Cacioppo et al., 2014). Thus, the link between gender and the social effects of IS remains unclear.

1.5 IS and neurodivergent conditions

IS and its social effects may differ in those with neurodivergent conditions – i.e. those who display psychological functioning that differs substantially from the neurotypical majority. For instance, challenges with social communication and social relationships are a diagnostic feature of autism (APA, 2013). Researchers have therefore paid particular attention to whether IS differs in autism, and whether any differences relate to social difficulties experienced by autistic people. There is also some evidence of IS-related differences in other neurodivergent populations.

1.5.1 Autism and the incidence of IS

Autism is a neurodivergent condition characterised by difficulties with social communication and interaction as well as restrictive and repetitive behaviour and interests (APA, 2013). Atypical social communication may manifest via atypical socio-emotional reciprocity and/or atypical use of non-verbal cues (APA, 2013). A significant body of research suggests that reduced IS is one aspect of atypical non-verbal behaviour in autism (McNaughton & Redcay, 2020). Autistic children displayed significantly lower levels of spontaneous and intentional IS than non-autistic children in experimental tasks involving chair rocking (Marsh et al., 2013) and pendulum swinging (Fitzpatrick et al., 2016) with a parent; clapping and limb/body movements with a researcher (Fitzpatrick et al., 2017b; Kaur et al., 2018); and in their computer game responses both with a parent and adult stranger (Kruppa et al., 2021). Reduced IS has also been observed in naturalistic interactions involving autistic children. Autistic 4- to 6-year-olds displayed lower levels of IS than TD comparators during a face-to-face free play session with a familiar adult (Chen et al., 2022). Autistic children and adolescents displayed lower levels of spontaneous IS during conversation with familiar and unfamiliar adults (Zampella et al., 2020) and in interactions that took place during neuropsychological testing sessions (Noel, De Niear, et al., 2018; Romero et al., 2018). In a joint attention task with a researcher, autistic children also synchronised their gaze shifts less than neurotypical children (Liu et al., 2021). Similar findings emerged from studies with adult samples. Autistic adults displayed reduced spontaneous IS during an improvised movement task (Brezis et al., 2017), a clinical diagnostic interview (Koehler et al., 2021) and in a conversational task (Georgescu et al., 2020), as well as reduced intentional IS during a hand movement task (Granner-Shuman et al., 2021). Further, autistic traits were dimensionally related to levels of IS in both children and adults, with higher levels of autistic traits associated with lower levels of IS (Brezis et al., 2017; Cheng et al., 2017; Fitzpatrick et al., 2017a; Romero et al., 2018; Zampella et al., 2020; Granner-Schuman et al., 2021; although cf. Kaur et al, 2018).

However, almost all studies evidencing reduced IS in autism were based on live interactions involving complex motor movements. By contrast, autistic and non-autistic adults displayed comparable levels of IS when the social, perceptual, and motoric content of the interaction was substantially reduced, in that it involved only the exchange of signals with an unseen partner *via* a computer button press (Koehne, Hatri, et al., 2016). Together with evidence that IS is reduced but still present at above chance levels in more complex interactions (Romero et al., 2018; Georgescu et al., 2020; Koehler et al., 2021, although cf Chen et al., 2022), it may be that a basic tendency to synchronise is intact in autism.

Notably, almost all of the studies described above compared levels of IS in neurotypical dyads with levels of IS in mixed dyads, i.e. dyads with one autistic and one neurotypical partner. However, interaction styles are more likely to be similar (Cho et al., 2022; Georgescu et al., 2020; Milton, 2012), and affiliation may be higher (Crompton et al., 2020a), within neurotypes than between neurotypes. Therefore, one might expect to see higher levels of IS within autistic dyads than in mixed dyads. Yet, IS was lower in *both* autistic dyads and mixed dyads, relative to neurotypical dyads, when partners engaged in an unstructured face to face interaction (Georgescu et al., 2020).

1.5.2 The incidence of IS in other neurodivergent conditions

Difficulties with social functioning may occur in neurodivergent conditions other than autism (Lense et al., 2021; Mikami et al., 2019; Missiuna et al., 2014). For example, although attention deficit hyperactivity disorder (ADHD) is primarily characterised by symptoms of inattention, hyperactivity and impulsivity (APA, 2013), children and adolescents with ADHD also experience higher levels of peer rejection and difficulties forming and maintaining social relationships, relative to neurotypical peers (Mikami et al., 2019; Missiuna et al., 2014; Mrug et al., 2012). Relatedly, developmental coordination disorder (DCD) is diagnosed according to the presence of impaired motor co-ordination that interferes with activities of daily living (APA, 2013), but has also been associated with an increased likelihood of social communication difficulties (Lingam et al., 2010), reduced self-perceptions of social competence, and peer rejection (Tamplain & Miller, 2021), In both ADHD (Mikami et al., 2019) and DCD (Tamplain & Miller, 2021; Zwicker et al., 2013), social difficulties have been conceptualised as secondary consequences of the primary characteristics of the condition.

Atypical social communication in neurodivergent conditions other than autism raises the question as to whether IS might also by atypical for people with such conditions. A small number of studies have addressed this question previously. Two studies found evidence of reduced IS in ADHD. In a population-based child sample, higher levels of ADHD-related traits were associated with reduced levels of synchrony in a rhymical group activity (Khalil et al., 2013). In an experimentally controlled hand gesture task, adults with ADHD displayed lower levels of intentional IS but comparable levels of spontaneous IS, relative to those without ADHD (Problovski et al., 2021). Only one study has examined the relation between DCD and IS, finding no association between self-reported symptoms of DCD and levels of IS during an adult clinical autism assessment (Koehler et al., 2021). There is also evidence of reduced IS in other conditions in which social difficulties are observed, including social anxiety disorder (Asher et al., 2020; Varlet et al., 2014) and schizophrenia (Cohen et al., 2017; Kupper et al., 2015; Varlet et al., 2012).

Overall, studies investigating IS in neurodivergent conditions other than autism are relatively scarce. Taken together, however, they suggest that reduced IS is not specific to autism and is also present in other conditions linked to atypical social functioning. However, differences in IS may be more extensive in autism than in other neurodivergent conditions. Specifically, differences in both spontaneous and intentional IS are consistently observed in autism, but the evidence of reduced spontaneous IS in other conditions is less consistent (Problovski et al., 2021).

1.5.3 Variation in the social effects of IS

The above studies suggest that neurodivergent people may experience IS less frequently and/or consistently relative to neurotypical people. Reduced experience of IS necessarily means that any positive social consequences will also be experienced less frequently. However, a separate question is whether, if and when IS does arise, it has social significance for neurodivergent populations. To my knowledge, sensitivity to the social effects of IS in neurodivergent individuals has been addressed by only two previous studies, both of which involved adult autistic samples. In a computer-based task involving the exchange of signals via button press, neurotypical adults experienced greater feelings of empathy towards partners who responded synchronously relative to those who responded asynchronously. Conversely, response synchrony did not influence autistic adults' feelings of empathy towards their partners (Koehne, Hatri, et al., 2016). Similarly, when participants watched videos of social partners walking together, neurotypical children and adults rated synchronous walkers as significantly higher in 'closeness' than asynchronous walkers, but the closeness ratings given by autistic adults did not differ across conditions (Au & Lo, 2020). However, in a ranking task based on the same videos, autistic adults were more likely to rate synchronised walkers as higher in closeness than non-synchronised walkers (Au & Lo, 2020), suggesting that the presence of IS did have some influence on the social judgements of autistic participants.

Overall, although these two studies suggest that the social significance of IS may be reduced or absent for autistic adults, the evidence as to the social effects of IS outside typical development is extremely limited. In particular, there is no evidence to date of the social effects of IS in children other than those who are typically developing.

1.6 Factors associated with variation in the social effects of IS

In addition to exploring variation in social sensitivity to IS, it is relevant to consider which factors might relate to, and are potentially responsible for, such variation. This thesis takes two different approaches to investigating the correlates of social sensitivity to IS. The first is to examine the relation between levels of traits relevant to neurodivergent diagnoses and social sensitivity to IS. The second is to explore the extent to which social sensitivity to IS is explained by variation in the perceptual, motor and social component processes of IS.

1.6.1 Diagnostic traits

Given evidence of a dimensional relation between diagnostic traits and the incidence of IS (see section 1.5 above), diagnostic traits might also be correlates of sensitivity to the social effects of IS. Although this is potentially the case for a number of neurodivergent conditions, this thesis will focus specifically on the relation between traits relevant to diagnoses of autism and ADHD (hereafter, 'autistic traits' and 'ADHD traits' and, collectively, 'diagnostic traits') and social sensitivity to IS.

The primary characteristics of autism and ADHD are believed to give rise to atypical social functioning via different pathways. Autistic people may experience difficulties in producing and/or interpreting non-verbal social cues (APA, 2013). For autistic people, other aspects of social interactions may be more important for social bonding, such as efficient information exchange or feelings of shared experience (Crompton et al., 2020b; Heasman & Gillespie, 2019; Morrison et al., 2020). Thus, increased levels of autistic traits may be associated with reduced social sensitivity to IS via a decreased tendency to process IS as socially relevant. By contrast, social difficulties in ADHD are thought to arise, in part, as a consequence of difficulty in directing and maintaining social attention, causing social cues to be missed (Dahan et al., 2016; Harkins et al., 2022; Leitner, 2014). Thus, increased ADHD traits may relate to reduced social sensitivity to IS via a reduced tendency to detect and/or process levels of IS within an interaction. These two possible pathways are not mutually exclusive: the ways in which social cues are attended to and processed may each contribute to variation in sensitivity to the social effects of IS. Autism and ADHD frequently co-occur (for reviews see Lai et al., 2019; Hollingdale et al., 2020), with evidence that social challenges in autism are greater when symptoms of ADHD are also present (Chiang & Gau, 2016; Factor et al., 2017). Thus, autistic and ADHD traits may independently or interactively predict reduced social sensitivity to IS.

1.6.2 Component processes

IS emerges as a function of multiple component processes operating in concert with each other (Dean et al., 2021; Delaherche et al., 2012; Konvalinka et al., 2010; McNaughton & Redcay, 2020; Mills et al., 2019). Processes that have been found to play a role include social orienting (Richardson et al., 2007); attention (e.g. Temprado and Laurent, 2004; Varlet et al., 2012); temporal perceptual processing (e.g. Noel et al., 2018); anticipation (Meyer et al., 2015; Pecenka & Keller, 2011) motor behaviour (e.g. Hart et al., 2014; Monier and Droit-Volet, 2019); as well as social factors (Kirschner & Tomasello, 2009; Fitzpatrick et al., 2018; Honisch et al., 2021). Atypical functioning in a number of these domains has been observed across a range of neurodivergent conditions (see e.g. Frazier et al., 2021; Falter & Noreika, 2014; Wallace & Stevenson, 2014; Lense et al., 2021; Hudry et al, 2020; Harkins, 2022).

Examining the specific contributions of the component processes of IS is thus an alternative approach to explaining variation in social sensitivity to IS. This thesis will consider the role of three component processes in explaining variation in social sensitivity to IS: temporal perception, motor behaviour and the ability to make mental state inferences, i.e. theory of mind (ToM) (Frith & Frith, 2003; Premack & Woodruff, 1978).

1.6.2.1 Temporal perception

1.6.2.1.1 Synchrony perception and IS

IS is facilitated by perceptual coupling, for example, by partners having mutual visual and/or auditory access to each other's movements (Koul et al., 2023; Miyata et al., 2017; Oh Kruzic et al., 2020; Oullier et al., 2008; Richardson et al., 2007). Perceptual coupling, in turn, is believed to facilitate mutual monitoring and adaptation (Gvirts Probolovski & Dahan, 2021; Shamay-Tsoory et al., 2019) so that temporal alignment between partners can be achieved. As such, partners' ability to perceive the relative timing of their behaviour is likely to be a critical ingredient of IS (Novotny & Bente, 2022). Further, the influence of IS on social outcomes depends on the ability of those involved to perceive (a)synchrony between partners (Lakens, 2010; Novotny & Bente, 2022; Oullier et al., 2008; Trainor & Cirelli, 2015). In sum, temporal perceptual acuity, and specifically the capacity to perceive the relative timing of events, likely contributes both to the incidence of IS and to sensitivity to its social effects.

1.6.2.1.2 Synchrony perception in typical development

Infants display sensitivity to the temporal structure of events from the first months of life (Baruch & Drake, 1997; Anne Bobin-Bègue et al., 2006; Provasi, 2014), but their capacity to process the relative timing of stimuli is initially limited. For example, a habituated looking paradigm indicated that infants aged between 2 and 8 months were able to detect audiovisual asynchrony between a bouncing ball and a corresponding sound, but only when the stimulus onset asynchrony (SOA), i.e. the delay between presentation of the auditory and visual stimuli, was relatively large. To detect asynchrony, infants required an SOA of 350 or 450 ms, depending on whether the auditory or visual stimulus was presented first. In adults, the equivalent SOAs were 67 and 112 ms respectively (Lewkowicz, 1996). Similarly, 4- to 10-month-old infants were sensitive to audio-visual speech asynchrony, but only at SOAs of several hundred milliseconds (Lewkowicz, 2010). During childhood (Kaganovich, 2016; Lewkowicz & Flom, 2014; Pons et al., 2013) and adolescence (Hillock-Dunn & Wallace, 2012), judgements of the relative timing become increasingly accurate, as evidenced by an age-related decrease in the SOA at which synchronous and asynchronous stimuli can reliably be differentiated.

In TD children and adolescents, better detection of asynchrony in an audio-visual stimulus was associated with higher levels of spontaneous IS during a subsequent interaction (Noel et al., 2018). Such increased perceptual acuity presumably supports IS by enhancing the perceptual cohesion and salience of the behaviour (Bahrick & Todd, 2012) with which synchrony is to be achieved. Notably, however, IS typically requires not just the detection of synchrony *within* a single source of multisensory information (e.g. a bouncing ball, or a person speaking), but the detection and monitoring of synchrony between two separate sources of information (i.e. two social partners). Research has not directly addressed how the detection of (a)synchrony from two separate information streams develops. Nevertheless, the social effects of IS seen in the second year of life (Cirelli et al., 2014; Cirelli et al., 2018; Cirelli et al., 2016; Fawcett & Tunçgenç, 2017) are presumably underpinned by an ability to detect (a)synchrony between two separate social stimuli, although the boundary conditions of this ability are not clear.

1.6.2.1.3 Synchrony perception in neurodivergent conditions

A variety of differences in temporal perception have been observed in neurodivergent conditions (Casassus et al., 2019; Falter & Noreika, 2014; Isaksson et al., 2018; Meilleur et al., 2020; Zheng et al., 2022; Zhou et al., 2022). In relation to the perception of relative timing of events specifically, research across conditions presents a complex picture (see **Table 1.1** for a summary of findings).

In autism, for example, findings tend to differ by stimulus type (Casassus et al., 2019; Meilleur et al., 2020). When audio-visual, speech-based stimuli are used, there is consistent evidence that autistic people are less sensitive to asynchrony than non-autistic comparators (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Grossman et al., 2015; Noel, De Niear, et al., 2018; Stevenson et al., 2014; Suri et al., 2023; Zhou et al., 2022). However, findings in relation to multisensory non-social, non-speech stimuli are mixed, with some studies finding evidence of reduced sensitivity in autism (de Boer-Schellekens et al., 2013; Foss-Feig et al., 2010; Kwakye et al., 2011), and others finding no differences between autistic and non-autistic groups (Bebko et al., 2006; Smith et al., 2017; Stevenson et al., 2014; Suri et al., 2023; Zhou et al., 2022). There is also inconsistent evidence of sensitivity to uni-sensory auditory and visual synchrony. Many studies found no differences in autistic and non-autistic samples (Kwakye et al., 2011; Poole et al., 2022; Stevenson et al., 2014; Zhou et al., 2022), but one observed reduced sensitivity to auditory synchrony in autistic children (Kwakye et al., 2011) and another found enhanced sensitivity to visual synchrony in autistic adults (Falter et al., 2012). One study found no group-level differences in visual perceptual acuity, but greater variability within the autistic group than within the non-autistic group, suggesting that *both* reduced and enhanced detection of visual synchrony may be present at an individual level (Isaksson et al., 2018). Overall, it is unclear whether atypical synchrony perception in autism depends on social context or stimulus modality, or whether there are generalised differences in how autistic people perceive (a)synchrony (Meilleur et al., 2020).

In contrast to the range of studies investigating synchrony perception in autism, there is little evidence of the perception of the relative timing of events in ADHD. Inconsistent findings (Breier et al., 2003; Fostick, 2017; Panagiotidi et al., 2017) mean that the existence and nature of any differences are unclear. There is, however, more consistent evidence of reduced sensitivity to synchrony, irrespective of stimulus type (flashes/tones vs speech-based stimuli) or modality (audio; visual; audio-visual) in developmental dyslexia (Ben-Artzi et al., 2005; Fostick & Revah, 2018; Francisco et al., 2017; Hairson et al., 2005; Virsu et al., 2003, although cf. Laasonen et al., 2001; Laasonen et al., 2002).

Table 1.1

Summary of evidence of differences in synchrony perception in neurodivergent conditions

	Stimulus type			
	Unisensory		**Multisensory – audiovisual**	
	Auditory	**Visual**	**Non-speech**	**Speech**
Autism	**Reduced** (Kwakye et al., 2011) acuity in younger autistic children. **No difference** in middle childhood/adolescence (Stevenson et al., 2014; Zhou et al., 2022), or adulthood (Poole et al., 2022) using ToJ tasks.	**Enhanced** acuity in autistic adults in an SJ task (Falter et al., 2012). **No difference** in acuity in autistic and non-autistic children (although more variable performance in autism) in an SJ task (Isaksson et al., 2018). No difference between autistic and non-autistic children/adolescents (Kwakye et al., 2011; Stevenson et al., 2014; Zhou et al., 2022) or adults (Poole et al., 2022) in ToJ tasks.	**Reduced** acuity in autistic children using a flash-beep illusion (Foss-Feig et al., 2010) and ToJ tasks (de Boer-Schellekens et al., 2013; Kwakye et al., 2011). **No difference** in in acuity between autistic and non-autistic children (Bebko et al., 2006; Stevenson et al., 2014; Zhou et al., 2022), adolescents (Smith et al., 2017), or infants at elevated likelihood of autism (Suri et al., 2023) using implicit or explicit SJ tasks.	**Reduced** acuity in autistic children (Bebko et al., 2006; de Boer-Schellekens et al., 2013; Stevenson et al., 2014; Zhou et al., 2022), adolescents (Grossman et al., 2015; Noel, Stevenson, et al., 2018), and in infants at elevated likelihood of autism (Suri et al., 2023) when detecting speech synchrony with faces. **Enhanced** acuity in autistic children when detecting speech synchrony with objects (Smith et al., 2017).
ADHD	**Reduced** acuity in children (Cardy et al., 2010) and adults with ADHD (Fostick, 2017) using ToJ tasks. N**o difference** in acuity in older children with ADHD (Breier et al., 2003) using a forced-choice SJ task.	-	**Enhanced** acuity in those with high vs low levels of ADHD traits in a population sample when assessed via SJ, but **no difference** when assessed via ToJ (Panagiotidi et al., 2017).	-

(cont.)

Developmental Dyslexia	**Reduced** acuity in adults with DD (Ben-Artzi et al., 2005; Fostick & Revah, 2018; Hairston et al., 2005; Laasonen et al., 2001; Pasquini et al., 2007) using ToJ/SJ.	**Reduced** (Hairston et al., 2005) or **no difference** (Laasonen et al., 2001) in acuity in adults with DD using ToJ/SJ	**Reduced** acuity in DD adults (Virsu et al., 2003) using ToJ, although potentially only where explicit judgement required (Francisco et al., 2017). **No difference** in ToJ thresholds between DD and typical adults (Laasonen et al., 2002).	**Reduced** acuity in DD adults, potentially only when explicit judgement required (Francisco et al., 2017)

A particular challenge when comparing findings within and across neurodivergent conditions relates to the type of task used to assess sensitivity to synchrony. Studies have variously used ToJ tasks (in which participants must specify which stimulus came first), explicit SJ tasks (in which participants must specify whether or not stimuli were simultaneous/together/at the same time etc), and implicit SJ (in which participants' perceptual acuity is assessed via changes in their visual attention to stimuli) (see **Table 1.1**). However, there is considerable debate as to whether such tasks measure the same constructs (Coull & Giersch, 2022; García-Pérez & Alcalá-Quintana, 2015; Van Eijk et al., 2008). Although there is evidence that both ToJ and SJ tasks tap into common underlying neuropsychological processes (Binder, 2015; García-Pérez & Alcalá-Quintana, 2015; Love et al., 2013), behavioural measures of SJ and ToJ performance are typically found to be unrelated (Love et al., 2013; Panagiotidi et al., 2017; Van Eijk et al., 2008; Vatakis et al., 2008). Differing task demands are likely responsible for this dissociation. For example, it may be possible to perceive stimuli as asynchronous without being able to discern their temporal order (Love et al., 2013; Van Eijk et al., 2008). Because ToJ tasks require participants to detect temporal order as well as asynchrony, they may overestimate the threshold at which participants can detect asynchrony. Relatedly, in explicit SJ tasks, participants' responses likely depend not only on their underlying perceptual capacities but also on the stringency with which they subjectively assess stimuli to be 'simultaneous' (Van Eijk et al., 2008; Vroomen & Keetels, 2010).

Overall, therefore, atypical synchrony perception is widely observed in individuals with neurodivergent conditions. However, evidence as to the nature and extent of differences is inconclusive, and the methods most commonly used to measure synchrony perception provide only indirect assessments of synchrony perception. Further, as most studies have considered group-level differences, the extent to which abilities vary within and/or across conditions, or co-vary with diagnostic traits, is unclear. Finally, particularly given that IS during day-to-day actions may variously involve synchrony between visual, auditory and or multisensory stimuli, it is unclear how variation in perceptual differences might map on to differences in the perception of IS, and therefore to its related social effects.

1.6.2.2 Motor abilities

1.6.2.2.1 Motor synchrony and IS

During IS, partner synchrony is not just perceived, but created via partners' motor behaviour. For IS to arise, partners make implicit spatial and temporal predictions about one another's movements (Meyer et al., 2015; Pecenka & Keller, 2011), and plan (Granner-Shuman et al., 2021), execute, and adapt (Candidi et al., 2015; Konvalinka et al., 2010) their own movements so that they become temporally aligned. Thus, motor function is believed to be an important contributor to IS (Georgescu et al., 2020; Trainor & Cirelli, 2015). By contributing to the frequency and reliability with which IS is experienced over time, motor synchrony is also likely to be closely linked to the extent to which individuals experience the positive social effects of IS.

1.6.2.2.2 Motor synchrony in typical development

The evidence indicates that infants change the tempo of their motor behaviour in response to tempo changes in the external environment as early as the first months of life (Bobin-Bègue & Provasi, 2008; A. Bobin-Bègue et al., 2006; Zentner & Eerola, 2010), but synchronisation with external stimuli does not emerge until later in development. For example, children aged 2 to 4 years produced periodic body movements in response to music, but did not significantly entrain their movement to stimulus tempo (Eerola et al., 2006).

The basic ability to synchronise motor behaviour, in the absence of social confounds or complex co-ordination requirements, is typically measured by having participants temporally align simple movements e.g. hand or finger taps with an isochronous audio or visual stimulus (for reviews see Repp, 2005, Repp & Su, 2013). Evidence obtained using this paradigm indicated that children between 18 months and 2.5 years were able to synchronise their hand tapping with an isochronous rhythm, so long as the tempo was close to their own spontaneous rate of tapping, i.e. their SMT (Bobin-Bègue & Provasi, 2008; Provasi & Bobin-Bègue, 2003). Similarly, 3-year-old children were able to synchronise finger tapping with music at tempos close to their own SMT, although not substantially beyond it (Van Noorden & De Bruyn, 2009). However, younger children may be able to synchronise at a wider range of tempos in a social context. Children synchronised their drumming with that of a human partner as early as 2.5 years of age, but did not synchronise a mechanical arm under otherwise equivalent conditions until 4 years of age (Kirschner & Tomasello, 2009). There is further evidence that, for non-social stimuli, children are unable to synchronise their tapping at a tempo substantially slower than SMT before the age of 4.5 years (Bobin-Bègue & Provasi, 2008; Provasi & Bobin-Bègue, 2003).

Overall, children reliably synchronise with non-social external stimuli at above chance levels by the age of 4 to 5 years. However, children's emerging ability to synchronise continues to depend on the complexity of the stimulus, with evidence that children aged 4 years were able to synchronise to a musical beat as well as adults, but the ability to synchronise with non-musical, isochronous or rhythmic stimuli increased in accuracy beyond the age of 10 years (Drake et al., 2000). A number of other studies have found that the range of tempos at which children can synchronise (Kurgansky & Shupikova, 2011) as well as the accuracy with which synchronisation is achieved (McAuley et al., 2006; Monier & Droit-Volet, 2018; Van

Noorden & De Bruyn, 2009) increases over the course of childhood. There is evidence that age-related improvements in motor synchrony are attributable to improvements in motor control, rather than improved cognitive abilities (Monier & Droit-Volet, 2019).

1.6.2.2.3 Motor synchrony in neurodivergent conditions

Atypical motor behaviour is frequently observed in neurodivergent conditions including autism (Fournier et al., 2010; Hocking & Caeyenberghs, 2017; Hudry et al., 2020; Lim et al., 2021; Zampella et al., 2021), ADHD (Dahan et al., 2016; Goulardins et al., 2017; Kaiser et al., 2015), developmental dyslexia (Gooch et al., 2014), and is a diagnostic feature of DCD (APA, 2013; Kilroy et al., 2022; Rosenblum & Regev, 2013). In relation to basic motor synchronisation abilities specifically, there is mixed evidence of reduced accuracy in autism, but more consistent evidence of less accurate motor synchrony in a number of other conditions.

For example, autistic adolescents were, on average, less able than neurotypical comparators to synchronise their hopping with an auditory stimulus (Moran et al., 2013), and autistic adults were less accurate than non-autistics at synchronising their drumming with an auditory rhythm (Franich et al., 2021). Autistic adolescents (Morimoto et al., 2018) and adults (Kasten et al., 2023; Vishne et al., 2021) displayed greater within-subject variability than neurotypical comparators when synchronising their finger tapping with an auditory stimulus, indicating less stable entrainment in autistic samples. Task-dependent differences in motor synchrony were found in autistic children aged 5 to 12 years, with evidence of less accurate synchronisation when marching and clapping to an auditory beat, but comparable synchronisation when drumming to the same stimulus (Kaur et al., 2018). Relatedly, autistic and non-autistic 7- to 16-year-olds were equally able to synchronise their woodblock tapping with auditory rhythms of various complexities (Tryfon et al., 2017). Finally, autistic adults also displayed in tact auditory-motor synchrony, as well as superior motor synchrony when the stimulus rhythm was presented visually (Edey et al., 2019).

In ADHD, there is more consistent evidence of reduced motor synchrony. Children with ADHD displayed less stable synchronisation when tapping to auditory tones, music as well as to visual and audio-visual stimuli, relative to TD children (Ben-Pazi et al., 2003; Puyjarinet et al., 2017; Rubia et al., 2003; Rubia et al., 1999). Similarly, adults with ADHD who carried out auditory-motor finger tapping tasks generally displayed less stable entrainment than comparators without ADHD (Valera et al., 2010; Hove et al., 2017, Puyjarinet et al. 2017; although cf. Amrani & Golumbic, 2020). There is a similar pattern of findings in relation to children with DCD, who displayed less accurate synchronisation when tapping their fingers, hands or feet with an auditory metronome (Puyjarinet et al., 2017; Rosenblum & Regev, 2013; Whitall et al., 2008), and when aligning finger movements to a predictable visual stimulus (de Castelnau et al., 2007, 2008; Debrabant et al., 2013). Children with developmental dyslexia also displayed less accurate synchronisation with an auditory metronome and/or musical beat, relative to comparators (Bégel et al., 2022; Overy et al., 2003; Pagliarini et al., 2020; Thomson & Goswami, 2008; Waber et al., 2000).

1.6.2.2.4 Motor synchrony, neurodivergence and IS

Overall, atypical motor synchronisation has been observed across atypically developing populations, and is thus a potential contributor to atypical IS. However, whether and to what extent motor synchronisation abilities relate to the experience and social effects of IS is unclear. The relation between motor function and IS has been explored in autism, although not in other neurodivergent conditions, with mixed results. Some studies have found a positive association between motor abilities and observed levels of IS. For example, a general measure of motor skills (e.g. number of repetitive hand/limb actions in a set time; correct motor execution of a set of instructions) was positively associated with duration of IS in an improvisation task (Brezis et al., 2017). Performance on a solo motor drumming task (Fitzpatrick et al., 2017a) was positively associated with IS in a hand clapping game, but unrelated to levels of IS in other activities involving the co-ordination of limb and facial movements. Self-reported motor difficulties were not associated with levels of IS during an autism diagnostic assessment (Koehler et al., 2021) and the amount and quality of intrapersonal movement was unrelated to levels of IS during a conversational task (Noel et al., 2018).

Notably, the few studies investigating the relation between motor ability and IS used a variety of generalised measures of motor skills. Such tasks are directed at the amount and/or quality of movements rather than to the temporal co-ordination of motor behaviour, and may be affected by multisensory and/or social confounds. Further, the role of motor synchrony in IS in neurodivergent conditions other than autism is yet to be explored. Overall, it is unclear how variation in basic motor synchrony contributes to variation in IS and its social effects.

1.6.2.3 Theory of Mind

1.6.2.3.1 Theory of Mind and IS

ToM refers to the ability to make inferences about the mental states of oneself and others (Frith & Frith, 2003; Premack & Woodruff, 1978). It encompasses inferences about thoughts and beliefs, i.e. cognitive ToM, and about feelings and emotions i.e. affective ToM (Beaudoin et al., 2020; Shamay-Tsoory & Aharon-Peretz, 2007). ToM is of potential relevance to the social effects of IS, because IS generates affiliative and prosocial outcomes by influencing the implicit assessment of other minds. For example, when observing social partners and judging their degree of affiliation, an implicit inference is made about their mental states (e.g. how much they like each other, and/or feel close to one another). During first person experience of IS, there is an implicit effect on an individual's own mental state (e.g. how affiliated they feel towards their social partner), and/or an implicit comparison with the mental state of their partner (e.g. how similar they are). The tendency and/or ability to make ToM judgements is therefore a likely contributor to sensitivity to the social effects of IS.

1.6.2.3.2 Theory of Mind in typical development

The ability to understand others as agents with distinct perspectives is believed to emerge towards the end of the first year of life (Gergely & Csibra, 2003; Rakoczy, 2022). Around this age, infants form expectations about others' behaviour based on factors including their desires (Poulin-Dubois et al., 2007; Repacholi & Gopnik, 1997) false beliefs (Onishi & Baillargeon, 2005; Surian et al., 2007) and the helping behaviour of their social partners (Hamlin et al., 2007; Kuhlmeier et al., 2003). Indeed, the emerging influence of IS on infants' perceptions of third-party affiliation (Cirelli et al., 2018) and on their prosocial behaviour (Cirelli et al., 2014) can in itself be interpreted as an instance of emerging mental state understanding. The tendency to make spontaneous predictions about social actors' behaviour, based on an understanding of their mental states, is referred to as implicit ToM (Fizke et al., 2017).

At 4 to 5 years of age, children begin to demonstrate explicit first-order ToM understanding (Apperly & Butterfill, 2009; Callaghan et al., 2005; Happé & Frith, 2014), i.e., they are able to respond accurately to direct questions about others' mental states. There is evidence that different components of explicit mental state reasoning emerge sequentially, with reasoning about individuals' subjective desires typically emerging before reasoning about beliefs, and false belief- and emotion-based reasoning emerging thereafter (Peterson et al., 2012; Poulin-Dubois et al., 2023; Ruffman et al., 2002; Wellman et al., 2011; Wellman & Liu, 2004). Second order ToM (understanding what a second person believes about the mental state of a third person: "He thinks that she thinks…") emerges later, around the ages of 6 to 7 years (Miller, 2009; Osterhaus & Koerber, 2021). An appreciation of more nuanced constructs that depend on the understanding of other minds, such as irony and sarcasm (Peterson et al., 2012), and white lies and faux pax (Banerjee et al., 2011), continue to develop during childhood and adolescence (Fu et al., 2023; Meinhardt-Injac et al., 2020; Osterhaus & Bosacki, 2022; Weimer et al., 2021).

1.6.2.3.3 Theory of Mind in neurodivergent conditions

On average, autistic people display reduced ToM understanding relative to neurotypical comparators (Frith, 2012; Happé, 2015; Jones et al., 2018; Tager-Flusberg, 2007; Velikonja et al., 2019). The evidence indicates that explicit ToM acquisition in autism is delayed rather than absent. For example, while autistic children typically perform less well than age-matched comparators on explicit ToM tasks in early childhood (Happé, 1995), they display age-related gains in ToM (Peterson et al., 2012) and are typically able to 'pass' false beliefs tasks by the age of 9 years (Baldimtsi et al., 2021; Happé & Frith, 2014). Autistic adolescents (Barendse et al., 2018; Callenmark et al., 2014; Scheeren et al., 2013) and adults (Schuwerk et al., 2015) performed comparably with neurotypical groups on a range of more advanced measures requiring explicit ToM reasoning. However, autistic adults continue to experience difficulties when interpreting social scenarios more closely aligned with real world interactions, such as those in which explicit information must be combined with vocal intonation or non-verbal cues in real time (Livingston et al., 2019; Murray et al., 2017).

Evidence obtained via anticipatory looking paradigms indicates that autistic children exhibit reduced implicit ToM as well as reduced explicit ToM (Kimhi, 2014; Senju, 2012; Slaughter, 2015). Further, autistic adolescents (Callenmark et al., 2014) and adults (Schuwerk et al., 2015; Senju et al., 2009) whose explicit ToM understanding was comparable with neurotypicals also displayed reduced implicit ToM. In sum, the evidence indicates that the acquisition of explicit ToM reasoning is delayed in autistic people, and that challenges with implicit and/or complex ToM persist into adulthood. Consequently, researchers have proposed that autistic people may principally come to understand the mental states of others via effortful cognitive strategies, rather than by an intuitive ToM (Happé & Frith, 2014; Livingston & Happé, 2017; Senju, 2012).

A small number of studies have investigated whether cognitive and affective ToM are differentially affected in autism, with inconsistent findings (Kim et al., 2016). One study reported that autistic participants displayed in-tact cognitive ToM but difficulties with affective ToM (Shamay-Tsoory et al., 2002); others have found that ToM difficulties are specific to cognitive understanding (Dziobek et al., 2008; Mazza et al., 2014), and still others have found difficulties across both constructs (Baldimtsi et al., 2021; Jones et al., 2018). There is also conflicting evidence as to the relation between cognitive and affective ToM. One study found the two to be significantly associated in autistic children (Baldimtsi et al., 2021), but another found a dissociation between cognitive and affective ToM in autistic children, with affective ToM more closely related to social difficulties (Altschuler et al., 2018).

Challenges with ToM are not unique to autism. Children with ADHD tend to display reduced ToM relative to TD comparators (Bora & Pantelis, 2016), although findings are mixed. For example, some studies found that children with ADHD performed less well than neurotypical comparators on first- and second-order ToM tasks (Buitelaar et al., 1999; Caillies et al., 2014; Sahin et al., 2018), but others found no differences in performance using such measures (Charman et al., 2001; Sodian & Hülsken, 2005; Yang et al., 2009). One study found children with and without ADHD performed comparably on explicit ToM tasks, but a parent-report measure suggested that children with ADHD experienced greater difficulty in applying ToM during everyday situations (Hutchins et al., 2016). Relatedly, there is some evidence that children with ADHD have reduced understanding of constructs requiring ToM such as faux pas, sarcasm and irony (Caillies et al., 2014; Maoz et al., 2019; Mary et al., 2016; Parke et al., 2021), although again findings are somewhat mixed (see e.g. Sodian et al. 2005; Gonzalez-Gadea et al. 2013). Children and adolescents with ADHD were also less able to recognise affective mental states, relative to TD comparators (Uekermann et al., 2010; Mary et al. 2016; Baribeau et al., 2015; Tatar et al., 2022; Özbaran et al., 2018; although cf. Parke et al., 2021).

There is also evidence that altered ToM understanding is associated with other aspects of atypical development. For example, children with conduct disorders (Anastassiou-Hadjicharalambous & Warden, 2008; Mandy et al., 2013; Poletti & Adenzato, 2013) display reduced ToM, and there is evidence of both reduced and superior ToM in children with symptoms of social anxiety (An & Kochanska, 2021; Nikolić et al., 2019; Tibi-Elhanany, 2011; Zainal & Newman, 2018). Finally, children with a range of emotional and behavioural difficulties, but no diagnosed neurodivergent or psychiatric condition, displayed reduced cognitive ToM, but intact affective ToM, relative to TD comparators (Howe-Davies, 2020).

Overall, therefore, atypical ToM is widely observed in atypically developing populations, although there is a complex profile of difficulties both within and between conditions.

1.6.2.3.4 Theory of mind and IS in those with and without a neurodivergent condition

There is evidence that ToM abilities relate to the production of IS. For example, those with higher self-reported levels of mental state understanding displayed higher levels of IS in a joint finger tapping task (Dai et al., 2018) and in a musical performance (Novembre et al., 2019). In a computer based interaction task, ToM abilities and levels of IS were positively related in autistic but not neurotypical adults (Koehne, Hatri, et al., 2016). ToM ability, measured using a set of explicit false belief tasks, was positively associated with levels of spontaneous IS displayed by autistic children in interaction with an experimenter (Fitzpatrick et al., 2017a). Similarly, autistic adolescents' performance on an implicit ToM task was positively associated with the degree of spontaneous IS displayed in a pendulum swinging task (Fitzpatrick et al., 2018). Further, when levels of IS were experimentally manipulated, adults who experienced a synchronous interaction reported an increased tendency to consider the mental states of their partners, relative to those who experienced an asynchronous interaction (Baimel et al., 2018). Thus, ToM and IS can be considered related constructs that potentially share common underlying processes (Fitzpatrick et al., 2018). However, there is no evidence as to whether ToM abilities are associated with sensitivity to the social effects of IS, i.e. whether better ToM understanding is associated with an increased tendency to feel affiliated towards a partner as a result of IS.

1.7 A transdiagnostic approach

In recent years, researchers have highlighted a number of limitations of research designs that seek to identify diagnosis-based, group differences in functioning. First, because there are multiple symptom profiles that may meet the criteria for the same condition, and symptoms may be experienced with varying levels of severity, there is considerable heterogeneity within diagnostic groups (Ameis, 2017; Astle et al., 2022; Mareva et al., 2019; Márquez-Caraveo et al., 2021). Therefore, where participants are categorised by diagnosis, group-level findings are not necessarily generalisable to all members of affected groups (Astle et al., 2022; Mareva et al., 2019). Second, individuals with co-occurring conditions are typically excluded from study samples (Astle & Fletcher-Watson, 2020), so that group differences can be attributed to the specific to the diagnosis of interest, rather than to the presence of co-occurring conditions or traits. However, there are high rates of co-occurrence between diagnoses (see e.g. Miller et al., 2021; Goulardins et al., 2015; Stevens et al., 2016; Taurines et al., 2012). Consequently, research based on those with a single diagnosis reflects neither the typical nor more complex neurodivergent presentations (Astle et al., 2022), and samples may not ultimately reflect the populations researchers aim to understand (Astle & Fletcher-Watson, 2020). Third, disruptions in a domain of interest, such as motor behaviour (Hirjak et al., 2018; Hudry et al., 2020) or social functioning (Happé & Conway, 2016; Uljarević et al., 2020), are frequently seen across multiple conditions (Dalgleish et al., 2020). Identifying disruptions within a particular domain in a particular diagnostic group is thus likely to lead to an incomplete picture and limit the generalisability of any conclusions reached. Fourth, there is substantial evidence that traits of particular conditions are not categorically present or absent. Rather, differences in functioning exist along multiple continuums that encompass both the general population and diagnostic groups (Astle et al., 2022; Cuthbert, 2014; Dalgleish et al., 2020). Group-based approaches are less able to capture such variability (Astle & Fletcher-Watson, 2020).

1.7.1 The Research Domain Criteria (RDoC)

In response to the limitations of group-based study designs, there have been calls to adopt research approaches that identify particular processes that contribute to the onset and maintenance of functional difficulties, either across diagnostic groups, or independent of diagnostic status (Cuthbert, 2022; Dalgleish et al., 2020; Garber & Bradshaw, 2020; Sauer-Zavala et al., 2017; Uljarević et al., 2020). The National Institute of Mental Health Research Domain Criteria (RDoC) project (Cuthbert & Insel, 2013) proposes that both typical and atypical functioning should be investigated within the context of six 'domains': (1) negative valence systems (processes that respond to aversive situations); (2) positive valence systems (processes that respond to rewards); (3) cognitive systems; (4) systems for social processes; (5) arousal/regulatory systems; and (6) sensorimotor systems (Cuthbert, 2014; Garvey & Cuthbert, 2017). Within this framework, the RDoC project aims to describe and support dimensional, process-oriented approaches to explaining and mitigating functional difficulty (Casey et al., 2014; Cuthbert & Insel, 2013; Patrick & Hajcak, 2016).

An RDoC informed approach is likely to be particularly suited to understanding sensitivity to IS as a social cue. Although the predominant approach in previous IS-related research has been to identify differences in functioning between groups with and without a particular diagnosis, synthesis of the evidence also reveals that differences in IS are not exclusive to a particular diagnostic group (see section 1.5 above). Similarly, variation in the perceptual, motor, and social processes that potentially contribute to social sensitivity to IS occurs across and within neurodivergent populations (see 1.6.2 above). Further, where studies have examined and reported on within-group differences in functioning, there is often substantial overlap in the functioning of individuals with and without the diagnosis of interest (see e.g. Puyjarinet et al., 2017; Isaksson et al., 2018). Overall, therefore, it is likely that the experience and interpretation of IS varies transdiagnostically, as a function of dimensional variation in contributory processes. Accordingly, an RDoC informed approach, that seeks to understand how children's skills within these component processes map on their sensitivity to IS when making social judgements, is highly suited to exploring variation in the component processes of IS and its social effects.

1.7.2 The Cardiff University Neurodevelopmental Assessment Unit (NDAU)

To investigate the social effects of IS and potential contributory processes in atypical development, this thesis draws on a sample of children referred to the Cardiff University Neurodevelopmental Assessment Unit (NDAU)[1] from mainstream schools in South Wales. In line with the RDoC approach outlined above, the NDAU aims to assess transdiagnostic variation in patterns of functioning across multiple psychological domains, such as language, cognition and emotion. Children are selected for assessment via 'functional' recruitment (Astle et al., 2022), in that they are eligible for referral and assessment if identified by the school as experiencing cognitive, emotional and/or behavioural difficulties requiring additional support at school and/or at home. As a result of these behavioural indicators, the children in the sample can be considered at elevated likelihood of having a neurodivergent condition. Although some children in the sample were on a relevant diagnostic pathway at the time of assessment, those already clinically diagnosed with a learning disability or neurodivergent condition at the time of referral are not accepted for assessment. Therefore,

[1] https://www.cardiff.ac.uk/neurodevelopment-assessment-unit

the children included in the samples used in this thesis are of unknown diagnostic status, and are referred to hereafter as children with emerging emotional and behavioural difficulties (EE&BDs).. Overall, the NDAU sample incorporates broad variation in functioning across emotional, behavioural and cognitive dimensions. It is therefore particularly appropriate for exploration of variation in the social effects of IS, together with variation in functioning across contributing perceptual, motor, and social processes. Further, the use of this sample also aligns with the general need for a better understanding of the social processes and functioning in children who constitute the 'missing middle' – that is, children who display emerging emotional and behavioural difficulties (EE&BDs) but who do not hold a formal clinical diagnosis because they have not been assessed as meeting the relevant thresholds (National Assembly for Wales Children Young People and Education Committee, 2018, 2020). It is important to understand the ways in which such children are developing atypically before clinically significant difficulties emerge, so that early intervention strategies can be better informed (National Assembly for Wales Children Young People and Education Committee, 2018, 2020).

1.8 Summary of Existing Literature and Thesis Outline

IS is integral to social interactions from the earliest months of life, constituting a mechanism by which bonds with both caregivers (1.3.1) and social partners (1.3.2) are established. However, the factors that account for the association between IS and its positive social outcomes are unclear (1.3.3). Further, little is known about how IS is experienced outside typical populations. There is evidence of reduced IS in autism (1.5.1) and emerging evidence of reduced IS other conditions in which social difficulties have been observed (1.5.2). Yet, whether and to what extent IS holds social significance outside typical development is largely unknown (1.5.3). Further, there are a number of processes that potentially contribute to the experience of IS and its social effects, including temporal perception, motor behaviour, and mental state understanding. Atypicalities in each of these domains have been observed in neurodivergent populations (1.6.2), but research is yet to establish the contributions of such processes to the social effects of IS. The transdiagnostic nature of differences in IS and in perceptual, motor and social processes calls for a dimensional, process-oriented approach to understanding variation in the social effects of IS (1.7).

This thesis aims to contribute to understanding of children's social experiences by exploring the social significance of IS in both typically developing children and those with EE&BDs, and by establishing factors and component processes underpinning and explaining variation in such experiences. The following research questions are addressed:

(1) How and why does IS influence affiliation in TD children?
(2) Are the social effects of IS seen in children with EE&BDs? Is the extent to which such children are socially sensitive to IS associated with levels of diagnostic traits?
(3) What is the profile of basic perceptual and motor synchrony abilities in children with EE&BDs?
(4) Does variation in the potential component processes of IS explain variation in its social significance in children with EE&BDs?

1.8.1 Overview of experimental chapters

Chapter 2 investigates IS as a marker of affiliation in TD children. Two novel experimental tasks are used to investigate the temporal properties of IS that influence children's perceptions of partner affiliation, and whether they differ according to whether IS is witnessed or experienced. The role of children’s subjective assessments of partner ‘togetherness’ is also explored.

Chapter 3 uses the tasks described in Chapter 2 to investigate whether comparable social effects of IS are observed in children with EE&BDs. The relation between variation in the social effects of IS and children’s levels of emotional and behavioural difficulties and diagnostic traits is also investigated.

Chapter 4 profiles variation in the basic synchrony perception and motor synchrony abilities of children with EE&BDs. A novel measure of perceptual sensitivity to synchrony and an established basic finger-tapping paradigm are used to isolate synchrony-specific abilities, without the confounds of extraneous task demands and multisensory and social processing that are inherent in IS tasks.

Chapter 5 explores the relative contributions of basic synchrony perception, motor synchrony (both explored in Chapter 4) and ToM abilities to sensitivity to the social effects of IS in children with EE&BDs.

Chapter 2

Interpersonal Synchrony and Affiliation in Typically Developing Children: Temporal Properties and Mechanism of Effect

2.1 Introduction

As described in Chapter 1, IS acts as a social cue that influences TD children's evaluations of social relationships within their wider social environment (Hoehl et al., 2021; Rauchbauer & Grosbras, 2020). TD infants (Fawcett & Tunçgenç, 2017) and children (Abraham et al., 2022) infer greater levels of affiliation between social partners they witness interacting synchronously ('witnessed IS'), compared to those observed acting asynchronously. Similarly, for TD children, experiencing IS within an interaction ('experienced IS') fosters social relationships, by precipitating perceived similarity and closeness (Rabinowitch et al., 2015), bonding (Tarr et al., 2015) and prosocial behaviours (Kirschner & Tomasello, 2010; Rabinowitch & Meltzoff, 2017a; Rabinowitch & Meltzoff, 2017b; Tunçgenç & Cohen, 2018). Although the affiliative effects of witnessing and experiencing IS in TD children are well documented, little is known about how or why such effects come about.

For example, it is unclear which temporal qualities of IS drive affiliation (Cirelli, 2018; Hu et al., 2022; Rabinowitch, 2020; Wan & Zhu, 2022). Competing theoretical accounts suggest either that affiliative effects are driven by contiguity, that is, the extent to which behaviours co-occur in time (Dignath et al., 2018; Rauchbauer & Grosbras, 2020), or by temporal contingency, that is, the extent to which partners' actions predict one another (Cirelli et al., 2014; Tunçgenç et al., 2015; Wan & Fu, 2019). On the first account (contiguity), the affiliative effects of IS depend on simultaneity of partner action (Hove & Risen, 2009; Tarr et al., 2016;

Howard et al., 2021). The second account (contingency) takes a broader view. On this account, any temporal relation giving rise to a shared temporal framework would foster affiliation (Demos et al., 2012; Kirschner & Tomasello, 2010; Wan & Zhu, 2022). Simultaneity *and* temporal regularity – whereby partners' actions occur at a constant (but non-zero) temporal interval – would each create the necessary conditions of temporal contingency, and therefore lead to affiliation. A further possibility is the effects of simultaneity and regularity are cumulative, such that affiliation is greatest when both are present.

Disentangling the effects of simultaneity and regularity based on existing empirical research is challenging, with only two studies having manipulated both simultaneity and regularity independently (Cacioppo et al., 2014; Cirelli et al., 2014). Each used different samples (adults vs infants) and outcome measures (self-reported perceived affiliation vs helping behaviour). In adults, both simultaneity and regularity significantly influenced affiliation (Cacioppo et al., 2014), whereas in infants only simultaneity had such an effect (Cirelli et al., 2014). No studies have investigated the separable and combined effects of simultaneity and regularity on children's affiliation judgements beyond infancy. Overall, therefore, the temporal properties driving the social effects of IS in children are yet to be established.

A related question concerns how the objective temporal properties of an interaction come to influence subjective social judgements. Adult participants' subjectively perceived levels of IS were significantly associated with partner liking (Launay et al., 2014) and trust (Launay et al., 2013), and subjectively perceived synchrony mediated the relationship between objective levels of IS and corresponding social judgements in adults (Hagen & Bryant, 2003; Lakens, 2010). However, there is no evidence of how children subjectively perceive IS, or how such perceptions relate to their assessments of affiliation between interacting partners.

One possibility is that objective and subjective perceptions of IS are closely aligned in children, with the influence of the former mediated by the latter. Alternatively, the effects of objective IS in children may be implicit and direct, and wholly or partially independent of their subjectively reported perceptions of IS.

Previous studies have examined the effects of IS within a narrow age range, and employed a diverse range of paradigms both for manipulating synchrony and for measuring affiliation (e.g. behavioural measures; self-report). As such, it is currently unknown whether there are developmental differences in sensitivity to the affiliative effects of IS. However, IS and its affiliative effects are the product of children's developing perceptual, motor and social communication abilities (Trainor & Cirelli, 2015). Improvements in synchrony-related perceptual acuity (Hillock-Dunn & Wallace, 2012; Lewkowicz, 1996), motor synchronisation (McAuley et al., 2006; Monier & Droit-Volet, 2018) and socio-cognitive abilities (Rakoczy, 2022; Weimer et al., 2021) have all been observed across early and middle childhood. Thus, it is possible that sensitivity to the affiliative effects of IS is also subject to age-related change during this period.

Finally, it is notable that theoretical accounts of the temporal properties and mechanisms that influence affiliation do not differentiate explicitly between witnessed and experienced IS. Yet, witnessed and experienced IS contribute to social cognition in different ways. Witnessed IS entails making judgements about others' relationships based on observations of their non-verbal behaviour. By contrast, experienced IS concerns the ways in which affiliation might be generated via active, first-person participation in an interaction. As such, the ways in which affiliation is identified (in the case of witnessed IS) or generated (in the case of experienced IS) may differ. For example, when experiencing IS, the predictability of a partner's actions may reduce cognitive load. Reduced cognitive load is theorised to increase mutual attention, and ultimately affiliation, between partners (Hoehl et al., 2021; Miles et al., 2009). By contrast, someone who merely witnesses IS is not part of the interaction, meaning predictability within the interaction will not have the same consequences for the way in which the interaction is processed. Therefore, a comprehensive account of the relative importance of simultaneity and regularity on affiliation judgements can only be established by examining both witnessed and experienced IS.

To better understand the processes by which IS generates affiliative outcomes in children, the current study investigated the separable effects of simultaneity and regularity on children's affiliation judgements, together with the role of children's subjective perceptions of synchrony, both when witnessing and experiencing IS. As the exploration of the separable effects of simultaneity and regularity are relatively novel, it was decided to first explore and establish their effects in a sample of TD children (current chapter), before examining their effects in children with EE&BDs (Chapter 3).

In two online tasks, TD children aged 4-11 years listened to a pair of children tapping together (Witnessed IS) or themselves tapped with another child (Experienced IS). Tapping partners were presented as real, but the sounds attributed to them were computer generated so that their temporal relations could be experimentally manipulated. Following each interaction, participants rated affiliation between partners (Witnessed IS), or towards their partner (Experienced IS). Participants also reported whether they perceived witnessed interacting partners to have acted 'together' or not.

Based on the idea that the affiliative effects of IS arise from a shared temporal framework, and given that simultaneity and regularity are both aspects of temporal organisation, it was hypothesised that simultaneity and regularity would both lead to increased affiliation ratings both when witnessing and experiencing IS. Based on previous findings in adults as to the relation between subjectively perceived IS and affiliation, it was predicted that perceived togetherness would mediate the relation between objective simultaneity and affiliation ratings. However, because togetherness is not necessarily implied by regularity, no predictions were made as to whether perceived togetherness would be associated with regularity, or whether it would mediate the relationship between regularity and affiliation judgements.

2.2 Method

2.2.1 Participants

Participants were children aged 4 to 11 years whose caregivers responded to a study advertisement on social media (Witnessed IS task: n = 68, 40 male; M_{age} = 7 years 6 months, SD = 2 years 2 months; Experienced IS task: n = 63, 38 male; M_{age} = 7 years 8 months, SD = 1 year 10 months; 65% White, 19% Asian, 13% of multiple ethnic backgrounds, 3% no ethnic background specified). Ethnicity information for participants in the Witnessed IS task was not available. Nineteen participants completed both tasks, at least a week apart (four completed the Witnessed IS task first). Post-hoc exploration of the data established that there was no effect of task order on performance in the Experienced IS task (p = .25). It was not possible to explore order effects in the four participants who completed the Witnessed IS task first, because of the small number of participants potentially affected. No participants had a recognised hearing impairment or diagnosed neurodivergent condition. Caregivers provided informed consent on participants' behalf. Participants were offered a voucher to compensate them for their time. The study was approved by the Cardiff University School of Psychology Research Ethics Committee.

2.2.2 Materials and procedure

Both tasks were completed online due to COVID-19-related restrictions on in-person testing. Caregivers were asked to assist participants in accessing the task in a quiet area free from distractions, and to refrain from influencing participants' responses. A URL opened the task in the browser of a PC, tablet or mobile device. Before the task began, a 'sound check' was performed in which auditory stimuli, comparable to those used in the main task, were presented. Caregivers were prompted to adjust the volume to a level that was comfortable for the participant. All auditory stimuli were generated using Audacity®, version 3.0.2, https://audacityteam.org/. Both tasks were created using PsychoPy3 (Peirce et al., 2019) and presented via its online platform Pavlovia (pavlovia.org). Task instructions were presented on screen and via a pre-recorded voice over. Participants controlled the pace of progress through each task: following presentation of instructions and at the end of each trial, a button marked 'NEXT' appeared in the bottom right-hand corner of the screen, which participants pressed to trigger delivery of the next element in the task.

2.2.2.1 Witnessed IS task

Stimuli. Auditory stimuli of 11.5 s duration were described to participants as interactions in a tapping game played between two children. Eight of the 10 stimuli consisted of a series of 'taps' generated by a plastic beater striking a glockenspiel (G4, 392 Hz approx.) and by a finger pressing a piano key (C3, 131 Hz approx.). The simultaneity and regularity of the 'tapping' was manipulated across conditions according to a 2x2x2 design, in which taps were either simultaneous or non-simultaneous; the rhythm was either regular (i.e. isochronous) or irregular (i.e. non-isochronous); and the basic tempo was either fast (500 ms beat interval) or slow (800 ms beat interval). Tempo was manipulated to introduce variation in stimuli between trials and to investigate the generalisability of any effects.

Stimuli in individual conditions are described in **Table 2.1**. Following the approach taken by Tarr et al. (2018), taps played with minor deviations (±2% of the beat interval) from the basic patterns indicated, so that stimuli more closely resembled a 'real life' tapping interaction.

Table 2.1

Witnessed IS: temporal relation between glockenspiel and piano notes in tapping interactions for both fast (500 ms) and slow (800 ms) beat intervals

Temporal relation	**Simultaneous**	**Non-Simultaneous**
Regular	Piano and glockenspiel played simultaneously and on the beat.	Piano played on the beat. Glockenspiel played 25% of the beat interval later at a fixed latency (fast trials = 125 ms; slow trials = 200 ms).
Irregular	Piano and glockenspiel played simultaneously, at varying intervals from the beat.	Timing of piano and glockenspiel notes varied independently from each other, and at varying intervals from the beat.

For irregular tapping, latency from the beat varied quasi-randomly, such that it fitted a normal distribution with standard deviation of 25% of the beat interval. This ensured that mean beat interval was the same across all trials of the same tempo, and mean latency between notes was the same across all non-simultaneous trials.

The remaining two stimuli consisted of a voice-over which said '*We cannot hear the sounds made by this pair*,' at the onset of the 11.5 s stimulus duration. This meant participants had no information about the temporal properties of the interaction. The remaining two stimuli therefore provided a control condition in which a baseline measure of perceived affiliation between pairs of children could be obtained.

Procedure. Participants were told that they would hear pairs of children playing a game in which they '*made some sounds,*' and then respond to questions about each pair. An example pair of children was pictured (**Figure 2.1(a)**). The glockenspiel and piano notes described above were played, and attributed to the child pictured on the left and right, respectively. After the introduction, 10 experimental trials were presented. For each trial, images of a named pair of children, of the same gender as the participant, were presented (**Figure 2.1(b)**). Children were pictured from behind to ensure that their facial features or expressions did not influence participants' affiliation judgements. Their 'names' were drawn from the last 20 names on a list of most popular for boys/girls born in Wales in 2012 (Office for National Statistics, 2013a; 2013b). The pair of children shown in each trial was randomly selected without replacement from a set of 10 pairs.

Figure 2.1

Witnessed IS task: overview of procedure

Note. Participants were told they would hear some children 'make some sounds' and then answer questions about them. An example pair was pictured (a). In each of 10 trials, the participant was introduced to two virtual children and told they would hear the sounds made by the pair shown (b); the audio track (in which simultaneity and regularity was manipulated across trials) was presented, during which time an orange frame was (continuously) displayed around each child in the pair (c). Immediately after each interaction, the participant rated affiliation between the pair (d) (second affiliation question not pictured). Following presentation of all 10 trials, participants were told they would listen to each pair again and judge whether they sounded 'together' or not (e). Each of the eight heard interactions were presented again. After each, participants stated whether partners sounded 'together' or 'not together' (f). A figure moving left to right along a path at the bottom of the screen indicated progress through trials. Child images in the figure have been obscured for anonymity and as such are modified versions of those used in the task.

Participants were told they would hear the sounds made by the pair shown, and one of the stimuli described above was presented. To indicate that the audio track was being played, an orange line forming a frame around the image of each partner was displayed. The frames appeared when the audio track began and were continuously visible until the audio track ended (**Figure 2.1(c)**). Immediately afterwards, participants rated the level of affiliation between the two children by responding to two questions, presented sequentially, assessing perceived liking and similarity on a four-point Likert scale. The first question was '*How much do you think* [names of children] *like each other?'* Available responses were: '*Not at all*'; '*A little bit*'; '*Quite a lot*'; and '*Very much*' (**Figure 2.1(d)**). The second question was *'At playtime, how often do you think* [names of children] *would choose the same toy to play with?'* Available responses were: *'Never'*; *'Sometimes'*; *'Usually'*; and *'Always'*. Questions and response options remained on screen until one was selected.

All participants were presented with the same 10 experimental trials, presented in one of two fixed orders, counterbalanced across participants. The two fixed orders were constructed so that the first five trials in each included tapping interactions with all combinations of simultaneity/regularity described above, and a trial in which no interaction was heard; the order of conditions was otherwise selected randomly without replacement.

The second part of the task assessed 'togetherness', i.e. perceived IS. Each pair of children and their associated tapping interaction (if previously heard) were presented again in the same order. Participants were told that '[w]*e want to know whether the children played their sounds together or not. We would say they played "together" if their sounds come at exactly the same time as each other*' (**Figure 2.1(e)**). Participants then reported whether they perceived the sounds as '*together*' or '*not together*' (**Figure 2.1(f)**). Response options remained available until one was selected.

2.2.2.2 Experienced IS task

Stimuli. For this task, the participant and a 'partner' listened together to an auditory pacing stimulus, and then both immediately reproduced the rhythm presented by tapping. The pacing stimulus consisted of a series of eight isochronous tones (440 Hz), which was either fast (ISI 500 ms) or slow (ISI 800 ms). Participants' and partners' taps were represented respectively by the piano and glockenspiel notes described in the Witnessed IS task above. All partner taps were in fact computer generated, so that their onset, relative to the taps of the participant, could be manipulated across conditions. Partners' taps were either: (i) simultaneous with those of the participant; (ii) non-simultaneous but at regular intervals from those of the participant; (iii) non-simultaneous and at irregular intervals from those of the participant. There were two trials for each condition, in which the tempo of the pacing stimulus was either fast or slow. **Table 2.2** contains further details of the temporal relation between participants' and partners' taps within each condition. Similar to the Witnessed IS task, minor deviations (±2% of the beat interval) were introduced so that the interaction would more closely resemble a 'real life' experience.

Table 2.2

Experienced IS: temporal relation between participants' and 'partners'' tapping across conditions

Condition	Temporal Relation
Simultaneous	Partner's taps were simultaneous with the participant.
Non-Simultaneous/Regular	Partner's taps followed participant's with a fixed latency of 25% of pacing stimulus tempo, i.e. 125 ms (fast) or 200 ms (slow).
Non-Simultaneous/Irregular	Partner's taps followed participant's with a variable latency.

For irregular tapping, the latency of the partner's taps varied quasi-randomly, such that it fitted a normal distribution with standard deviation of 25% of the beat interval. This ensured that mean beat interval was the same across all trials of the same tempo, and mean latency between notes was the same across both non-simultaneous trials (i.e. 125 ms and 200 ms in the fast and slow trials respectively).

So that the timing of partners' taps could be linked accurately to those of the participant in the way prescribed by each condition, each participant tap initiated a pre-recorded, computer-generated audio file which contained the sound attributed both to their own tap (i.e. a single piano sound) and to that of their partner (i.e. a single glockenspiel sound), with the onset of the glockenspiel varying according to the conditions described above.

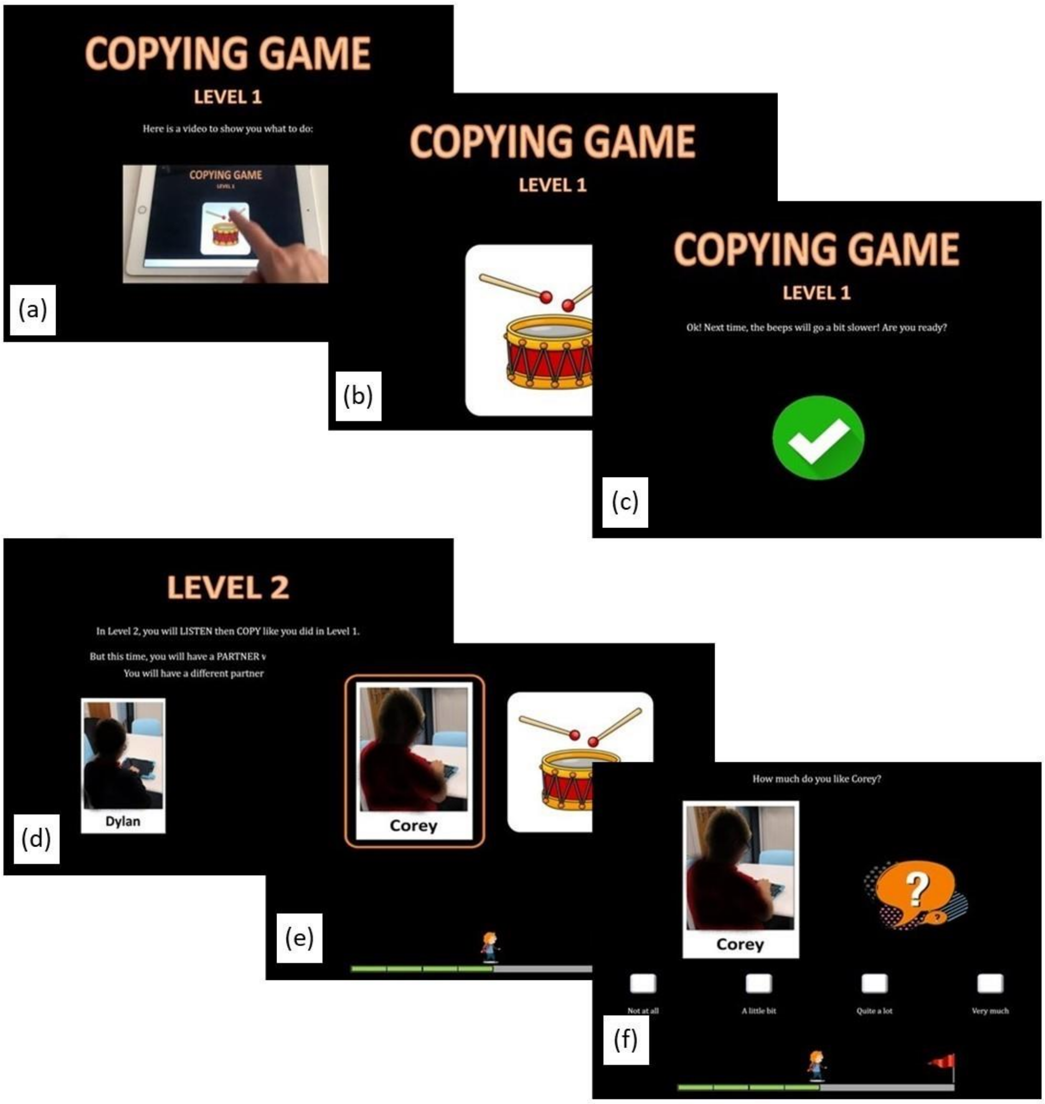
There was a fourth, 'baseline' condition in which the participant had no information about the timing of their partner's taps. Participants were informed that they would only hear their own taps.

Procedure. Participants completed three practice trials in which they were familiarised with reproducing a series of isochronous beats. For these trials, and following a short video demonstration (**Figure 2.2(a)**), participants were instructed to '*listen to the sound, then copy the pattern it makes*' by tapping '*at the same speed*' as the sound presented. Following this a pacing stimulus, as described above, was heard. The ISIs of the pacing stimuli were 800 ms, 500 ms and 800 ms in the first, second and third practice trials respectively. Immediately after presentation of the pacing stimulus, participants tapped eight times on an on-screen image of a drum, either directly with their finger or indirectly by tapping on their device's trackpad or mouse (**Figure 2.2(b)**). Each tap generated the piano sound described above. At the end of each trial, the image of the drum was replaced by an image of a green circle containing a white tick (**Figure 2.2(c)**).

In the experimental part of the task, participants were told that they would repeat the practice trial activity, but that '*this time you will have a partner who will be doing it too'* (**Figure 2.2(d)**). The glockenspiel sound, described above, was introduced as the sound made by partners' taps. In each trial, a child's photograph and 'name' was displayed in the same format as in the Witnessed IS task, and described as the participant's partner for the 'round'. Eight partner image/name combinations from the Witnessed IS task were chosen at random to be re-used in the present task, from which the partner for each trial was randomly selected without replacement. The participant was told that '*You and* [partner name] *will listen then copy by tapping*.' As before, a pacing stimulus was heard, following which participants responded by tapping on an image of a drum (**Figure 2.2(e)**), with each tap generating the piano sound described above. Whether or not partners' tapping was also heard, and if so, its timing relative to the participant, depended on the condition. After completing 21 taps, the image of the drum was replaced by an image of a green circle containing a white tick, which was displayed for 3 s. Immediately afterwards, participants rated their feelings of affiliation towards their partner by responding to two questions, as described in the Witnessed IS task, save that they were worded to target the participant's own feelings towards each of their tapping 'partners' (**Figure 2.2(f)**). As before, response options remained available until one was selected.

Figure 2.2

Experienced IS task: overview of procedure



Note. Participants were shown an instruction video demonstrating how to reproduce an isochronous pacing signal (a). Three practice trials followed in which they reproduced a pacing signal by tapping on an image of a drum (b). A tick indicated completion of each trial (c). Participants were told they would repeat the activity but a partner 'will be doing it too' (d). There were eight trials in which the taps of both the participant and their partner were heard (with partner tapping manipulated for simultaneity and regularity with the participant across trials).The partner's image was outlined in orange throughout the tapping portion of the trial to denote their participation (e). Immediately after each partner interaction, participants rated their feelings of affiliation towards their partner (f) (second affiliation question not shown). A figure moving left to right along a path at the bottom of the screen indicated progress through trials. Child images in the figure have been obscured for anonymity and as such are modified versions of those used in the task.

All participants were presented with the same eight experimental trials. Trials were presented in one of two fixed orders, counterbalanced across participants. The two fixed orders were constructed such that the first four trials included the three simultaneity/regularity conditions described above and a trial in which the partner's taps were not heard. The order of conditions was otherwise selected randomly without replacement.

2.2.2.3 Statistical analysis

Data were prepared in Microsoft Excel and imported into IBM SPSS version 25.0 for statistical analysis. Likert ratings for the affiliation questions in both tasks were converted to scores between 1 and 4, with higher values indicating greater liking/similarity. For both tasks, scores for questions 1 (liking) and 2 (similarity) were positively associated, $r_s(680) = .65$, $p < .001$ (Witnessed IS); $r_s(504) = .59$, $p < .001$ (Experienced IS). Analysing scores for question 1 and 2 as separate outcome variables made no difference to the pattern of results. Therefore, the mean of the two scores was used as a single outcome variable ('affiliation score'). Comparison of mean affiliation scores between fast (ISI 500 ms) and slow (ISI 800 ms) conditions revealed no significant effect of tempo on affiliation score, $t(67) = 0.16$, $p = .87$ (Witnessed IS); $t(67) = 0.56$, $p = .58$ (Experienced IS). All affiliation scores were therefore collapsed across tempo.

Data were inspected to assess whether the assumptions for parametric testing were met. Q-Q plots revealed that affiliation scores were normally distributed within each cell. Greenhouse-Geisser corrections were applied where required. For both tasks, repeated measures ANOVAs were used to assess: 1) the effect of fully synchronous tapping (i.e. both simultaneous and regular, as typically conceptualised in previous studies) on affiliation scores, relative to fully asynchronous tapping (i.e. neither simultaneous nor regular) and a condition in which no interaction was heard/experienced; 2) the separable effects of simultaneity and regularity on affiliation scores. Bonferroni-corrected post-hoc analysis was carried out as appropriate. For witnessed IS, GLMMs with a binomial distribution were used to assess whether simultaneity and regularity influenced the likelihood of tapping being perceived as 'together'. Adopting the approach to mediation analysis involving categorical variables recommended by Iacobucci (2012), it was then assessed whether the perceived 'togetherness' of an interaction mediated the relations between simultaneity and affiliation scores and between regularity and affiliation scores. LMMs and/or GLMMs with a binomial distribution, as appropriate, were used to obtain path estimates. Participant was entered as a random effects variable in all mixed models.

In addition to the above analysis, the extent to which individual participants' affiliation judgements were influenced by (a)synchrony was quantified using difference scores. For each task, 'synchrony difference scores' were calculated for each participant by subtracting affiliation scores in the fully asynchronous condition from scores in the fully synchronous condition, such that higher difference scores denoted higher sensitivity to synchrony when making affiliation judgements. Further difference scores were created to quantify sensitivity to simultaneity (mean score across two simultaneous conditions minus the mean score across the two non-simultaneous conditions), and to regularity (mean score across the two regular conditions minus mean score across the two irregular conditions). Correlations investigated the relation between sensitivity to synchrony when witnessing and experiencing (a)synchrony.

Finally, to explore whether the individual differences of gender or age were relevant to the pattern of findings in each task, mixed ANOVAs were used to explore the interaction between gender and the experimental conditions, and correlations investigated the relation between sensitivity to synchrony, as quantified by difference scores, and age.

2.3 Results

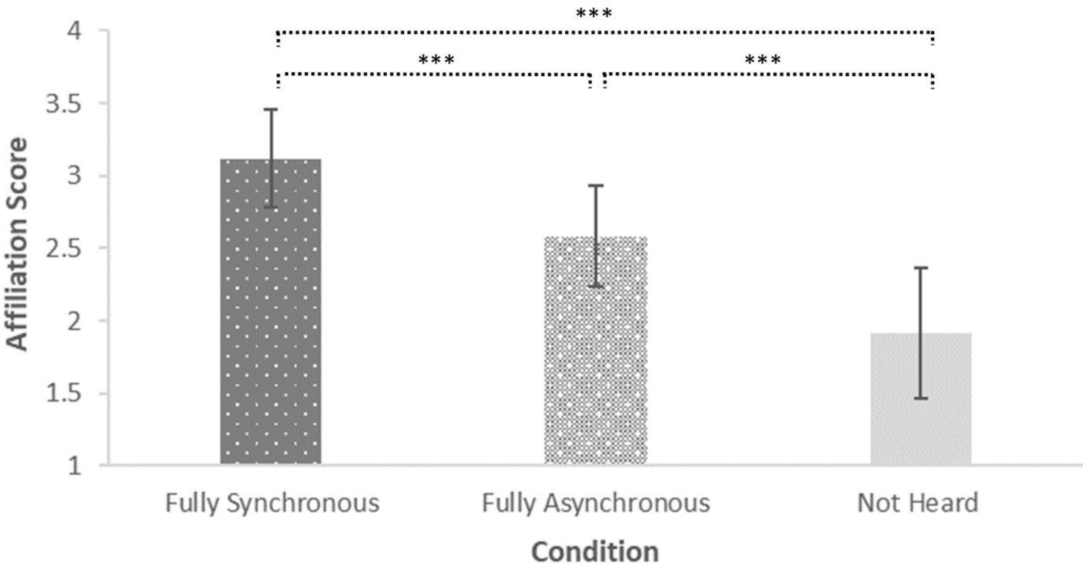
2.3.1 Witnessed IS

2.3.1.1 The effect of fully synchronous tapping on affiliation scores

A one-way repeated measures ANOVA showed that affiliation scores were significantly different across three conditions of synchrony exposure: 1) fully synchronous tapping (i.e. both simultaneous and regular); 2) fully asynchronous tapping (i.e. neither simultaneous nor regular); 3) partner tapping not heard, $F(1.75, 117.21) = 57.64$, $p < .001$, $\eta^2 = .46$. (**Figure 2.3**). Post-hoc analysis revealed that affiliation scores were significantly higher in the fully synchronous condition than in both the fully asynchronous ($p < .001$) and not heard ($p < .001$) conditions. Affiliation scores in the fully asynchronous condition were also significantly higher than in the not heard condition, $p < .001$.

Figure 2.3

Witnessed IS: effect of fully synchronous tapping on affiliation scores



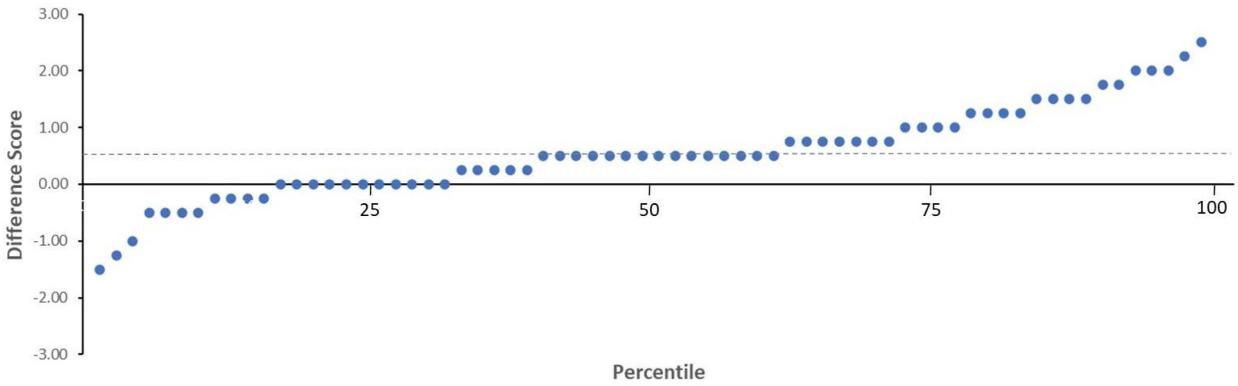
Note. 'Fully synchronous' = simultaneous and regular partner tapping; 'fully asynchronous' = partner tapping was neither simultaneous nor regular. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.
*** $p < .001$.

2.3.1.2 Individual differences in sensitivity to IS when judging affiliation

The mean synchrony difference score (score in the fully synchronous condition minus score in the fully asynchronous condition) was 0.54 (*SD* = 0.80). At the individual level, 68% of participants displayed positive synchrony difference scores (**Figure 2.4**).

Figure 2.4

Witnessed IS: difference scores of individual participants



Note. Each data point represents the difference score of an individual participant. Dotted line indicates mean difference score.

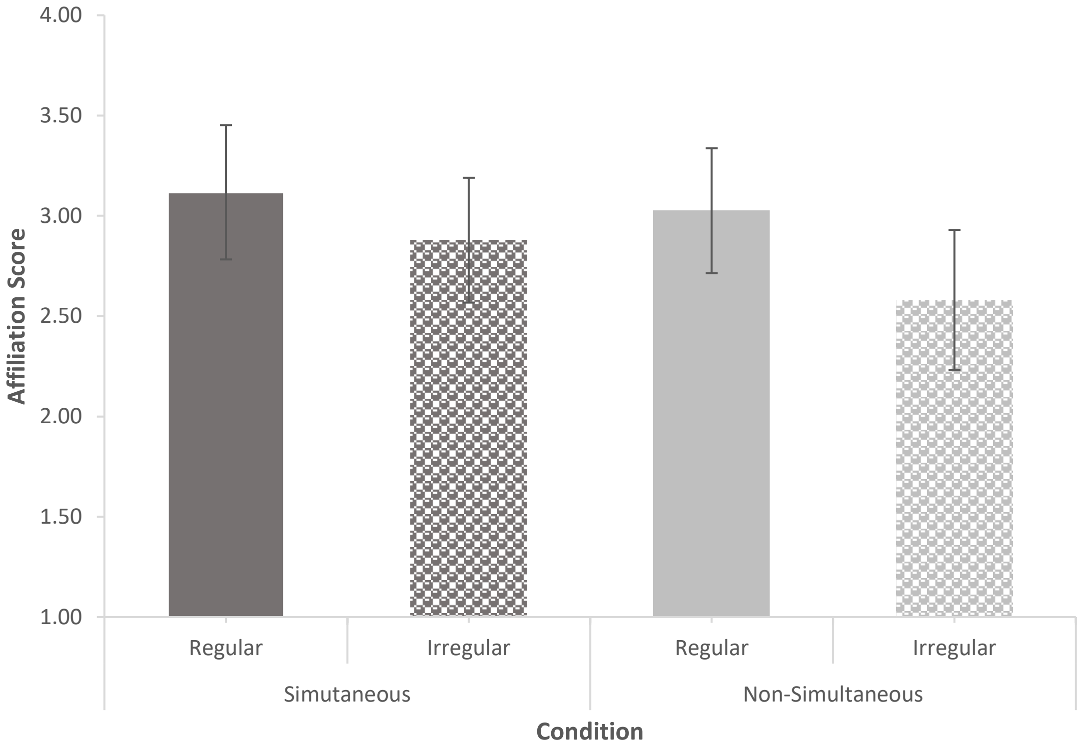
2.3.1.3 The separable effects of simultaneity and regularity on affiliation scores

A two-way repeated measures ANOVA indicated that there was a main effect of simultaneity on affiliation score, F (1,67) = 10.17, p = .002, η_p^2 = .13, with simultaneous tapping (M = 3.00; SD = 0.57) attracting significantly higher affiliation scores than non-simultaneous tapping (M = 2.80; SD = 0.52). There was also a main effect of regularity, F(1,67) = 26.86, p < .001, η_p^2 = .29, indicating that regular tapping (M = 3.07; SD = 0.55) attracted significantly higher affiliation scores than irregular tapping (M = 2.73; SD =0.56) (**Figure 2.5**).

The interaction between simultaneity and regularity was close to significance, F (1,67) = 3.33, p = .07, η_p^2 = .05. Post-hoc paired t-tests indicated that when tapping was irregular, simultaneity had a significant positive effect on affiliation scores, t(67) = 3.51, p = .001, d = 0.43. However, the relatively higher affiliation ratings achieved when tapping was regular were not affected by whether taps were simultaneous, t(67) = 1.13, p = .26, d = 0.14.

Figure 2.5

Witnessed IS: mean affiliation scores for each combination of simultaneity and regularity



Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

2.3.1.4 Effect of gender and age

When gender was entered into the ANOVA as a between-subjects factor, the interaction between simultaneity and gender (F (1,66) = 0.26, p = .62, η_p^2 = .004), the interaction between regularity and gender (F (1,66) = 0.28, p = .60, η_p^2 = .004), and the three-way interaction between simultaneity, regularity and gender (F(1,66) = 0.11, p = .74, η_p^2 = .002) were all non-significant, suggesting that the influence of neither simultaneity nor regularity depended on gender. Overall sensitivity to synchrony, represented by each participant's synchrony difference score, was significantly positively associated with age, r(68) = .28, p = .02. Regularity difference scores were significantly positively associated with age (r(68) = .39,

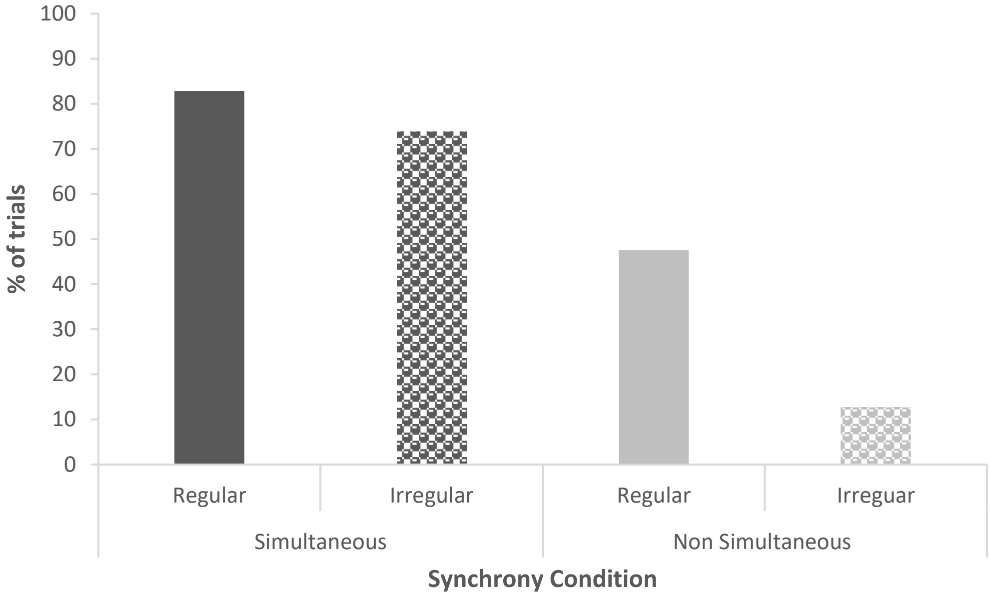
p = .001), but simultaneity difference scores were not (r(68) = .03, p = .79). This pattern of findings suggests the effect of IS on affiliation scores was age-sensitive, and driven specifically by increasing sensitivity to regularity with age.

2.3.1.5 The mediating effect of perceived 'togetherness'

Tapping was most frequently perceived as 'together' when it was both simultaneous and regular, and least frequently when it was neither. Tapping that was either simultaneous or regular (but not both), was perceived as 'together' in an intermediate number of trials (**Figure 2.6**). The effect of simultaneity and regularity on the likelihood of tapping being perceived as 'together' was investigated using a GLMM with simultaneity, regularity and a simultaneity x regularity interaction term as dummy-coded binary predictor variables and perceived togetherness as the binary outcome variable. Simultaneity (β = 3.10, t = 9.31, p < .001) and regularity (β = 1.95, t = 6.12, p < .001) each had a significant positive effect on the likelihood of perceiving tapping as 'together'.

Figure 2.6

Witnessed IS: percentage of trials in which tapping perceived as 'together', by synchrony condition

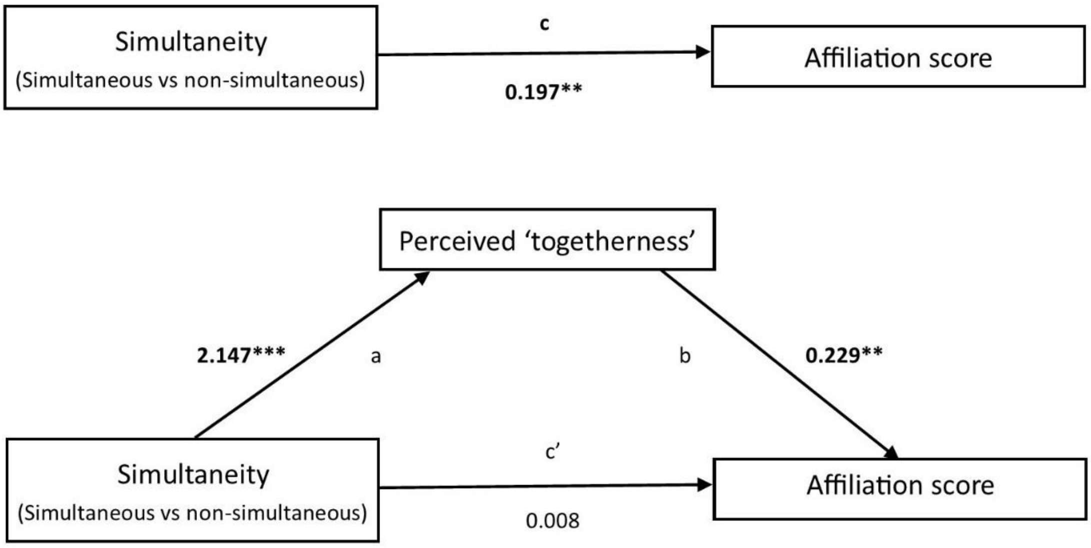


As the simultaneity/regularity interaction term (β = –1.44, t = –3.26, p = .001) was also significant, the effect of regularity for each simultaneity condition (simultaneous and non-simultaneous) was assessed using two further GLMMs, each with regularity as the single dummy-coded predictor variable. When tapping was non-simultaneous, regularity had a significant positive effect on the likelihood of tapping being perceived as 'together' (β = 2.09, t = 6.93, p < .001). However, when tapping was simultaneous, the effect of regularity on perceived togetherness was not significant (β = 0.51, t = 1.66, p = .10). These findings suggest that, at a group level, there was an interference effect of regularity when participants judged the 'togetherness' of non-simultaneous tapping. However, regularity did not influence participants' perceptions of the 'togetherness' of simultaneous tapping.

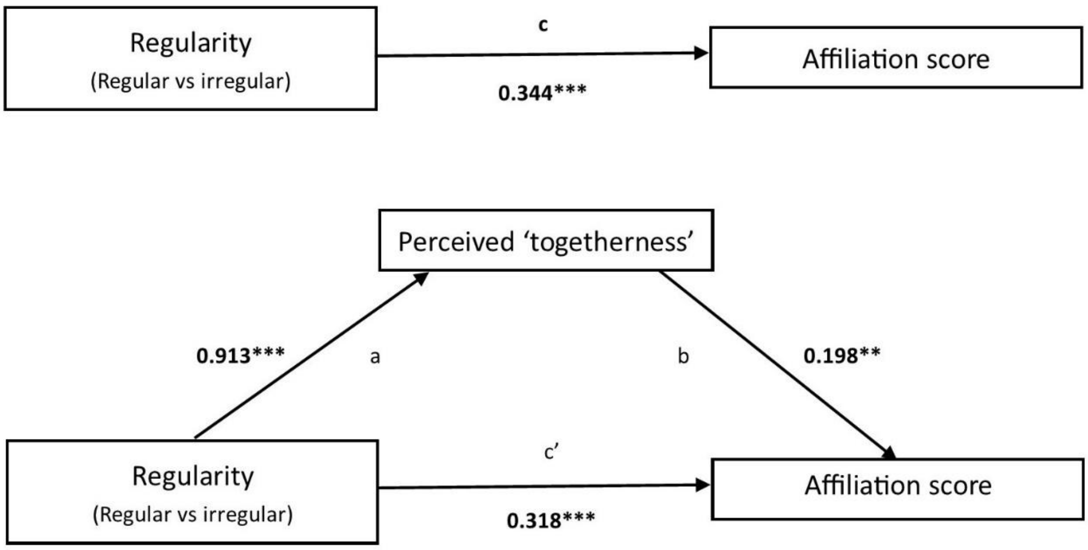
Mediation analyses indicated that perceived togetherness fully mediated the relation between simultaneity and affiliation score (**Figure 2.7a**), and partially mediated the relation between regularity and affiliation score (**Figure 2.7b**), $z_{Mediation}$ = 2.53, p = .001.

Figure 2.7

(a) Witnessed IS: path estimates and indirect effect of simultaneity on affiliation scores



(b) Witnessed IS: path estimates and indirect effect of regularity on affiliation scores



Note. Perceived togetherness fully mediated the relationship between objective simultaneity and affiliation scores, and partially mediated the relationship between objective simultaneity and affiliation scores. Path values are unstandardised regression coefficients. Significant effects in bold. ** p < .01. *** p < .001.

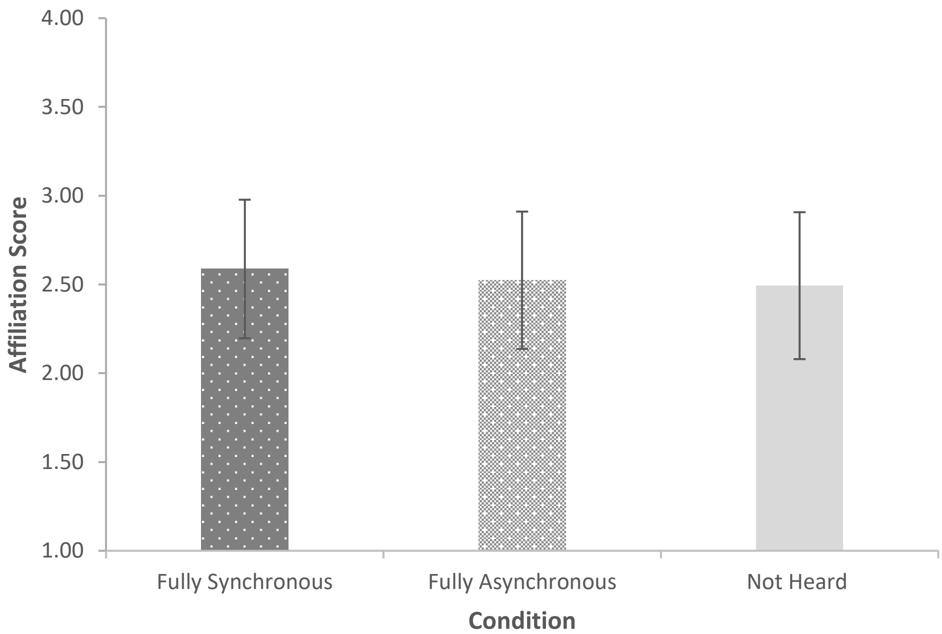
2.3.2 Experienced IS

2.3.2.1 The effect of fully synchronous tapping on affiliation scores

A one-way repeated measures ANOVA found no significant differences in affiliation scores across the three conditions in which: 1) partners tapped simultaneously with participants; 2) partners' tapping was fully asynchronous; and 3) partners' taps were not heard F(1.80, 111.80) = 0.61, p = .53, η^2 = .01) (**Figure 2.8**).

Figure 2.8

Experienced IS: effect of fully synchronous tapping on affiliation scores

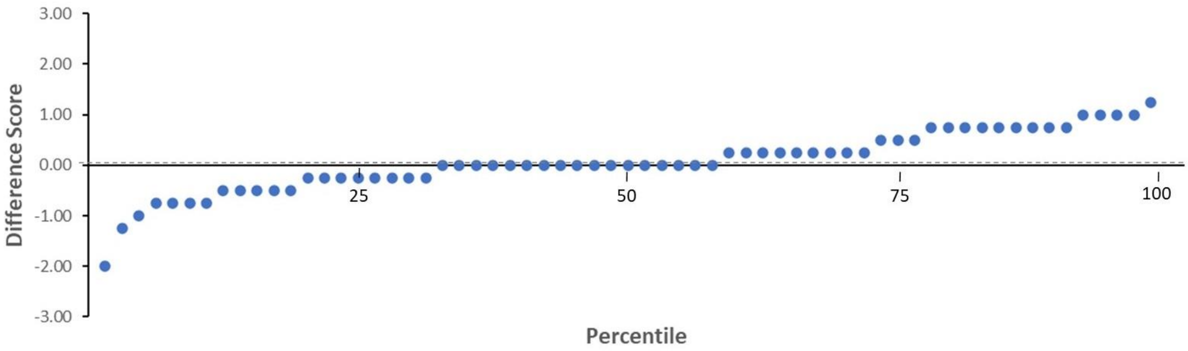


Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

The mean synchrony difference score (score in the fully synchronous condition minus score in the fully asynchronous condition) was 0.06 (SD = 0.60). At the individual level, 41% of participants displayed positive synchrony difference scores (**Figure 2.9**).

Figure 2.9

Experienced IS: synchrony difference scores of individual participants



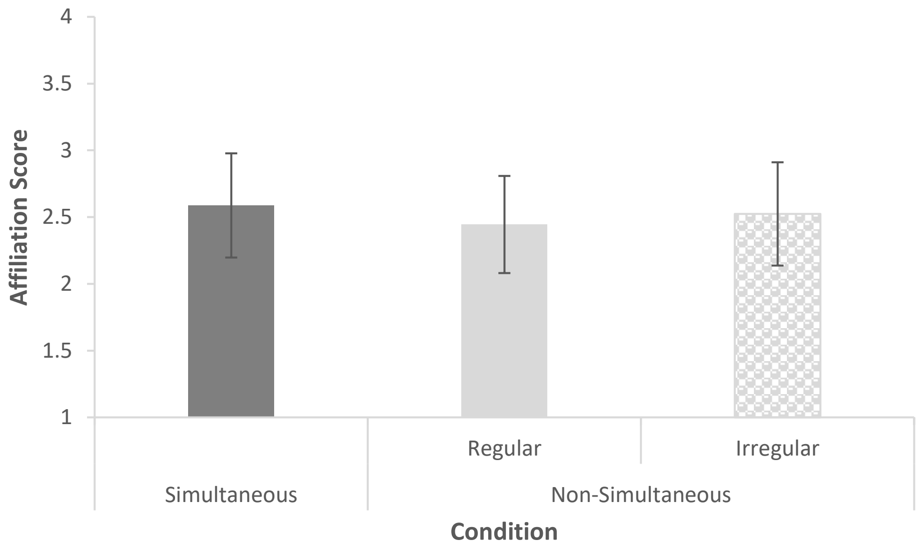
Note. Each data point represents the synchrony difference score of an individual participant. Dotted line (just visible) indicates mean synchrony difference score.

2.3.2.2 The separable effects of simultaneity and regularity on affiliation scores

A further one-way repeated measures ANOVA compared affiliation scores where: 1) partners tapped simultaneously; 2) partners' tapping was non-simultaneous but regular (i.e. at a fixed latency), and 3) partners' tapping was non-simultaneous and irregular (i.e. at a variable latency). Scores were not significantly different between conditions, $F(1.64, 101.53) = 1.65$, $p = .20$, $\eta^2 = .03$ (**Figure 2.10**).

Figure 2.10

Experienced IS: mean affiliation scores for each combination of simultaneity and regularity



Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Regular = partners tapped with fixed latency; Irregular = partners tapped with variable latency. Error bars indicate standard deviation.

2.3.2.3 Effect of gender and age

When gender was entered into the ANOVA as a between-subjects factor, the interaction between gender and synchrony condition was non-significant (F (1.7,100.9) = 2.9, p = .07, η_p^2 = .05) and the effect of the synchrony conditions remained non-significant (F (1.7,100.9) = 2.6, p = .09, η_p^2 = .04). Sensitivity to synchrony, represented by each participant's synchrony difference score, was not associated with age, $r(63)$ = .13, p = .31. Difference scores for simultaneity and regularity were not significantly associated with age (simultaneity: $r(63)$ = .08, p = .52; regularity: $r(63)$ = .16, p = .22).

2.3.3 Association between affiliation judgements following witnessed and experienced IS

For the 19 participants who completed both tasks, the mean synchrony difference score for witnessed IS was 0.86 (SD = 0.72) and the mean synchrony difference score for experienced

IS was 0.37 (SD = 0.64). There was no significant association between synchrony difference scores for witnessed and experienced IS, $r(17) = -.08$, $p = .37$.

2.4 Discussion

The affiliative effects of IS in TD children have been extensively documented in previous research (see Chapter 1, section 1.3 for a discussion). Much less is known about the mechanisms that translate the objective temporal relations between partners into subjective assessments of their social relationships. Using online tasks involving both witnessed and experienced IS, this study explored how the temporal properties of IS influenced the affiliation judgements of 4 to 11-year-old TD children. A novel approach examined the separable effects of simultaneity and regularity on children's affiliation judgements, as well as investigating the mediating effect of perceived 'togetherness'. Findings indicated that effect of IS on TD children's affiliation judgements for witnessed interactions was not uniquely contained in either the simultaneity or the regularity of an interaction: rather, simultaneity and regularity were each associated with increased perceived affiliation between partners. Both of these effects were mediated by children's subjective perceptions of the 'togetherness' of the interactions they heard. Taken together, these findings suggest that the affiliative effects of IS in TD children are not limited to interactions characterised by simultaneity, but emerge via a more generalised assessment of temporal interdependence between partners. In contrast, no affiliative effects of IS were found in the Experienced IS task. Potential explanations for this finding are discussed further below.

2.4.1 The separable effects of simultaneity and regularity when witnessing IS

Simultaneity and temporal regularity each positively influenced children's perceptions of affiliation when witnessing IS. The findings thus indicate that the affiliative effects of IS occur when there is a discernible temporal relationship between partners. While simultaneity and temporal regularity both fulfil this criterion, the relative effect sizes for each suggest that the influence of regularity is more substantial than that of simultaneity.

The data were less conclusive, however, regarding the interaction between simultaneity and regularity in driving affiliative effects. While the pattern of results could be interpreted as suggesting a simple additive effect of simultaneity and regularity, where each prompts an increase in perceived affiliation independently of the other, the borderline significant interaction between simultaneity and regularity hints at a more complex relationship. It suggests that simultaneity only led to significantly higher perceived levels of affiliation between partners when interactions were temporally irregular. When interactions were regular, simultaneity had *no* additional effect on the perceived degree of affiliation. Overall, the pattern of findings suggests that children perceive temporally organised partners as higher in affiliation than temporally disorganised partners, with both simultaneity and regularity playing a significant role. However, there is a tentative indication that simultaneity may only increase affiliation in the absence of regularity, and may not increase affiliation above that engendered by regularity. This pattern of interactions may reflect the fact that the size of the effect of regularity was substantially larger than that of simultaneity.

The principal finding – that both simultaneity and regularity lead to increased perceived affiliation in relation to witnessed IS – does not support narrower theoretical accounts that propose that the affiliative effects of IS stem from a perception of similarity that arises specifically when behaviour co-occurs in time (e.g. Valdesolo & Desteno, 2011; Dignath et al., 2018). Rather, the influence of *both* simultaneity and temporal regularity supports the broader interpretation whereby children's affiliation judgements are governed by the presence or absence of some form of temporal interdependence between partners (Wan & Zhu, 2022). A shared temporal framework – arising from simultaneity, regularity, or both – is likely, in turn, to connote co-operation, shared intentionality and thus affiliation between interacting partners (Kirschner & Tomasello, 2010; Reddish et al., 2013; Wan & Fu, 2019; Wan & Zhu, 2022). However, as perceptions of co-operation or shared intentionality were not directly measured or manipulated in this study, this element of the proposed pathway is not yet supported by direct evidence.

2.4.2 Developmental differences in the effects of witnessed IS on affiliation

Within the sample of 4- to 11-year-olds, witnessed IS had a greater effect on the affiliation judgements of older children compared to younger children. Further, this relation appeared to be driven specifically by an age-related increase in the influence of temporal regularity on affiliation. The effect of simultaneity, by contrast, did not vary with age. Previous evidence suggests that infants' affiliative behaviour is influenced only by simultaneity, and not by regularity (Cirelli et al., 2014), but that simultaneity and regularity each influenced the affiliation judgements of adults (Cacioppo et al., 2014). There is also some evidence of social sensitivity to temporal regularity in 5-year-olds: those who took part in an interaction governed by a regular beat displayed increased helping behaviour towards their social partners, relative to those who acted according to an irregular beat (Wan & Fu, 2019). Taken together with the finding from the present study that the influence of regularity increases during middle childhood, the evidence suggests that the affiliative influence of simultaneity may develop earlier than that of regularity, with the former present in infancy but the latter emerging in middle childhood. However, the limited existing research in this area, together with the diversity of paradigms and outcome measures, means that further research is needed to firmly establish such a developmental trajectory.

2.4.3 Subjectively perceived 'togetherness'

Simultaneity and regularity in witnessed IS both influenced children's judgements of whether partners acted 'together'. The fact that the temporal properties of interactions influenced explicit assessments of togetherness is consistent with evidence from the adult literature, in which a majority of studies have reported a significant association between objective and subjective levels of IS (e.g. Lakens, 2010; Reddish et al., 2013; Launay et al., 2014; Lang et al., 2017; although cf Demos et al., 2012). The current study also examined the separable effects of simultaneity and regularity on perceptions of togetherness, finding that objective simultaneity led to significantly higher perceptions of togetherness than non-simultaneity. This finding was not unexpected as participants were, in effect, instructed to make a simultaneity judgement ("*We would say they played 'together' if their sounds come at exactly the same time as each other.*"). Given this explicit definition, however, the finding that *regularity* also influenced togetherness judgements was surprising. One possibility is that regularity within an interaction gave some participants a (false) impression of simultaneity. However, this seems unlikely given that the relatively large latencies within our stimuli (125 or 200 ms) were substantially beyond the threshold at which young children can detect gaps in auditory stimuli (consistently estimated at less than 50 ms: see, e.g. Irwin et al., 1985; Wightman et al., 1989; Ismaail et al., 2019). It seems more likely that many participants reported perceiving regular interactions as 'together' because temporal regularity conveyed an impression of subjective togetherness in a broader sense – that is, of temporal contingency or interdependence between interacting partners.

The findings from the present study further suggest that the perceived togetherness of interacting partners is a key mechanism through which the objective temporal properties of an interaction influence children's social understanding, and accords with similar findings in adults (Hagen & Bryant, 2003; Lakens, 2010). Perceived togetherness fully mediated the link between simultaneity and affiliation judgements, but partially mediated the relation between regularity and affiliation judgements, suggesting that regularity had both a direct and indirect effect (via perceived togetherness) on children's affiliation judgements. This difference may partly reflect the tighter conceptual coupling between simultaneity and togetherness. However, the data are clear in demonstrating that both simultaneity and regularity contribute to the perception of partners' temporal interdependence. Overall, the findings suggest that the affiliation judgements of children, like those of adults (Hagen & Bryant, 2003; Lakens, 2010; Lakens & Stel, 2011), are intuitively informed by a subjective cognitive appraisal of the temporal relation between social partners. Further, the mediating role of perceived IS suggests that, for children, as for adults, variation in the ability to perceive IS is likely to lead to variation in the extent to which objective levels of IS influence social outcomes (Lakens, 2010).

2.4.4 IS as a social heuristic in children

The finding that children perceived synchronised partners as higher in affiliation than asynchronous partners is consistent with previous research into the influence of witnessed IS on children's social judgements (Abraham et al., 2022; Cirelli et al., 2018; Fawcett & Tunçgenç, 2017). In previous studies, participants visually observed the target interactions and the context in which they took place. For example, one previous study involved teddy bears moving either synchronously or asynchronously and 'talking' with each other (Fawcett

& Tunçgenç, 2017), and another involved a child and adult engaged side-by-side in a painting activity using either synchronous or asynchronous movements (Abraham et al., 2022). The paradigm used in the current study was socially 'lean' in comparison: the brief (11.5 s) interactions on which affiliation judgements were based included no visual movement information and minimal social contextual information. Nevertheless, IS influenced affiliation judgements with medium to large effect sizes. The current study thus extends previous findings by providing evidence that the temporal structure of an interaction is itself sufficient to influence children's affiliation judgements when witnessing IS, even in the absence of physical congruency or of other visible features of the interaction. The findings suggest that for children, like adults (Fessler & Holbrook, 2016; Miles et al., 2009), the temporal properties of interactions are a heuristic for interpreting relationships between other people.

2.4.5 Experienced IS

The temporal relations between partners had no effect on children's affiliation judgements in the Experienced IS task. This result contrasts with findings from previous studies in which experiencing IS elicited affiliative effects in children (e.g. Rabinowitch et al., 2015; Kirschner & Tomasello, 2010; Tarr et al., 2015; Cirelli et al., 2014; although cf. Kirschner & Ilari, 2014). Notably, however, these studies all employed in-person interactions between children, or between child participants and an adult researcher. In the current study, 'partners' were not physically present but were represented by a photograph and name, and their movements were not visible. For any affiliative effects to arise, children would have had to attribute the stimuli to the movements of a human actor (Launay et al., 2014). It seems that children are willing and able to make such an attribution, at least under certain circumstances, given that the Witnessed IS task also employed photographs and auditory-only stimuli. When experiencing IS, however, the attribution of sounds to the actions of a human partner – and thus any affiliative effect – may further depend upon the salience of the partner's 'live' involvement in the interaction. A sense of partner involvement was intended to be conveyed in the Experienced IS task by using the names and pictures of real children, and by referring to the partner in task instructions. However, comparable adult studies in which interactions took place via computer button presses (e.g. Launay et al., 2014; Cacioppo et al., 2014; Koehne et al., 2016) incorporated more substantial measures to create the impression that a partner was engaged in the task in real time (e.g. by having a researcher pretending to talk to the 'partner' in the next room). Thus, a likely explanation for the null finding is that the task design did not convey to participants a sufficiently keen sense of their partner's involvement in the interaction. This interpretation is consistent with evidence that a computer-generated experience of synchrony was insufficient to influence affiliation with a partner who was present but not actively engaged in co-creating synchrony (Howard et al., 2021). Indeed, it may be that some or all participants did not believe that they were interacting with a 'real' partner at all, particularly as they completed the activity online at a time of their own choosing. However, as participants were not asked directly about their beliefs/experience in relation to their partners' participation, it is not possible to assess the extent to which these factors affected the current findings. A further possible explanation for the null finding in the Experienced IS task relates to the absence of movement cues. IS conveyed only via auditory signals has previously been found to elicit affiliative effects in adults (e.g. Kokal et al., 2011; Cacioppo et al., 2014; Koehne et al., 2016; Launay et al., 2013). However, it is possible that the affiliative effects of experienced IS in children further depend on the presence of direct sensorimotor coupling between partners (Howard et al., 2021). Lastly, although no participants reported experiencing technical difficulties, it is conceivable that some participants experienced a lag between initiating and hearing their own tap because of internet connection/speed issues. This would have been a source of noise in the data, although not one that directly impacted the synchrony between participant and partner. Overall, the relative influence of simultaneity and regularity on affiliation judgements in the context of experienced IS, together with the importance of movement cues in generating such effects in children remain open questions. Future research should aim to explore these questions using a paradigm in which partner engagement is more explicit and the presence/absence of movement cues can be contrasted.

2.4.6 Limitations and future directions

Findings in the current study were based upon highly rhythmical auditory interactions. Some of children's everyday social interactions are characterised by deliberate or spontaneous rhythmical co-ordination (e.g. clapping games; walking in step). However, many real-life social interactions exhibit subtle, transient, and variable degrees of synchrony over time (Mayo & Gordon, 2020; Tronick & Cohn, 1989). In contrast to the experimental stimuli, they are also likely to contain substantial visual content and other forms of social information. It remains to be seen whether the findings in relation to simultaneity, regularity and perceived togetherness generalise to contexts with a less pronounced temporal structure and/or contexts involving additional social and environmental factors.

Despite observing significant group-level differences in affiliation in the Witnessed IS task, at the individual level some participants did not display positive effects on perceived affiliation, as reflected in individual difference scores that were negative or zero. One possible explanation for this variability is levels of participant attention to the task, which it was not possible to monitor directly. However, it is also possible that the variability within difference scores reflects individual differences in children's responsiveness to IS when judging affiliation between others, stemming, for example, from individual differences in perceptual and/or social processing.

The findings from the current study have potential implications for the development of IS-based interventions that target social functioning and/or bonding. Such interventions have been employed, for example, to enhance mother-child attachment (e.g. Bernard et al., 2013), to improve inter-group relations (Atherton et al., 2019; Tunçgenç & Cohen, 2016) and to promote social cohesion in the workplace (Göritz & Rennung, 2019). To date, IS-based interventions have largely aimed to induce simultaneity of movement between partners. However, in relation to witnessed IS at least, the findings suggest that temporal regularity within an interaction has comparable social effects. Future interventions might seek to target the temporal and cognitive processes that influence affiliation by incorporating activities that foster temporal interdependence more broadly, and/or more directly induce a sense of 'togetherness' between partners.

The fact that IS did not influence affiliation in the socially lean paradigm employed in the Experienced IS task has implications for our understanding of analogous interactions in the real world. Online or other screen-based interactions, in which actors are not physically present together but instead represented by some form of avatar, are now common during childhood (Przybylski & Weinstein, 2019). Virtual interactions are increasingly employed with the aim of enhancing children's social wellbeing in clinical contexts (Wong et al., 2020) as well as to support social functioning in neurodivergent conditions (Jiménez-Muñoz et al., 2021; Stone et al., 2019). The current findings highlight the possibility that, if partner presence and engagement is insufficiently salient in such interactions, the social benefits they are designed to deliver may be reduced or absent. As such, they support the need to understand the minimal conditions required to generate a sense of social context and partner engagement in the virtual environment (Rinott & Tractinsky, 2022).

Finally, the current study examined affiliative effects of IS in TD children. However, differences in rhythm and timing (Lense et al., 2021) and in social cognition (Baribeau et al., 2015; Bora & Pantelis, 2016) have been observed across neurodivergent populations. There is also specific evidence that individuals with ADHD (Problovski et al., 2021), as well as autistic people (Georgescu et al., 2020; Marsh et al., 2013) exhibit reduced IS (see Chapter 1, sections 1.5.1 and 1.52 for a discussion). However, there is limited existing research on the affiliative effects of IS in people with neurodivergent conditions (see Chapter 1, section 1.5.3), which may be relevant in understanding differences in social functioning in neurodivergent populations. The extent of individual differences in the affiliative effects of IS in atypical development, together with the factors that underpin them, will be explored further in Chapters 3 to 5.

2.4.7 Conclusion

This is the first study to establish that the simultaneity and the regularity of partners' actions both influence the affiliation judgements of TD children when they witness IS. The findings indicate that TD children judge affiliation between partners according to their temporal interdependence, which includes but is not limited to simultaneity of action. Further, this is the first study to establish the mediating role of children's perceptions of 'togetherness' when judging affiliation from witnessed IS. Importantly, these effects were established in the context of very limited social cues, providing strong support for the importance of temporal structure in influencing TD children's perceptions of affiliation. By contrast, when children experience IS, affiliative effects are likely to require a richer social context. Future research should explore the affiliative role of simultaneity and regularity within a wider range of social contexts, as well as individual differences in social sensitivity to IS. In particular, whether and to what extent IS has social effects in atypically developing children is largely unknown, and will be addressed in the next chapter.

Chapter 3

Interpersonal Synchrony and Affiliation in Children with Emerging Emotional and Behavioural Difficulties

3.1 Introduction

In Chapter 2, TD children displayed robust sensitivity to social timing when judging partner affiliation. Both simultaneity and temporal regularity led to children perceiving increased levels of affiliation between social partners, mediated by a perception of partner 'togetherness'. For TD children, sensitivity to the social effects of IS plays a significant role in social functioning and longer term developmental outcomes (see Chapter 1, section 1.3). Contrastingly, challenges with social communication are common in atypically developing children (Lense et al., 2021; Mikami et al., 2019; Missiuna et al., 2014). Further, reduced IS has been observed in autistic people and, to some extent, in other neurodivergent populations (McNaughton & Redcay, 2020; Problovski et al., 2021). Therefore, atypical IS may be relevant to atypical patterns of social communication and/or social difficulties experienced by children with emerging signs of neurodivergence and/or social difficulties. To understand how IS relates to atypical social communication, it is important to understand whether and to what extent IS has social effects atypically developing individuals. However, research is yet to establish the social relevance of IS in atypical development (see Chapter 1, section 1.5.3). To address this gap in the research, the study presented in this chapter investigated whether the affiliative effects of IS occur in children with EE&BDs, and whether social sensitivity to IS relates to any particular set of diagnostic traits.

In contrast to a range of studies demonstrating the reduced incidence of IS in neurodivergent populations (see Chapter 1, sections 1.5.1 and 1.5.2), only two previous studies, to my knowledge, have investigated the social effects of IS in neurodivergent samples. Both studies involved autistic adults. Unlike typical comparators, autistic adults did not feel higher levels of empathy towards synchronous partners than to asynchronous partners in a computer-based task (Koehne, Hatri, et al., 2016). Similarly, in contrast to neurotypical children and adults, autistic adults did not rate synchronous walkers as significantly higher in 'closeness' than asynchronous walkers. However, synchrony did positively affect their responses when required to rank partners by closeness (Au & Lo, 2020). Together with evidence of reduced behavioural IS in neurodivergent populations, this (limited) evidence of attenuated social effects in autistic adults suggests that the social effects of IS may be reduced or absent in children with EE&BDs.

Differing pathways may account for variation in the social effects of IS. For example, children with high levels of autistic traits may experience difficulties in producing and interpreting non-verbal social cues (APA, 2013) and/or experience other aspects of social interactions as more important for social bonding (Crompton et al., 2020b; Heasman & Gillespie, 2019; Morrison et al., 2020). As such, increased levels of autistic traits may be associated with reduced social sensitivity to IS via a decreased tendency to process IS as socially relevant. In contrast, children with high levels of ADHD traits may experience reduced sensitivity to social cues via difficulty in directing and maintaining social attention (Dahan et al., 2016; Harkins et al., 2022; Leitner, 2014). Increased levels of ADHD traits may therefore relate to reduced social sensitivity to IS via a reduced tendency to detect and/or process levels of IS within an interaction. Further, the ways in which social cues are attended to and processed may each contribute to variation in sensitivity to the social effects of IS, such that autistic and ADHD traits may each be related to sensitivity to the affiliative effects of IS. Co-occurrence of autism and ADHD is common (Lai et al., 2019; Hollingdale et al., 2020) and may contribute to increased social challenges, relative to singular presentation (Chiang & Gau, 2016; Factor et al., 2017). Thus, it is important to explore whether autistic and ADHD-related traits independently or interactively predict reduced social sensitivity to IS.

The participants in the present study were drawn from the NDAU sample (see Chapter 1, section 1.7.2). Because children referred to the NDAU display a range of emotional and behavioural difficulties that differ both in nature and degree, the sample is apt to capture variation both in sensitivity to IS as a social cue and in levels of trait-related characteristics. As previously noted, none of the children in the sample had been diagnosed with a neurodivergent condition at the time of assessment. Therefore, the use of the terms 'autistic' and 'ADHD traits' (collectively, 'diagnostic traits') in relation to this sample is not intended to infer the presence of diagnosable neurodivergent conditions. On the contrary, there may be a number of reasons that account for high scores on the measures used (see e.g. Duvall et al., 2022) that are beyond the scope of this research. However, such traits are frequently measured in non-clinical samples, including in samples drawn from the general population (Sasson & Bottema-Beutel, 2022). The common practice is to refer to the presence and/or levels of 'autistic traits' etc in such samples. For convenience, the same terminology is used here.

To assess social sensitivity to IS, the Witnessed and Experienced IS tasks described in Chapter 2 were used. The tasks incorporated a number of features to ensure they were suitable for use with children across the spectrum of neurodiversity. First, IS was presented via uni-sensory, auditory stimuli. This ensured that participants' experiences of IS would not be differentially affected by multisensory processing and/or social visual attention, both of which may be atypical in neurodivergent populations (see Chapter 1, section 1.6.2). Second, social sensitivity to IS may differ in children with EE&BDs depending on whether IS is witnessed or experienced. For example, witnessing IS, unlike experiencing IS, requires no motor input and therefore involves lower processing demands. Because the Witnessed and Experienced IS tasks share a common format and stimuli, they were well placed to explore such differential effects. Third, in the Witnessed IS task, participants judged partner 'togetherness' as well as partner affiliation. The 'togetherness' judgement assessed the extent to which participants detected IS, and the affiliation judgement assessed the extent to which IS was processed as socially relevant. Accordingly, it was possible to address whether variation in children's social sensitivity to IS was attributable to differences in attending to and/or perceiving IS, or to differences in its social relevance. Importantly, unlike the sample in the previous chapter, children with EE&BDs completed all tasks in person in a university lab-based setting, so that it was possible to ensure that all participants were on-task. In-person testing also provided a more believable set up for the interactions presented in the tasks. For example, 'partners' were pictured in a similar lab based environment to the participant, meaning participants were more likely to believe that the interactions in the Experienced IS task were genuine.

The present study had three aims. The first was to establish whether IS influenced the affiliation judgements of children with EE&BDs. The second was to explore whether any reduction in the affiliative effects of IS was because of a reduced tendency to detect IS, or a reduced tendency to be influenced by IS when judging affiliation. The third aim was to explore trait-based correlates of sensitivity to IS as a social cue, namely, overall levels of emotional and behavioural difficulties; autistic traits; and ADHD traits. Because the sample was comprised of children with EE&BDs, it was predicted that sensitivity to IS as a social cue would be reduced or absent in the sample as a whole, either as a result of disrupted perceptions of partner 'togetherness' and/or a dissociation between perceived 'togetherness' and affiliation. It was predicted that lower sensitivity to IS would be associated with higher levels of emotional and behavioural difficulties, autistic traits, and ADHD traits.

Finally, age and gender effects in the relation between IS and affiliation in children with EE&BDs were also explored. Findings from TD children (Chapter 2) indicated that the affiliative effects of IS increased with age in that sample. Comparable age effects were therefore predicted in children with EE&BDs. As no gender differences in the effect of IS on affiliation had been observed in TD children (Chapter 2), none were predicted in the current sample. However, the symptom profiles of girls and boys with EE&BDs (see e.g. Maguire et al., 2016; Rescorla et al., 2007) and their identification by teachers (Soles et al., 2008) may differ. Therefore, it was important to explore whether gender influenced the relation between IS and affiliation in the current sample.

3.2 Method

3.2.1 Participants

One hundred and thirty-six participants completed the Witnessed IS task (101 male; M_{age} = 6 years 7 months; *SD* = 12 months), and 150 completed the Experienced IS task (110 male; M_{age} = 6 years 7 months; *SD* = 12 months), 125 of whom completed both tasks. They were part of a larger sample of 4- to 8-year-old children referred to the NDAU by schools because of emerging emotional/or and behavioural difficulties (see Chapter 1, section 1.7.2).

Caregivers provided written informed consent on participants' behalf. The study was approved by the Cardiff University School of Psychology Research Ethics Committee.

3.2.2 Materials and procedure

Participants completed the study task as part of a wider assessment of their socio-emotional, behavioural, and cognitive functioning. The full assessment battery was delivered over two sessions lasting approximately 5 hours in total. Tasks were administered by a trained researcher in a dedicated testing room. The participant's caregiver completed a range of questionnaires, including those used in the present study, in a separate interview room.

3.2.2.1 Witnessed and Experienced IS tasks

Participants carried out in-person versions of the Witnessed and Experienced IS tasks described in Chapter 2. All aspects of both tasks were identical to the online versions described in Chapter 2, apart from the following. The tasks were presented in E-Prime 2.0 (Psychology Software Tools, 2012) on a laptop computer. Before the task began, an example auditory stimulus was played. The volume was pre-set at 40% of the computer's maximum volume and then adjusted as necessary so that it was comfortable for the participant. Task instructions were presented as text on screen and read aloud by the researcher, who controlled the pace of progress through the task with a mouse click that initiated the next instruction/trial. Unlike in the online version of the Witnessed IS task (Chapter 2) the onset and offset of auditory stimuli were not accompanied by any visual indicators. In the Experienced IS task, there was no video demonstration of isochronous tapping; rather, the researcher demonstrated isochronous tapping in person. The researcher/participant tapped on the computer spacebar instead of on a tablet screen or trackpad. When responding to the questions in the tasks, participants answered either verbally or by pointing to the relevant response box on the screen and the researcher inputted the chosen response. There was no graphic to indicate progress through trials, although the researcher gave an indication of progress through the task if asked by the participant.

3.2.2.2 Questionnaire measures

Emotional and behavioural difficulties. The SDQ (Goodman, 1997) assessed emotional and behavioural difficulties and is a well-established screening tool for psychosocial problems (Goodman, 2001; Goodman, Ford, Simmons, et al., 2000). The present study used the parent-report version for children aged 4 to 17 years. There were 25 items with five subscales: four related to difficulties (emotional symptoms; conduct problems; hyperactivity/inattention; peer relationship problems) and one related to strengths (prosocial behaviour). Example items include, '*Often has temper tantrums or hot tempers*,' and '*Rather solitary, tends to play alone*.' Parents rated how true each item was of their child's presentation over the previous 6 months on a three-point Likert scale: '*not true*'; '*somewhat true*'; '*certainly true*'. Five subscale scores (0 to 10) were generated and a 'total difficulties' score was obtained by summing the four difficulty-related subscale scores (0 to 40). Higher scores indicated greater levels of difficulty, save for on the prosocial subscale in which higher scores indicated higher levels of prosociality. Cut off scores[2] for each subscale and total score indicated whether, based on data from a United Kingdom community sample, scores were 'slightly raised' (80-90th percentile), 'high' (90-95th percentile) or 'very high' (>95th percentile).

[1] SDQ Info. Scoring the Strengths & Difficulties Questionnaire for Age 4–17 or 18+. 2016. Available online: **https://www.sdqinfo.org/py/sdqinfo/c0.py** (accessed on 12 October 2022).

Autistic traits. The Autism Spectrum Quotient (Children's Version) (AQ-Child) (Auyeung et al., 2008) is a 50-item parent-report questionnaire that is used to quantify autistic traits in children aged 4 to 11 years. It assessed five areas of functioning (social skills; attention switching; attention to detail; communication; imagination). Example items include '*Good at social chit-chat*' and '*Does not let others get a word in edgeways*'. Each item was rated on a four-point Likert scale: '*definitely agree*'; '*slightly agree*'; '*slightly disagree*'; '*definitely disagree*'. Scores for each subscale (0 to 30) and a total score (0 to 150) were generated, with higher scores indicating higher levels of autistic traits. A total score of 76 or more is consistent with a diagnosis of autism at 95% specificity and sensitivity in a general population sample (Auyeung et al., 2008), albeit evidence suggests lower predictive accuracy in clinical samples (Aiello et al., 2021; Kästner et al., 2015; Ketelaars et al., 2008).

Inattention and hyperactivity/impulsivity. The Development and Well-Being Assessment (DAWBA) (Goodman, Ford, Richards, et al., 2000) can be used to assess diagnostic traits from a number of disorders in the DSM-5 (APA, 2013). For primary school-aged children, parents reported on their child's presentation in the previous six months via questionnaire and semi-structured interview. The present study used the questionnaire items on the Attention and Activity Section (AAS) of the DAWBA only. A screening question asked whether, considering the child's age, they '*definitely* [have] *some problems with overactivity or poor concentration*.' If the answer was no, a score of 0 was awarded. If the answer was yes, a further 18 items, corresponding to each ADHD symptom listed in the DSM-5, were administered. Nine items related to inattention (e.g. '*Is s/he easily distracted?*') and nine to hyperactivity/impulsivity (e.g. '*Is it hard for him/her to stay sitting down for long?*'). The child was rated as having experienced each symptom '*no more*', 'a little more' or 'a lot more' than other children of the same age. Two subscale scores were calculated by summing the scores for the inattention items and for the hyperactivity/impulsivity items respectively, with potential values between 0 and 18, and a total potential score of between 0 and 36. Scores therefore reflected both the number and severity of inattention- and hyperactivity/impulsivity-related difficulties.

3.2.2.3 Statistical analysis

Data were collated in Microsoft Excel and imported into IBM SPSS version 25.0 for statistical analysis.

Data cleaning. Questionnaires with >10% of items missing were excluded from analysis, on the basis that a greater proportion of missing data is likely to result in a biased analysis (Bennett, 2001). For the AQ-Child there were 16 participants (out of 121) with <10% missing data. Little's Missing Completely at Random (MCAR) analysis (Little, 1988) indicated that these data were missing completely at random ($\chi^2(706) = 728.14$, $p = .27$). Missing item scores were replaced by the mean value of the available items in the same subscale. No participant had incomplete data for the SDQ, DAWBA(AAS), or Witnessed and Experienced IS tasks.

Questionnaire measures. Descriptive statistics were used to characterise the type and degree of emotional and behavioural difficulties, and levels of autistic and ADHD traits in the sample as a whole, and Spearman's Rank correlations assessed the relations between measures of difficulties/diagnostic traits. T-tests assessed gender differences in total levels of emotional and behavioural difficulties and in diagnostic traits.

Witnessed and Experienced IS tasks. The Witnessed and Experienced IS tasks were analysed using the method described in relation to the equivalent tasks in Chapter 2. For both tasks, scores for questions 1 (liking) and 2 (similarity) were positively associated, $r_s(1360) = .52$, $p <$

.001 (Witnessed IS); $r_s(1195) = .63$, $p < .001$ (Experienced IS). As there was no difference in the pattern results when questions 1 and 2 were treated as separate outcome variables, a single outcome variable, ‘affiliation score’ was generated from the mean of the two scores. Mean scores in the fast (ISI 500 ms) and slow (ISI 800 ms) conditions were not significantly different, $t(136) = 1.70$, $p = .09$ (Witnessed IS); $t(150) = 0.95$, $p = .35$ (Experienced IS), so affiliation scores were collapsed across tempo.

Assumptions for parametric testing were met. The effects of the simultaneity/regularity manipulations on affiliation, and the relations between objective simultaneity/regularity, perceived ‘togetherness’ and affiliation in the Witnessed IS task, were assessed using ANOVAs and GLMMs respectively, as described in Chapter 2. Difference scores, as described in Chapter 2, quantified participants’ sensitivity to synchrony when making affiliation judgements. Correlations investigated the relation between sensitivity to synchrony and total difficulties/diagnostic traits, as assessed by parent-report questionnaires.

Finally, a series of GLMMs investigated whether the relation between simultaneity/regularity and affiliation scores in the Witnessed IS task depended on levels of total difficulties and/or diagnostic traits. The predictors in each GLMM were: a single experimental manipulation (simultaneity or regularity); one of the parent-report questionnaire total scores; and an interaction term. Affiliation score was the outcome variable in all models. For the Witnessed IS task, analysis did not detect any interaction between simultaneity and regularity in their effects on affiliation, so the moderating role of presenting difficulties was assessed separately for simultaneity and for regularity. Because levels of difficulty in one domain were significantly associated with levels of difficulties in other domains with medium to large effect sizes, separate GLMMs were constructed to examine the moderating effect of levels of total difficulties, autistic traits and ADHD-traits. Participant was a random effects variable in all mixed models.

3.3 Results

3.3.1 Sample characteristics

Consistent with participants' referral to the NDAU because of emotional and/or behavioural difficulties, the proportion of participants who displayed levels of total difficulties on the SDQ that were above the population average was 83.7%, with a further 6.7% scoring on the borderline between 'close to average' and above average levels of difficulty.

Average scores on the SDQ were consistent with 'high' levels of attention and conduct problems, 'slightly raised' emotional and peer problems and 'low' prosociality. Mean total difficulties were in the 'very high' range. Mean AQ-child scores were just above the cut-off for high likelihood of autism (**Table 3.1**). The proportion of participants above the cut-off point for risk of psychopathology on the SDQ (total difficulties) was 73%. The proportion of participants with a high likelihood of autism on the AQ-child was 58%. There was substantial variation within the sample in the scores on each measure (**Figure 3.1**). Increasing levels of difficulties/traits on one measure was associated with increasing levels of difficulties/traits in the other two, with medium to large effect sizes (SDQ/AQ-Child: $r_s(121) = .48$, $p < .001$; SDQ/DAWBA(AAS): $r_s(131) = .55$, $p < .001$; AQ-Child/DAWBA(AAS): $r_s(119) = .34$, $p < .001$). Comparison of total scores in each domain by gender indicated that girls displayed significantly higher levels of total difficulties on the SDQ (M = 24.0) than boys (M =

20.8), $t(133) = 2.44$, $p = .02$. There were no significant gender differences in total scores on the other two parent-report measures.

Table 3.1

Descriptive statistics for parent-report questionnaires

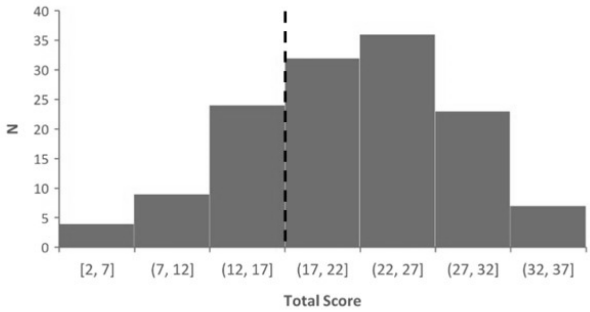
Measure	Subscale	Mean *(SD)* Boys	Girls	Total	Min-max; cut-off
	N	*100*	*35*	*135*	
SDQ	Emotional	4.6 *(2.5)*	5.4 *(3.0)*	**4.8** *(2.7)*	0-10; 5
	Conduct	4.4 *(2.6)*	5.6 *(2.6)*	**4.7** *(2.7)*	0-10; 4
	Hyperactivity	8.1 *(2.4)*	8.7 *(2.2)*	**8.3** *(2.4)*	0-10; 8
	Peer	3.8 *(2.1)*	4.3 *(2.4)*	**3.9** *(2.2)*	0-10; 4
	Prosocial	6.1 *(2.6)*	5.8 *(3.0)*	**6.1** *(2.7)*	0-10; 6
	TOTAL DIFFICULTIES	**20.8** ***(6.7)***	**24.0** ***(7.2)***	**21.6** ***(6.9)***	**0-40; 17**
	N	*91*	*30*	121	
AQ-Child	Social Skills	15.6 *(6.4)*	15.2 *(6.2)*	**15.5** *(6.3)*	0-30
	Attention Switching	19.7 *(5.9)*	18.4 *(5.6)*	**19.4** *(5.8)*	0-30
	Attention to Detail	16.3 *(5.9)*	13.8 *(5.3)*	**15.7** *(5.8)*	0-30
	Communication	18.9 *(5.2)*	19.3 *(6.5)*	**19.0** *(5.5)*	0-30
	Imagination	13.6 *(5.2)*	13.7 *(6.0)*	**13.6** *(5.5)*	0-30
	TOTAL	**84.1 (*****22.3)***	**80.3 (*****24.2)***	**83.2** ***(22.7)***	**0-150; 76**
	N	*98*	*33*	*131*	
DAWBA (AAS)	Inattention	12.4 *(5.2)*	11.7 *(6.1)*	**12.3** *(5.4)*	0-18
	Hyperactivity/Impulsivity	13.0 *(5.7)*	12.5 *(6.4)*	**12.9** *(5.8)*	0-18
	TOTAL	**25.5** ***(10.4)***	**24.2** ***(12.3)***	**25.1** ***(10.8)***	**0-36**

Note. SDQ= Strengths and Difficulties Questionnaire; AQ-Child = Autism Spectrum Quotient (Children's Version); DAWBA(AAS) = Development and Well-Being Assessment (Attention and Activity Section). Higher scores indicate higher levels of difficulty, save for on the SDQ prosocial subscale, on which higher scores indicate higher prosociality. Quoted SDQ 'cut-off' scores represent a 'high' level of difficulty (ie in the 90th+ percentile at a population level). *N* = number of participants for whom questionnaire data was included in analysis, which varies by measure because not all questionnaires were completed for each participant, and questionnaires with >10% items missing were excluded.

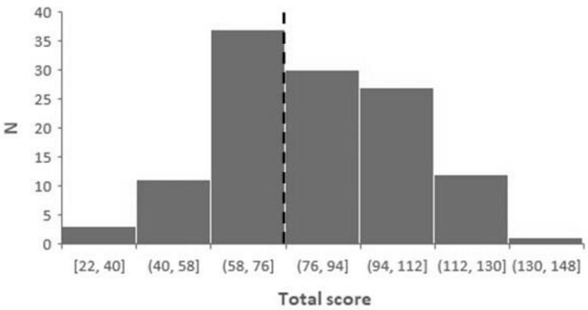
Figure 3.1

Distributions of total scores on parent-report questionnaires

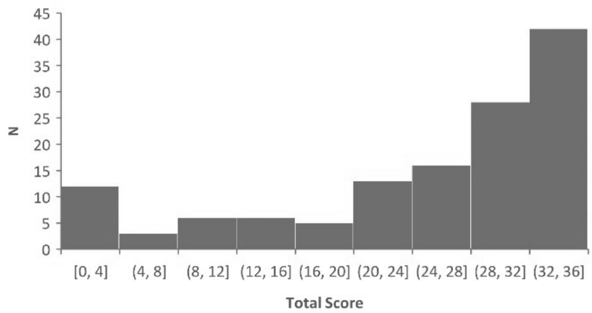
(a) Emotional and Behavioural Difficulties (SDQ)



(b) Autistic Traits (AQ-Child)



(c) Inattention and Hyperactivity (DAWBA (AAS))



Note. SDQ= Strengths and Difficulties Questionnaire; AQ-Child = Autism Spectrum Quotient (Children's Version); DAWBA(AAS) = Development and Well-Being Assessment (Attention and Activity Section). Higher scores indicate higher levels of difficulty. Dotted lines indicate cut-off points (where available).

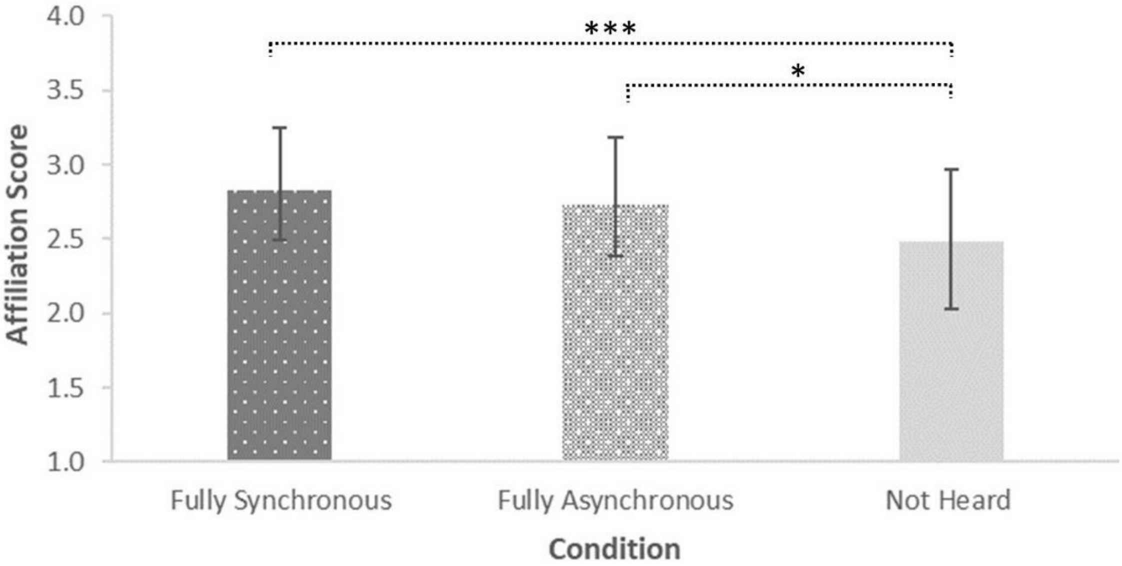
3.3.2 Witnessed IS

3.3.2.1 Effect of fully synchronous tapping on affiliation scores

Affiliation scores were compared across the three conditions in which partners' tapping was: 1) fully synchronous (i.e. both simultaneous and regular), 2) fully asynchronous (i.e. neither simultaneous nor regular), or 3) not heard. A one-way repeated measures ANOVA revealed that affiliation scores were significantly different across conditions, $F(1.88, 253.08) = 10.43$, $p < .001$, $\eta^2 = .07$. (**Figure 3.2**). Post-hoc analysis indicated that affiliation scores were significantly higher in both conditions in which partner tapping was heard compared to when no partner tapping was heard (fully synchronous: $p < .001$; fully asynchronous: $p =$ .01). However, there was no significant difference between affiliation scores in the fully synchronous and fully asynchronous conditions ($p = .49$).

Figure 3.2

Witnessed IS: effect of fully synchronous tapping on affiliation scores



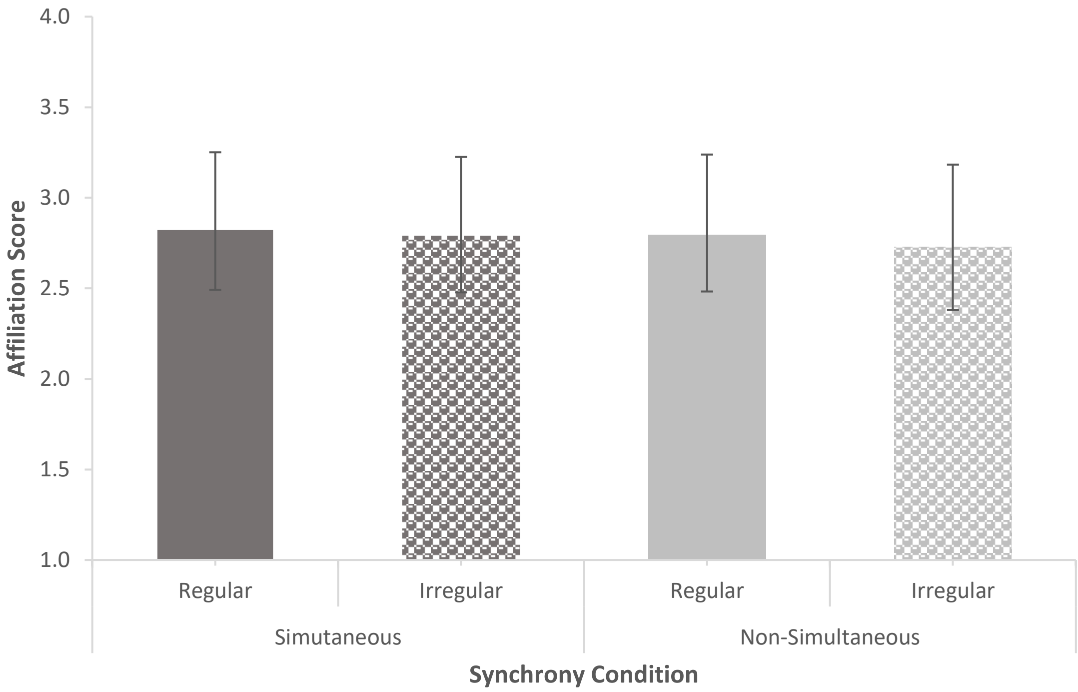
Note. 'Fully synchronous' = simultaneous and regular tapping; 'fully asynchronous' = tapping neither simultaneous nor regular. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.
*$p < .05$. ** $p < .01$. *** $p < .001$.

3.3.2.2 The separable effects of simultaneity and regularity on affiliation scores

Mean affiliation scores were 2.81 for simultaneous tapping and 2.76 for non-simultaneous tapping (collapsed across regularity). Mean affiliation scores were 2.81 for regular tapping and 2.76 for irregular tapping (collapsed across simultaneity). A two-way repeated measures ANOVA revealed that neither simultaneity, $F(1,135) = 0.86$, $p = .36$, $\eta_p^2 = .006$, nor regularity, $F(1,135) = 1.17$, $p = .28$, $\eta_p^2 = .009$ had a significant effect on affiliation scores (**Figure 3.3**). The interaction between simultaneity and regularity was also non-significant, $F(1,135) = 0.05$, $p = .83$, $\eta_p^2 < .001$.

Figure 3.3

Witnessed IS: mean affiliation scores for each combination of simultaneity and regularity



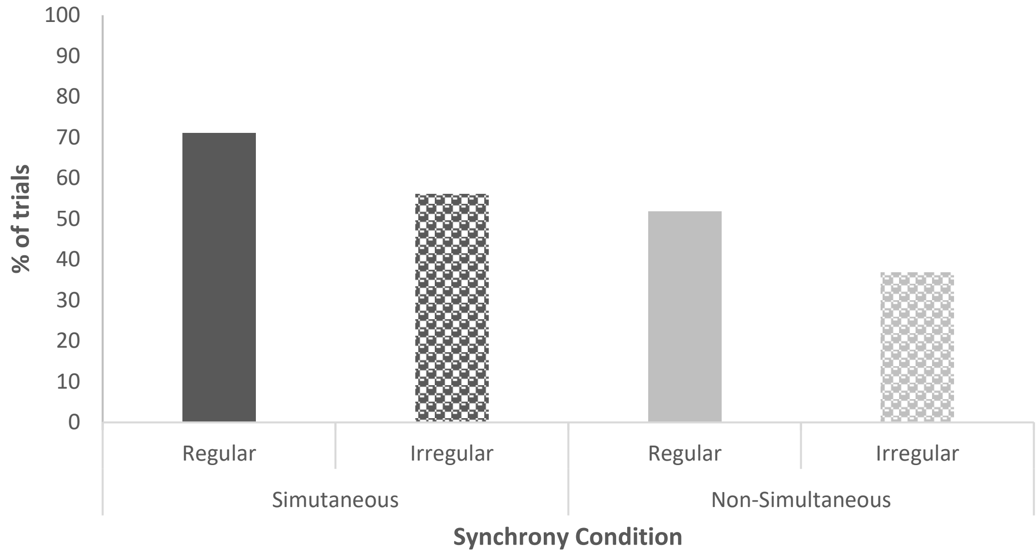
Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

3.3.2.3 Perceived 'togetherness' of tapping

Figure 3.4 indicates the frequency with which tapping was perceived as together for each combination of simultaneity and regularity. Simultaneity (β = 0.91, t = 4.74, p < .001) and regularity (β = 0.71, t = 3.74, p < .001) each had a significant positive effect on the likelihood of perceiving tapping as 'together'. The interaction between simultaneity and regularity was non-significant (β = 0.03, t = 0.13, p = .90). Further, tapping perceived as 'together' (M = 2.90) attracted significantly higher affiliation scores than tapping perceived as 'not together' (M = 2.68) (β = 0.13, t = 2.03, p = .04).

Figure 3.4

Witnessed IS: percentage of trials in which tapping was perceived as 'together', by synchrony condition



3.3.2.4 Gender differences

Gender and the effect of simultaneity and regularity. To explore whether gender moderated the effect of simultaneity and/or regularity on affiliation judgements, a mixed ANOVA was constructed with gender as a between-subjects factor, and simultaneity and regularity as within-subjects factors. The main effects of simultaneity, F(1,134) = 3.42, p = .006, η_p^2 = .03 and regularity F (1,134) = 0.02, p = .89, η_p^2 < .001, and the two-way interaction between simultaneity and regularity, F (1,134) = 0.09, p = .77, η_p^2 = .001, all remained non-significant. However, there were significant two-way interactions between gender and simultaneity, F (1,134) = 4.48, p = .04, η_p^2 = .03 and between gender and regularity, F (1,134) = 5.11, p = .03, η_p^2 = .04.

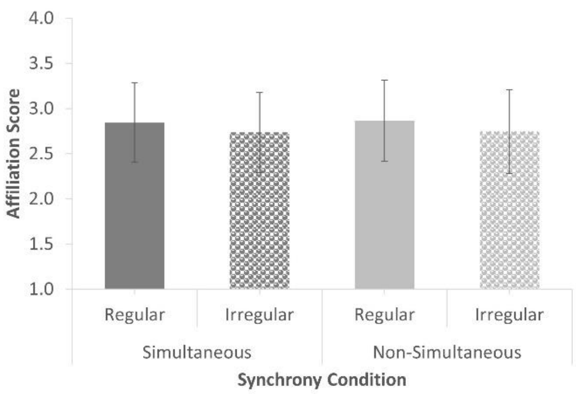
The effects of simultaneity and regularity on boys' and girls' affiliation judgements were therefore explored separately. For **boys** (**Figure 3.5(a)**), there was a main effect of regularity on affiliation score, F (1,101) = 4.51, p = .04, η_p^2 = .04, with regular tapping (*m* = 2.85; *s.d* =

0.81) attracting significantly higher affiliation scores than irregular tapping (*m* = 2.74; *s.d.* = 0.76). For **girls** (**Figure 5(b)**), a two-way repeated measures ANOVA disclosed a main effect of simultaneity on affiliation score, F (1,35) = 4.80, $p = .04$, $\eta_p^2 = .12$, with simultaneous tapping (*m* = 2.86; *s.d.* = 0.63) attracting significantly higher affiliation scores than non-simultaneous tapping (*m* = 2.64; *s.d.* = 0.67). No other main effects or interactions were significant for either gender.

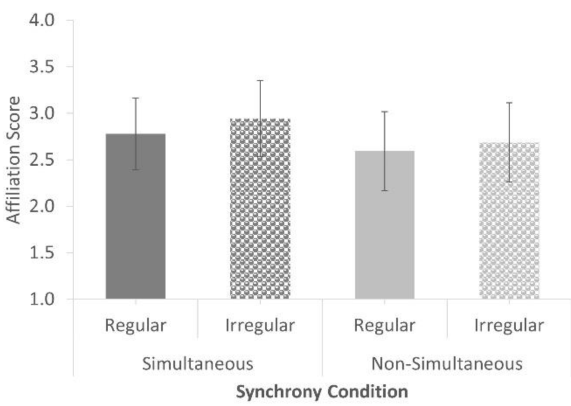
Figure 3.5

Affiliation scores for each combination of simultaneity and regularity, by gender

(a) Boys



(b) Girls



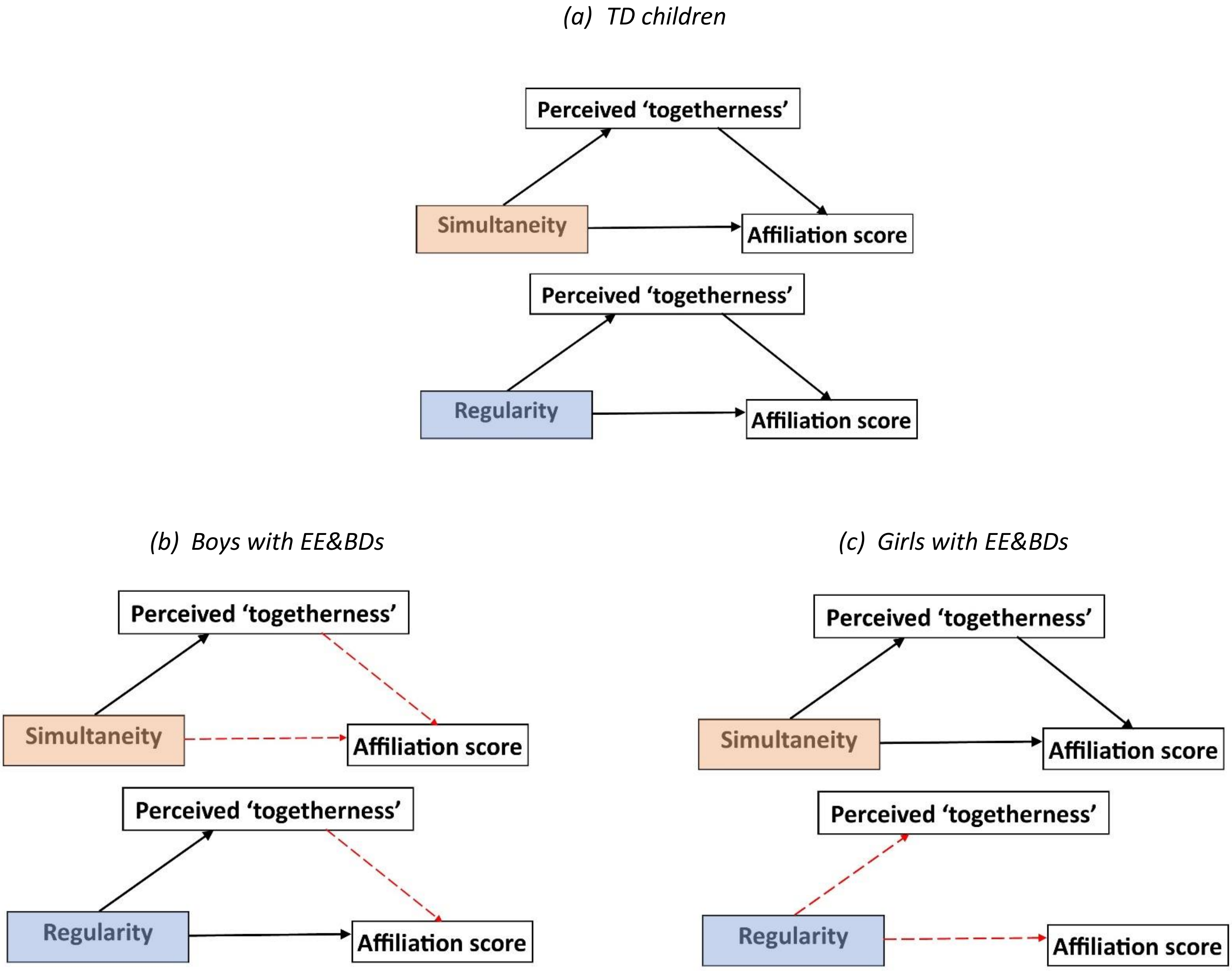
Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

Gender and perceived togetherness. To assess gender differences in the effects of simultaneity and regularity on perceived togetherness, two separate GLMMs (one for boys and one for girls) were constructed with simultaneity, regularity and a simultaneity x regularity interaction term as dummy-coded binary predictor variables and perceived togetherness as the binary outcome variable. For **boys**, simultaneity ($\beta = 0.77$, $t = 3.47$, $p < .001$) and regularity ($\beta = 0.72$, $t = 3.26$, $p < .001$) each had a significant positive effect on the likelihood of perceiving tapping as 'together'. For **girls**, only simultaneity had a significant positive effect on the likelihood of perceiving tapping as together (β = 1.37, t = 3.48, p < .001). No other main effects or interactions were significant in boys or in girls.

Finally, gender differences in the relation between perceived togetherness and affiliation scores were explored with two separate GLMMs, in which perceived 'togetherness' was a single dummy-coded binary predictor variable and affiliation score was the outcome variable. In **boys**, perceived 'togetherness' did not significantly predict affiliation score (β = 0.13, t = 0.67, p = .50), but in **girls**, tapping perceived as 'together' predicted significantly higher affiliation scores than tapping perceived as 'not together' (β = 0.43, t = 3.17, p = .002). The relations between simultaneity/regularity, perceived togetherness and affiliation in TD children (as reported in Chapter 2), boys with EE&BDs and girls with EE&BDs (as reported in the current chapter) are summarised in **Figure 3.6**.

Figure 3.6

Witnessed IS: relations between simultaneity/regularity, togetherness and affiliation in typically developing (TD) children (Chapter 2) and boys and girls with emerging emotional and behavioural difficulties (EE&BDs) (current chapter)



Note. Solid black arrows denote significant pathway; dotted red arrows denote non-significant pathway. NB for girls with EE&BDs, (c), no relation between perceived togetherness and affiliation score is shown for regularity as regularity was unrelated both to perceived togetherness and to affiliation.

3.3.2.5 Effect of age

Overall sensitivity to synchrony, represented by each participant's difference score, was not significantly associated with age in boys, $r(101) = -.01$, $p = .90$, in girls, $r(35) = -.02$, $p = .86$, or in the sample as a whole, $r(136) = -.14$, $p = .44$.

3.3.2.6 Relations with total difficulties and diagnostic traits

Parent report measures of total difficulties and diagnostic traits were not significantly associated with sensitivity to IS (as quantified by participants' difference scores), in either gender (**Table 3.2**).

Table 3.2

Witnessed IS: association between parent report measures and sensitivity to IS

		r_s *(p)*		
Measure	**Subscale**	**Boys**	**Girls**	**Total**
	N	*100*	*35*	*135*
SDQ	Emotional	–0.14 *(.16)*	–0.09 *(.62)*	–0.12 *(.16)*
	Conduct	0.13 *(.21)*	0.05 *(.75)*	0.10 *(.24)*
	Hyperactivity	0.06 *(.58)*	0.25 *(.15)*	0.11 *(.22)*
	Peer	0.05 *(.60)*	0.13 *(.44)*	0.07 *(.40)*
	Prosocial	–0.05 *(.63)*	–0.04 *(.82)*	–0.04 *(.66)*
	Total Difficulties	**0.06 *(.58)***	**0.07 *(.68)***	**0.06 *(.49)***
	N	*91*	*30*	*121*
AQ-Child	Social Skills	0.07 *(.53)*	0.20 *(.30)*	0.09 *(.30)*
	Attention Switching	–0.08 *(.48)*	0.06 *(.75)*	–0.05 *(.58)*
	Attention to Detail	–0.11 *(.28)*	0.15 *(.42)*	–0.06 *(.51)*
	Communication	0.04 *(.72)*	0.11 *(.55)*	0.06 *(.51)*
	Imagination	0.09 *(.40)*	0.17 *(.38)*	0.12 *(.19)*
	Total	**-0.02 *(.87)***	**0.21 *(.27)***	**0.04 *(.66)***
	N	*98*	*33*	*131*
DAWBA (AAS)	Inattention	0.04 *(.70)*	0.17 *(.38)*	0.07 *(.43)*
	Hyperactivity/Impulsivity	0.12 *(.25)*	0.21 *(.27)*	0.14 *(.11)*
	Total	**0.08 *(.43)***	**0.14 *(.34)***	**0.10 *(.27)***

Note. Sensitivity to IS quantified using difference scores on Witnessed IS task (affiliation score for fully synchronous tapping minus affiliation scores for fully asynchronous tapping).

Finally, there were no significant interactions between simultaneity/regularity and any of the questionnaire measures in predicting affiliation scores, indicating that the relations between simultaneity and affiliation score (**Table 3.3**) and between regularity and affiliation score (**Table 3.4**) were not moderated by total levels of emotional and behavioural difficulties, or by autistic or ADHD traits.

Table 3.3

Witnessed IS: co-efficients for GLMM exploring moderating effects of parent-reported difficulties/diagnostic traits on the relation between simultaneity and affiliation score, by gender

Domain	Term	β		
		Boys	Girls	Total
	N	100	35	135
Total Difficulties	Constant	2.55***	3.15***	3.03***
	Simultaneity	-0.21	-0.03	-0.14
	SDQ(Total Difficulties)	0.004	-0.02	-1.35
	Simultaneity x SDQ(Total Difficulties)	0.02	0.001	0.01
	N	91	30	121
Autistic Traits	Constant	2.86***	2.47***	2.56***
	Simultaneity	-0.46	0.08	-0.05
	AQ-Child(Total)	-0.003	0.004	0.003
	Simultaneity x AQ-Child(Total)	0.009	-0.001	0.001
	N	98	33	131
ADHD Traits	Constant	2.76***	2.86***	2.83***
	Simultaneity	-0.143	-0.13	-0.014
	DAWBA-AAS(Total)	-0.004	-0.003	-0.003
	Simultaneity x DAWBA-AAS(Total)	0.02	0.01	0.008

*** *p* < .001.

Table 3.4

Witnessed IS: co-efficients for GLMM exploring moderating effects of parent-reported difficulties/diagnostic traits on the relation between regularity and affiliation score, by gender

Domain	Term	β		
		Boys	**Girls**	**Total**
	N	100	35	135
Total Difficulties	Constant	2.39***	3.14***	2.92***
	Regularity	0.11	-0.01	0.09
	SDQ(Total Difficulties)	0.02	-0.02	-0.01
	Regularity x SDQ (Total Difficulties)	-0.01	0.01	-0.002
	N	91	30	121
Autistic Traits	Constant	2.61***	2.44***	2.49***
	Regularity	0.06	0.12	0.08
	AQ-Child(Total)	0.002	0.004	0.003
	Regularity x AQ-Child(Total)	-0.003	0.000	0.000
	N	98	33	131
ADHD Traits	Constant	2.67***	2.80***	2.75***
	Regularity	0.05	-0.01	0.02
	DAWBA-AAS(Total)	0.01	-0.003	0.000
	Regularity x DAWBA-AAS(Total)	-0.001	0.01	0.002

*** $p < .001$.

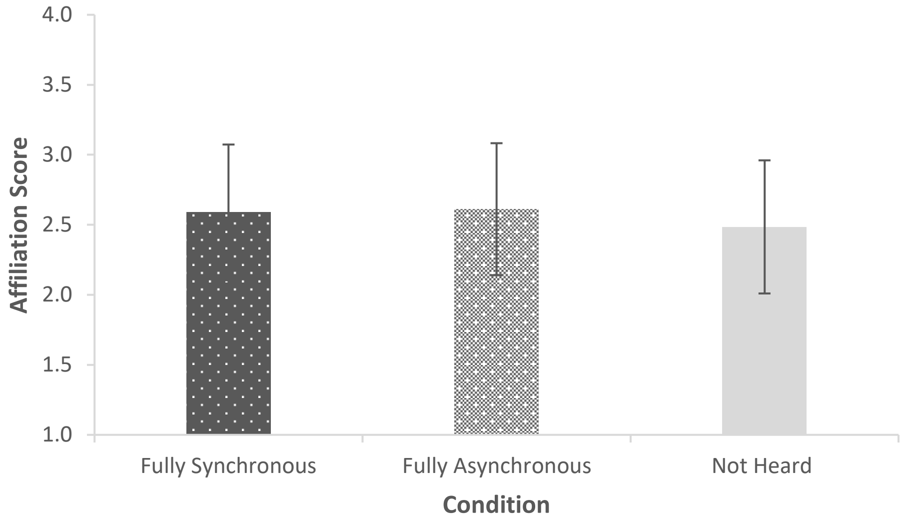
3.3.3 Experienced IS

3.3.3.1 Effect of fully synchronous tapping on affiliation scores

A one-way repeated measures ANOVA found no significant differences in affiliation scores across the three conditions in which: (i) partners tapped simultaneously with participants; (ii) partners tapping was fully asynchronous, i.e. neither simultaneous nor at a regular intervals from that of the participant; and (iii) partners' taps were not heard $F(2, 298) = 2.111$, $p = .13$, $\eta^2 = .01$) (**Figure 3.7**).

Figure 3.7

Experienced IS: effect of fully synchronous tapping on affiliation scores



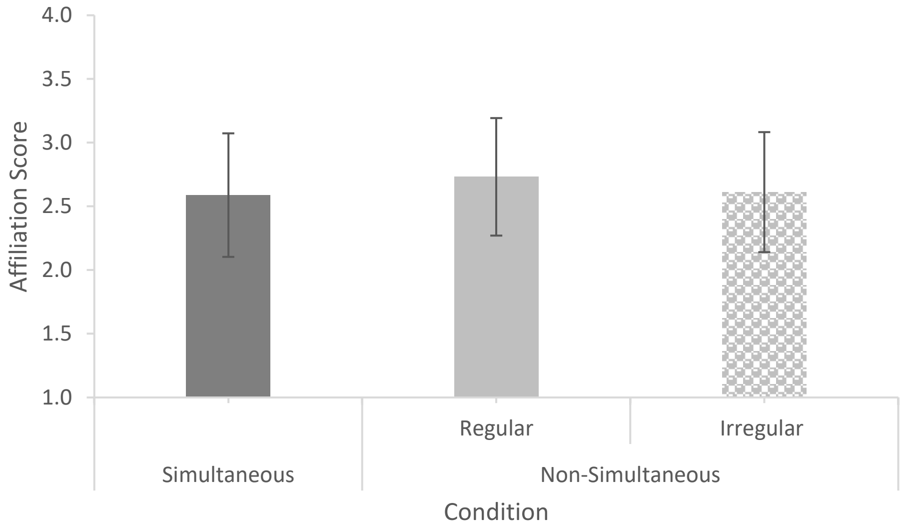
Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

3.3.3.2 The separable effects of simultaneity and regularity on affiliation scores

A further one-way repeated measures ANOVA explored the effect of simultaneity and regularity by comparing affiliation scores where: 1) partners tapped simultaneously; 2) partners' tapping was non-simultaneous but regular (i.e. at a fixed latency), and 3) partners' tapping was non-simultaneous and irregular (i.e. at a variable latency). The difference between conditions was close to significance, $F(2, 298) = 2.80$, $p = .06$, $\eta^2 = .02$ (**Figure 3.8**). Post-hoc analysis was carried out to explore which comparisons were driving the near-significant result. Affiliation scores were higher when partner tapping was non-simultaneous but regular (M = 2.73), relative to when tapping was simultaneous (M = 2.59), and relative to when tapping was at a variable latency (M = 2.61), but neither difference was significant (p = 0.10 and p = 0.17 respectively).

Figure 3.8

Experienced IS: mean affiliation scores for each combination of simultaneity and regularity



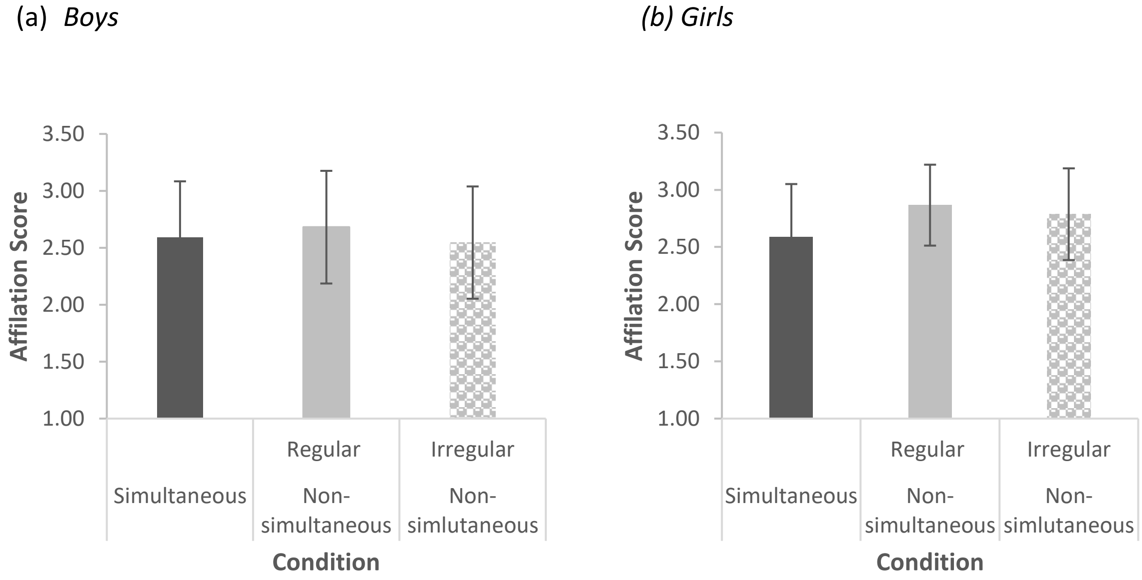
Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Simultaneous = partners' tapping was simultaneous; Non-Simultaneous Regular = partners tapped with fixed latency; Non-Simultaneous Irregular = partners tapped with variable latency. Error bars indicate standard deviation.

3.3.3.3 Effect of gender

A mixed ANOVA with gender as a between subjects factor and each of the three experimental conditions above as within subjects factors disclosed no significant interaction between the experimental conditions and gender F(2, 296) = 1.55, *p* = .21, η^2 = .01 (**Figure 3.9**). However, when gender was included as a between-subjects factor, there *were* significant differences across experimental conditions F(2, 296) = 3.296, *p* = .04, η^2 = .02. Post hoc analysis revealed that, when gender was included as a between-subjects variable, affiliation scores were significantly higher when partners' tapping was non-simultaneous and regular, compared with when partners' tapping was simultaneous (*p* = .04). No other paired comparisons were significant.

Figure 3.9

Experienced IS: mean affiliation scores across conditions, by gender



Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Simultaneous = partners' tapping was simultaneous; Non-Simultaneous Regular = partners tapped with fixed latency; Non-Simultaneous Irregular = partners tapped with variable latency. Error bars indicate standard deviation.

3.3.3.4 Effect of age

Sensitivity to synchrony, represented by each participant's difference score, was not associated with age, $r(150) = -.024$, $p = .775$.

3.3.3.5 Relations with total difficulties and diagnostic traits

Parent-reported difficulties and diagnostic traits were not significantly associated with sensitivity to IS (as quantified by participants' difference scores), in either gender (**Table 3.5**).

Table 3.5

Experienced IS: association between parent report measures and sensitivity to IS

Measure	Subscale	r_s *(p)* Boys	Girls	Total
	N	***108***	***41***	***149***
SDQ	Emotional	0.13 *(.18)*	0.02 *(.90)*	0.09 *(.30)*
	Conduct	–0.03 *(.77)*	–0.04 *(.79)*	–0.05 *(.52)*
	Hyperactivity	0.08 *(.43)*	0.16 *(.33)*	0.10 *(.26)*
	Peer	–0.02 *(.86)*	0.16 *(.32)*	0.02 *(.80)*
	Prosocial	–0.07 *(.48)*	0.20 *(.20)*	0.01 *(.93)*
	Total Difficulties	0.07 *(.50)*	**0**.10 *(.54)*	0.05 *(.52)*
	N	***97***	***37***	***134***
AQ-Child	Social Skills	–0.10 *(.31)*	–0.01 *(.96)*	–0.07 *(.42)*
	Attention Switching	–0.16 *(.13)*	0.05 *(.78)*	–0.08 *(.33)*
	Attention to Detail	–0.04 *(.68)*	–0.02 *(.90)*	–0.002 *(.98)*
	Communication	–0.03 *(.74)*	0.17 *(.30)*	0.02 *(.79)*
	Imagination	–0.17 *(.10)*	0.12 *(.47)*	–0.08 *(.38)*
	Total	-0.14 *(.16)*	0.10 *(.54)*	–0.06 *(.49)*
	N	***91***	***30***	***121***
DAWBA (AAS)	Inattention	0.15 *(.17)*	0.15 *(.42)*	0.15 *(.10)*
	Hyperactivity/Impulsivity	0.17 *(.12)*	0.18 *(.35)*	0.17 *(.06)*
	Total	0.16 *(.12)*	0.17 *(.37)*	0.17 *(.07)*

Note. Sensitivity to IS quantified using difference scores on Experienced IS task (affiliation score for fully synchronous tapping minus affiliation scores for fully asynchronous tapping).

3.3.4 Association between affiliation judgements following witnessed and experienced IS

There was no significant association between difference scores for witnessed and experienced synchrony, $r(126) = –.10$, $p = .28$.

3.4 Discussion

In Chapter 2 I established that, for witnessed interactions, both simultaneity and temporal regularity led TD children to perceive increased partner affiliation. The relations between simultaneity/regularity and affiliation were mediated by perceptions of partner 'togetherness'. By contrast, for experienced interactions, IS did not influence TD children's perceived affiliation towards their partner. The current chapter explored whether equivalent affiliative effects would be observed in children with EE&BDs, and whether sensitivity to the affiliative effects of IS was dimensionally related to children's level of difficulties and/or diagnostic traits. Importantly, the data were collected in person with an experimenter present, potentially enhancing the opportunity for finding affiliative effects compared to the online testing environment used in Chapter 1.

In the sample of children with EE&BDs as a whole, there was no significant direct relationship between witnessed IS and perceived affiliation. However, effects differed by gender, with affiliation judgements being positively influenced by regularity in boys and by simultaneity in girls, but not vice versa. For experienced IS, a near significant finding meant that the evidence of an effect of regularity on affiliation was ambiguous, but there was some indication that the regularity of partner tapping led to increased feelings of affiliation towards them. Both when witnessing and experiencing IS, children's social sensitivity to IS was unrelated to their levels of difficulties, autistic traits, or ADHD traits. Overall, although direct comparison was not possible, the effects of IS appear to be attenuated in children with EE&BDs, relative to the TD children assessed in Chapter 2, but it remains unclear what accounts for these differences.

3.4.1 Witnessed IS

3.4.1.1 No direct relation between witnessed IS and perceived affiliation

This was the first study to investigate the affiliative effects of IS in children with EE&BDs. In the sample as a whole, there was no direct relation between IS and perceptions of affiliation between interacting partners. This result contrasts with the findings from Chapter 2, in which IS had medium to large effects on TD children's affiliation judgments, as well as previous findings that TD infants (Cirelli et al., 2018; Fawcett & Tunçgenç, 2017) and children (Abraham et al., 2022) judge synchronous interactors as higher in affiliation than those who interacted asynchronously. Although direct comparison is required in future studies, the lack of an effect in the present sample supports a conclusion that children with EE&BDs are relatively insensitive to IS when judging affiliation between interacting partners.

3.4.1.2 Effects of witnessed IS attenuated but not absent

Nevertheless, participants did make some relevant social judgements based on the stimuli presented. First, they rated partners whose interactions they heard (regardless of IS) as significantly higher in affiliation than those whose interactions they did not hear. This suggests that the very fact of the interaction conveyed to participants a sense of affiliation between interacting partners. In Chapter 2 a comparable effect was found in TD children. Similarly, in other studies with TD child samples, the fact that an interaction took place (irrespective of its temporal properties) led to increased levels of partner closeness (Rabinowitch et al., 2015) and prosocial behaviour such as increased sharing (Rabinowitch & Meltzoff, 2017a), relative to a baseline condition in which no interaction took place. Overall, then, when the manipulation was particularly salient (i.e. the occurrence or non-occurrence of an interaction), children with EE&BDs responded similarly to TD children. They displayed reduced sensitivity only when the manipulation of the social cue was more subtle (i.e. the presence or absence of IS *within* an interaction).

Second, at a whole sample level, the temporal properties of the interaction influenced perceptions of togetherness, and partners perceived as together were also perceived as significantly higher in affiliation. The fact that there was nevertheless no direct link in the sample as a whole between objective levels of IS on the one hand and perceived affiliation on the other may be attributable to gender differences in effects, which are discussed further below.

3.4.1.3 Gender differences in sensitivity to witnessed IS

In contrast to the findings in TD children (Chapter 2), there were gender differences in the effects of IS on the affiliation judgements of the present sample. Boys with EE&BDs rated partners in regular interactions as higher in affiliation than those in irregular interactions, but simultaneity had no effect on their perception of affiliation. For girls with EE&BDs, the opposite pattern was observed: simultaneity led to significantly higher affiliation ratings, but regularity did not.

In TD children, perceived 'togetherness' moderated the link between both simultaneity and regularity and affiliation (Chapter 2). The equivalent relations differed in boys and girls with EE&BDs. Both simultaneity and regularity positively influenced boys' perceptions of partner togetherness, but there was no relation between perceived togetherness and perceived affiliation. For girls, simultaneity positively influenced perceptions of partner 'togetherness', which in turn positively influenced perceived affiliation. By contrast, regularity did not influence girls' perceptions of partner togetherness or partner affiliation.

Overall, in children with EE&BDs, boys' perceptions of affiliation were positively influenced by regularity, but not because such partners were perceived as acting 'together', and simultaneity had no affiliative effect. For girls, simultaneity positively influenced perceptions of partner 'togetherness', which in turn positively influenced perceived affiliation. By contrast, regularity did not influence girls' perceptions of partner togetherness or partner affiliation. Thus, the effect of simultaneity in girls with EE&BDs was comparable to the effects in TD children. In contrast to TD children, however, girls' perceptions of affiliation were not significantly affected by regularity. However, the findings in relation to girls must be interpreted with caution. The relatively small number of girls in the sample (*n*=35) may have been underpowered to detect relevant effects, particularly given other sources of heterogeneity within the sample (e.g. the type and severity of difficulties that prompted their referral).

The data were inconclusive as to whether one gender was more sensitive to IS as a social cue than the other. Both girls and boys in the sample displayed partial, albeit different, responses to simultaneity and regularity, suggesting sensitivity to IS as a social cue was reduced but not absent in both groups. Notably, the girls in the present sample were reported as experiencing significantly higher levels of emotional and behavioural difficulties than the boys. In the present study, controlling for differences in levels of EE&BDs in the analysis of gender effects was not feasible because of the relatively small number of girls in the sample. As described in Chapter 1, previous research has found higher levels of IS in females than males, in both neurotypical (Cheng et al., 2017; Fujiwara et al., 2019) and autistic (Paolizzi et al., 2022) samples, as well as some evidence of greater sensitivity to IS as a social cue in neurotypical females (Tschacher et al., 2014; Fujiwara et al., 2019; although cf. Kirschner and Tomasello 2010; Cacioppo et al., 2014 and Chapter 2). Thus, in a gender-balanced sample, matched for levels of emotional and behavioural difficulties, it is possible that girls would display *greater* sensitivity to IS as a social cue than boys. Overall, while the data hinted at the possibility of gender differences, further research is required to understand the relation between gender and sensitivity to IS as a social cue in children with EE&BDs, and in particular whether gender may be a protective factor for females.

3.4.2 Experienced IS

In TD children (Chapter 2), the Experienced IS task elicited no affiliative effects, likely because of limitations in the task design and/or administration. The results in the current study were partially consistent with this finding: in the sample as a whole, the temporal relations between participants' and partners' tapping did not significantly influence participants' feelings of affiliation towards their partner. However, unlike in Chapter 2, affiliation ratings were higher when partner tapping was non-simultaneous and regular, relative to other conditions. This difference was close to significance in the sample as a whole, and significant when gender was entered into the analysis. Thus, there is some limited evidence that children with EE&BDs felt increased affiliation towards a partner as a result of the timing of partner's behaviour. The fact that (limited) effects were observed in the current sample but not in the TD sample (Chapter 2) is contrary to the hypothesis that the effects would be reduced in children with EE&BDs, relative to TD children. However, as previously discussed, the in-person format of the task in the current study may have positively influenced the capacity of the tasks to produce affiliative effects. For example, participants' attention and task compliance could be more closely monitored in a lab setting than online, and in-person participation may have made the premise of the Experienced IS task more believable. The sample size in the present study was also substantially larger (N =

150 *vs* N = 68). Alternatively, or additionally, it may be that the socially lean nature of the stimuli had differing effects in the two samples. For example, the presence of minimal social information may have led to a reduced feeling of partner presence for TD children (see Chapter 2), but have made processing social information easier for children with EE&BDs. However, these explanations are necessarily speculative. Future research exploring variation in the social effects of IS across typical and atypical development should aim to examine effects using both socially lean and naturalistic interactions.

3.4.3 Relations between difficulties/diagnostic traits and sensitivity to IS

This was the first study to examine whether emotional and behavioural difficulties and/or diagnostic traits were dimensionally associated with social sensitivity to IS. Previous studies have found a dimensional relation between increasing levels of autistic traits and the incidence of IS in interactions, in both child and adult samples drawn from diagnostic groups and the general population (Brezis et al., 2017; Cheng et al., 2017; Fitzpatrick et al., 2017a; Romero et al., 2018; Zampella et al., 2020; Granner-Schuman et al., 2021; although cf. Kaur et al, 2018). Similarly, symptoms of inattention a population-based child sample were associated with reduced levels of IS (Khalil et al., 2013). In relation to social sensitivity to IS, two previous studies adopting a categorical approach found that the influence of IS on social judgements was reduced or absent in autistic adults, relative to non-autistic comparators (Au & Lo, 2020; Koehne, Hatri, et al., 2016). Thus, total difficulties and diagnostic traits were expected to be dimensionally related to social sensitivity to IS. Contrary to this hypothesis, however, this study found no evidence of a relation between sensitivity to IS as a social cue and parent-reported levels of difficulties; autistic traits; or ADHD traits.

Although this study found no relation between children's sensitivity to IS as a social cue and their behavioural characteristics, the possibility that such a link exists cannot be ruled out based on this study alone. For example, the current study used a simple and brief measure of affiliation between partners (two questions on a four-point Likert scale). Although this approach was necessary to ensure accessibility for children with EE&BDs, a more precise measure individuals' sensitivity to IS as a social cue might be needed to detect a relation with diagnostic traits. For example, adult participants would be able to attend to longer and/or a larger number of partner interactions, and to respond meaningfully to extended questionnaires measuring affiliation (see e.g. Tarr et al., 2016; Lang et al., 2017), giving rise to greater internal reliability and dimensionality in the measurement of affiliative effects.

A further consideration is that there are multiple symptom profiles that may meet the criteria for the same condition, and heterogeneous clusters of traits may give rise to comparable scores on instruments designed to measure symptom 'severity' (see discussion in Chapter 1, section 1.7). As such, trait-based measures such as the ones used in the present study may be insufficiently sensitive to variation in the processes giving rise to variation in sensitivity to IS. Variation in social sensitivity to IS may be more closely related to atypical functioning that is not directly captured in measures of diagnostic traits (e.g. in perception or motor abilities: see Chapter 1, section 1.6.2). Therefore, in line with the RDoC approach outlined in Chapter 1, it may be more useful to investigate how children's skills within the component processes of IS map on their sensitivity to IS when making social judgements. This will be the approach taken to understanding variation in sensitivity to IS as a social cue in Chapter 5.

3.4.4 Theoretical and practical implications

In contrast to the medium to large effect of IS on affiliation in TD children (Chapter 2), the effects of IS on affiliation were attenuated in children with EE&BDs. The relative dissociation between IS and affiliation in children with EE&BDs is likely to have implications for their social functioning. First, as previously observed in samples with neurodivergent diagnoses, it may lead them to display reduced levels of IS in interactions. In TD individuals, the desire to form social connections with others is believed to motivate partners to synchronise with each other (Hoehl et al., 2021; Lumsden et al., 2014). The reduced social significance of IS in children with EE&BDs is thus likely to precipitate a reduced motivation to synchronise, and therefore a reduced incidence of IS. In turn, TD social partners of such children are less likely to feel bonded towards them. Second, IS is less likely to act as a 'social glue' (Lakin et al., 2003; Vicaria & Dickens, 2016) for children with EE&BDs; even when they do enter into IS with others, they are less likely to feel bonded to their social partner as a result. This has clear implications for interventions which seek to increase levels of IS in atypically developing children, as a means of enhancing their social skills (e.g. Landa et al., 2011; Srinivasan et al., 2015; Koehne et al, 2016; Yoo & Kim, 2018; Daniel et al., 2022). Even if such interventions are effective at increasing levels of IS, they may be much less effective at increasing the extent to which intervention recipients subsequently feel bonded to others. Lastly, the limited relevance of IS to affiliation in children with EE&BDs underscores the need to identify mechanisms that *do* promote the formation of social bonds in atypical populations, and for a better understanding of atypical patterns of social relating in general (Crompton et al, 2020; Heasman & Gillespie, 2019).

3.4.5 Conclusion

This was the first study to investigate the social effects of IS in children with EE&BDs. Relative to TD children (Chapter 2), the findings in the present study suggest that IS is of reduced relevance as a social cue to children with EE&BDs. These findings further our understanding of how IS is experienced differently by atypically developing children. However, the factors that may explain, or protect against, reduced social sensitivity to IS remain unclear. The current study found no evidence of a dimensional association between sensitivity to IS and levels of emotional and behavioural difficulties or autistic/ADHD traits. An approach that targets specific underlying processes may be more fruitful to understand variation in children's social sensitivity to IS. To this end, Chapters 4 and 5 will explore synchrony perception and motor synchrony, and Chapter 5 will explore the relations between these abilities with their sensitivity to IS as a social cue.

Chapter 4

Perceptual and Motor Synchrony in Children with Emotional and Behavioural Difficulties

4.1 Introduction

Children with EE&BDs displayed reduced sensitivity to IS when judging partner affiliation (Chapter 3). However, levels of social sensitivity to IS were not related to levels of emotional and behavioural difficulties, autistic traits or ADHD traits. Looking beyond trait-based characteristics, a different approach to explaining variation in social sensitivity to IS is to examine variation in the component processes that likely contribute to the salience of IS as a social cue. In particular, children's temporal perception (Lakens, 2010; Novotny & Bente, 2022) and motor timing (Georgescu et al., 2020; Trainor & Cirelli, 2015) likely play a role in their experience of IS, and therefore in its social relevance. As disruptions in perceptual and motor timing are common in neurodivergent populations (Chapter 1, section 1.6.2), difficulties in either or both of these domains may, in part, underpin and explain reduced sensitivity to IS as a social cue in children with EE&BDs.

However, as described in Chapter 1, the nature and extent of differences in perceiving or producing synchrony in neurodivergent populations is unclear. Findings often vary depending on which particular abilities are assessed and how they are measured. In the perceptual domain, findings differ depending on the type of task used (e.g. SJ vs ToJ tasks) (Panagiotidi et al., 2017; Van Eijk et al., 2008); stimulus modality (multi- or uni-sensory; visual or auditory) (Falter et al., 2012; Meilleur et al., 2020); whether adult (Stevenson et al., 2014) or child samples (Kwakye et al., 2011) are used; whether stimuli are non-social (e.g.

flashes; beeps) or social (e.g. speech) in nature (Bebko et al., 2006; Foss-Feig et al., 2010; Meilleur et al., 2020; Smith et al., 2017). In the motor domain, differences are consistently observed when participants synchronise complex motor movements in a social context (Georgescu et al., 2020; Koehler et al., 2021; McNaughton & Redcay, 2020; Problovski et al., 2021) but less consistently when motor demands are reduced (Koehne, Hatri, et al., 2016), and/or they synchronise with a non-social stimulus (Amrani & Golumbic, 2020; Honisch et al., 2021; Hove et al., 2017; Morimoto et al., 2018; Puyjarinet et al., 2017; Tryfon et al., 2017; Vishne et al., 2021). Overall, the experimental confounds of multisensory and/or social stimuli mean that synchrony-specific perceptual and motor abilities in atypically developing children remain unclear.

Therefore, this chapter investigates fundamental, synchrony-specific abilities in children with EE&BDs. The first aim was to characterise their abilities to (1) detect temporal synchrony (Synchrony Perception) and (2) synchronise basic movements with an external stimulus (Motor Synchrony). Basic perceptual and motor synchrony processes were targeted because this was the first investigation into the factors contributing to social sensitivity to IS. Thus, tasks were constructed with a view to understanding the point in the perceptual/motor hierarchy such abilities become relevant to sensitivity to IS. The second aim was to examine potential trait-based correlates of these abilities. The same sample as in Chapter 3 was used (children referred to the NDAU because of EE&BDs, aged between 4 and 8 years).

Synchrony Perception and Motor Synchrony were assessed using two separate tasks, each designed to target children's synchrony-specific abilities and to exclude or minimise the influence of potentially confounding factors. In the Synchrony Perception task, uni-sensory (auditory), non-speech stimuli, embedded in a game with no social content, were used to exclude potential differences in visual orienting and processing multi-sensory and/or social stimuli (see Chapter 1, section 1.6.2). In the Motor Synchrony task, motor co-ordination demands were minimised by using a unimanual tapping task, a method well-established in the literature for assessing basic motor abilities in both typical and atypical populations (e.g. Repp, 2005; Hove et al., 2017; Tryfon et al., 2017). To exclude potential social confounds, participants synchronised with a non-social stimulus (a series of isochronous tones).

Finally, there is evidence that children's ability to synchronise their movements depends on how close the tempo of the external stimulus is to that of children's natural internal tempo, or referent period (Drake et al., 2000). Children's individual referent period is thought to be reflected in their spontaneous motor tempo (SMT), i.e. the speed they naturally adopt when tapping in the absence of any external stimulus. The evidence suggests that the range of tempos at which TD children can synchronise their tapping is initially a narrow one, centred on their SMT, with the range broadening with increasing age (Amrani & Golumbic, 2020; Drake et al., 2000; Kirschner & Tomasello, 2009; McAuley et al., 2006; Monier & Droit-Volet, 2019). Therefore, participants' SMT, and its relation with their ability to synchronise their movements, was also assessed.

Based on previous literature identifying increasing perceptual sensitivity to (a)synchrony over the course of development (Hillock-Dunn & Wallace, 2012; Lewkowicz, 1996), older children were expected to display greater perceptual acuity than younger children. Given evidence of reduced perceptual sensitivity to auditory temporal order in autistic children and adolescents (de Boer-Schellekens et al., 2013; Kwakye et al., 2011) and children with ADHD (Cardy et al., 2010; Fostick, 2017), higher levels of autistic and ADHD traits were expected to be associated with reduced perceptual sensitivity to synchrony. Similarly, motor synchrony abilities were expected to be positively associated with age (McAuley et al., 2006; Monier & Droit-Volet, 2018) and proximity of the stimulus to children's SMT (Bobin-Bègue & Provasi, 2008; Drake et al., 2000). Based on evidence of reduced motor synchrony in ADHD (Hove et al., 2017; Zelaznik et al., 2012), motor synchrony abilities were expected to be negatively associated with symptoms of inattention/hyperactivity.

4.2 Method

4.2.1 Participants

Participants were part of the NDAU sample described in Chapter 1. A total of 110 participants (85 boys; M_{age} = 6 years 8 months; *SD* = 11.6 months) completed one or both of the Synchrony Perception and Motor Synchrony tasks. Of these, 93 completed the Synchrony Perception task (67 boys; M_{age} = 6 years 8 months; *SD* = 11.5 months) and 84 completed the Motor Synchrony task (69 boys; M_{age} = 6 years 8 months; *SD* = 11.7 months). There were 66 participants who completed both tasks (52 boys; M_{age} = 6 years 8 months; *SD* = 11.4 months). There were different numbers of participants for each task because of time constraints and/or participant engagement during the testing sessions. Caregivers provided written informed consent on participants' behalf. The study was approved by the Cardiff University School of Psychology Research Ethics Committee.

4.2.2 Materials and procedure

The data were collected during the same two-day testing sessions described in Chapter 3 (see section 3.2.2).

4.2.2.1 Synchrony Perception task

Stimuli. Auditory stimuli were pairs of sounds generated with Audacity®, version 3.0.2, https://audacityteam.org/. Each pair consisted of a 'high' sound generated by a plastic beater striking a glockenspiel (G4, 392 Hz approx.) and a 'low' sound generated by a finger pressing a piano key (C3, 131 Hz approx.) (the same individual sounds as used in the Witnessed and Experienced IS tasks described in Chapter 2 and 3). Sounds of contrasting frequencies and timbres were used instead of pure tones, so that they were more easily distinguishable when presented simultaneously and/or with a small stimulus onset asynchrony (SOA).

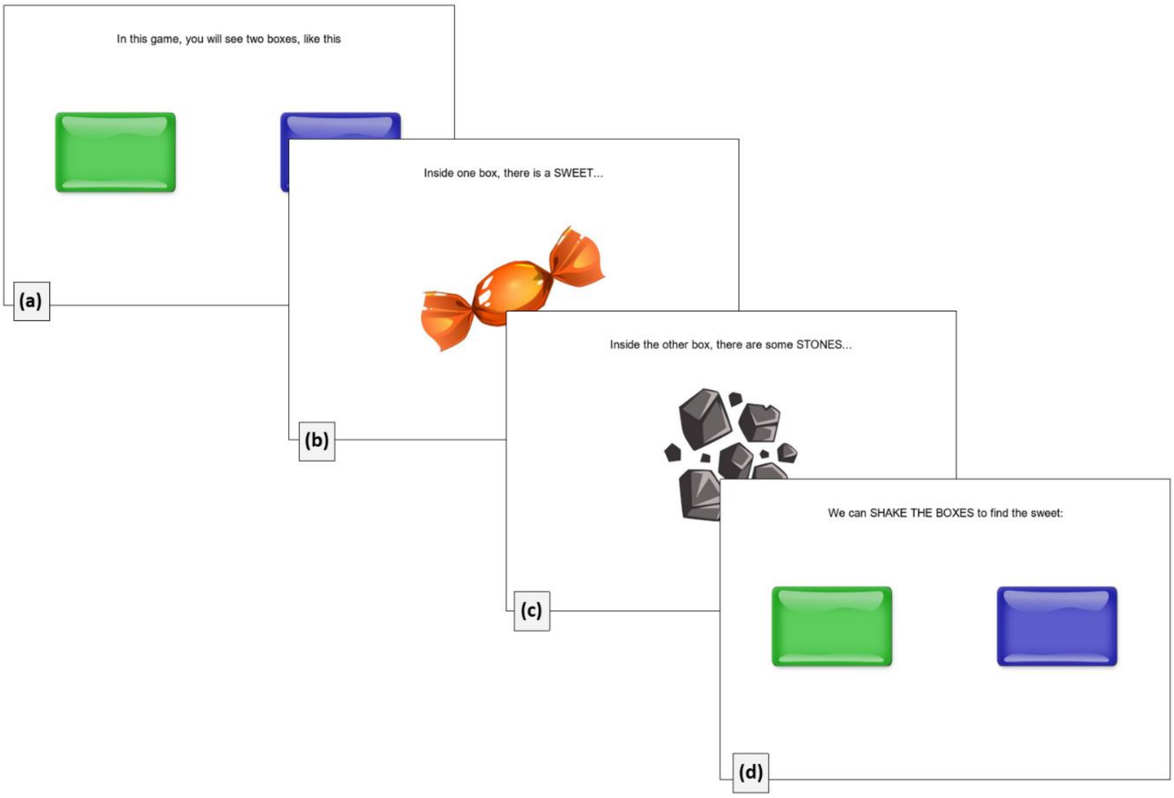
In each pair of sounds, the onset of the two sounds was either synchronous (high and low sounds presented with an SOA of 0 ms), or non-synchronous. In the non-synchronous pairs, the onset of the high sound always preceded that of the low sound, with the SOA varying across trials according to the procedure described below. The potential SOAs for each non-synchronous pair were between 30 and 300 ms in 10 ms increments. The range of SOAs was determined by reference to discrimination thresholds in previous studies in which typically and atypically developing children carried out auditory ToJ tasks (Berwanger et al., 2004; Fostick & Revah, 2018; Kwakye et al., 2011; Stevenson et al., 2018), as well as pilot sessions in which two TD 7-year-old children and a small number of NDAU participants completed the study task.

Procedure. The task was presented on a laptop computer. Stimulus presentation was controlled by custom-written MATLAB code (Version R2019a, The MathWorks, Natwick, MI, USA) code using the Psychophysics Toolbox (Version 3.0.14) (Brainard & Vision, 1997; Kleiner et al., 2007; Pelli, 1997) and the Palamedes Toolbox (Prins & Kingdom, 2018). Before the task began, an example auditory stimulus was played. The volume was pre-set at 40% of the computer's maximum volume and then adjusted as necessary so that it was comfortable for the participant. A 2-Interval-Forced-Choice (2IFC) paradigm was used to identify the threshold at which participants could reliably differentiate between synchronous and non-synchronous pairs of sounds. All task instructions were presented in writing in the middle of the screen and also read aloud by the researcher. The researcher controlled the pace of progress through the task, so that they could ensure the participant was paying attention before proceeding, and could replay key task instructions/stimuli if needed. To make the task engaging for participants, it was embedded in a 'game' in which the objective was to find as many 'sweets' as possible. The task had three phases: a demonstration phase, a practice phase, and an experimental phase.

Phase 1: demonstration phase. Two 'boxes' were shown side by side (**Figure 4.1(a)**) The green box always appeared on the left and the blue box always appeared on the right. Participants were told that one box contained a sweet (**Figure 4.1(b)**) and one contained some stones (**Figure 4.1(c)**), and that shaking the boxes would allow them to find the sweet (**Figure 4.1(d)**). Then, an image of a sweet was accompanied by the instruction: '*The box with the SWEET always sounds like this'*, following which the synchronous pair of sounds was played. Next, an image of stones was accompanied by the instruction: '*The box with the STONES always sounds different.'* No sound was played at this point, as in subsequent trials the 'stones' would be accompanied by non-synchronous pairs of sounds with varying SOAs (see below). The participant was then told: '*Remember, we want to find the box with the SWEET'* and the image of the sweet and the synchronous pair of sounds were presented again. Thus, participants could locate and 'win' sweets by identifying which box had made the synchronous pair of sounds.

Figure 4.1

Synchrony Perception task demonstration phase: introductory task screens



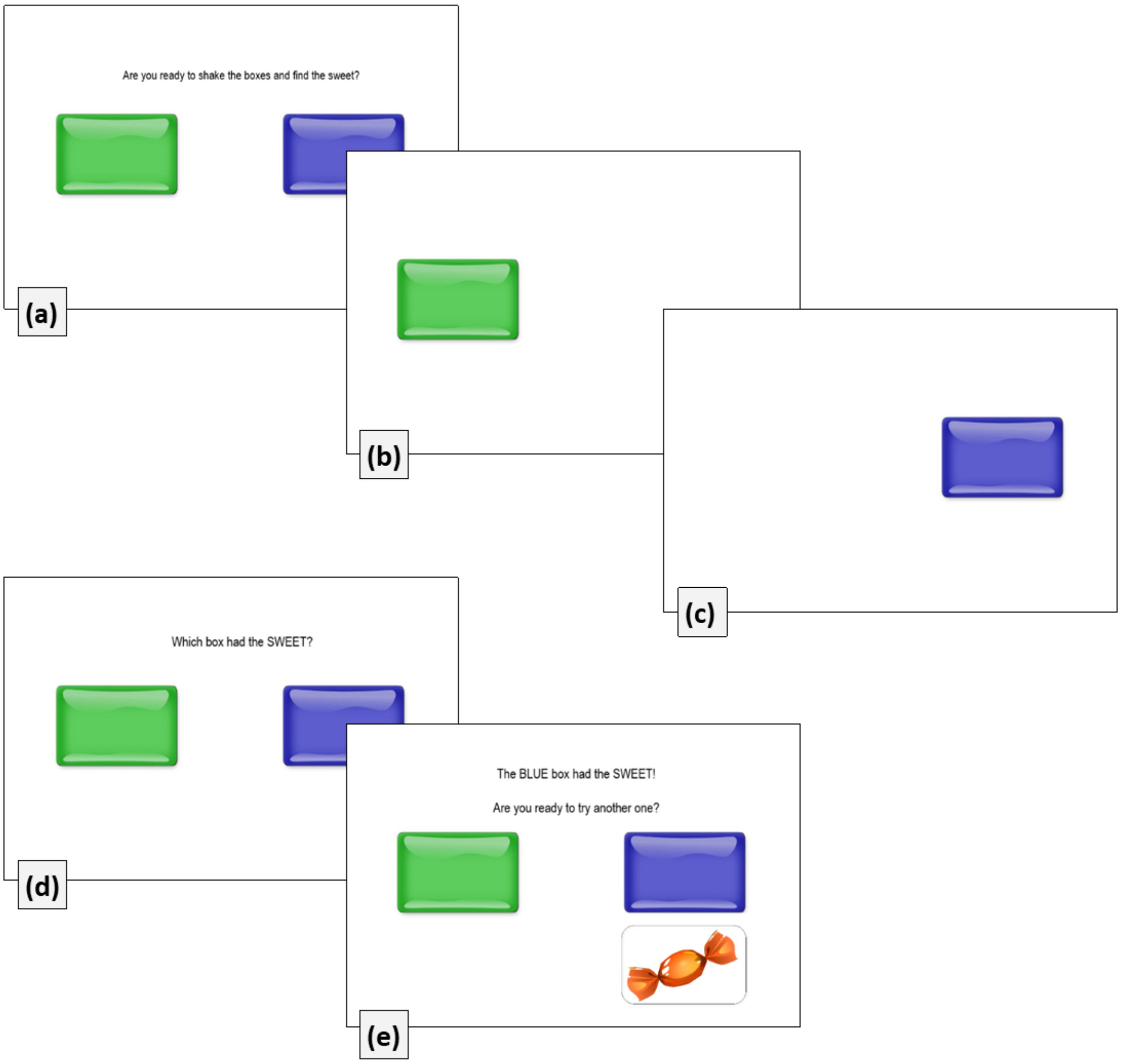
Note: the Synchrony Perception task was a 2IFC paradigm to identify the threshold at which participants could reliably differentiate between synchronous and non-synchronous pairs of sounds, embedded in a game. Two boxes were presented (a), one of which was said to contain sweets (b) and the other stones (c). The object of the game was to locate the sweet by listening to the sounds made by each box when they were shaken (d). The synchronous pair of sounds was presented as the sound made by the box containing the sweet. Thus, the participant could successfully locate the sweet by identifying which box made the synchronous pair of sounds.

Three demonstration trials followed. At the start of each trial, both boxes were visible and the participant was asked '*Are you ready to shake the boxes and find the sweet?*' (**Figure 4.2(a)**). Then, the two pairs of sounds (one synchronous and one non-synchronous) were presented sequentially, in random order. When the first pair of sounds was presented only the green box was on screen (**Figure 4.2(b)**); when the second pair of sounds was presented only the blue box was on screen (**Figure 4.3(c)**). After both pairs of sounds had been played, both boxes reappeared on screen with the instruction '*Which box had the SWEET?*' (**Figure**

4.2(d)). The participant responded either verbally or by pointing to one of the boxes on the screen. Following the participant's response, the correct box was presented on screen with a picture of a sweet below it, and identified in the feedback: '*The [BLUE/GREEN] box had the SWEET!*' (**Figure 4.2(d)**). After each demonstration trial, the participant was reminded of the sound associated with the sweet with the instruction: '*Remember, the box with the SWEET sounds like this,*' following which the image of the sweet and the synchronous pair of sounds were presented.

Figure 4.2

Synchrony Perception task: demonstration trial procedure



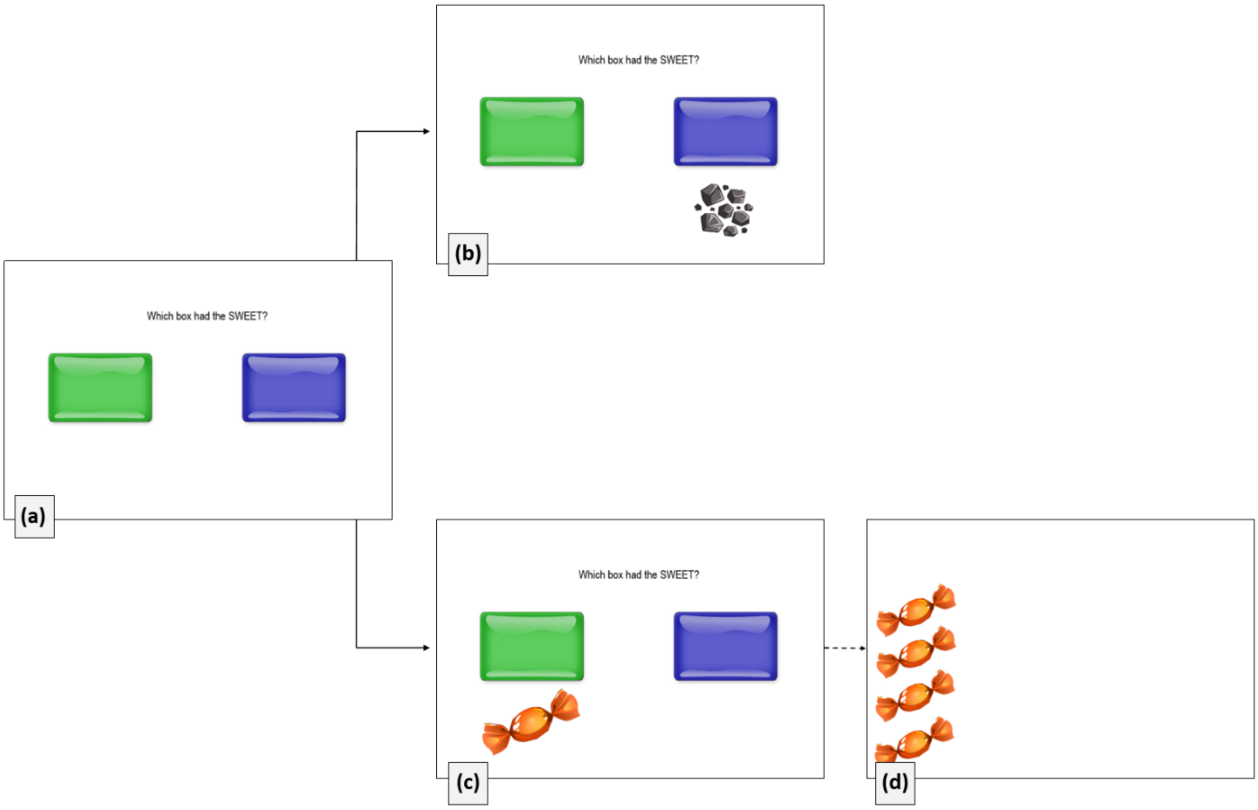
Note: two boxes are shown, one of which is said to contain sweets and the other stones. The aim in each trial was to identify the box containing a sweet (a), by differentiating between the sounds made by each box when 'shaken'. One box made a simultaneous pair of sounds (indicating it contains sweets) and the other made a non-simultaneous pair of sounds (indicating it contains stones). The location of the sweet varied randomly between the green and blue boxes. Each box was shaken sequentially: (b) and (c), after which a response was invited (d). Feedback was provided after each demonstration trial by revealing the location of the sweet (e). Each demonstration trial was also followed by a reminder of the sound made by the box with the sweet, i.e. the synchronous pair of sounds (reminder text not shown in figure).

Phase 2: practice phase. Next the participant was told: '*We are going to practice the experiment together now*.' There followed four practice trials. In each practice trial, as in the demonstration trials, the two pairs of sounds (one simultaneous and one non-simultaneous) were presented sequentially, in random order. The first pair was presented with the green box and the second with the blue box (see **Figure 4.2(a) to (c)**), then both boxes reappeared together with the instruction '*Which box had the SWEET?*' (**Figure 4.3(a)**). The participant responded either verbally or by pointing and the researcher inputted the response via the laptop keyboard. The 'true' contents of the selected box, i.e. either stones (**Figure 4.3(b)**) or a sweet (**Figure 4.3(c)**) then appeared underneath. Following the four practice trials, the participant was again reminded of the sound associated with the sweet with the instruction: '*Remember, the box with the SWEET sounds like this:*' following which the image of the sweet and the simultaneous pair of sounds were presented.

Phase 3: experimental phase. In the final phase, the participant was told: *'You are now ready to start the experiment. Try to collect as many sweets as you can.'* The experiment had a fixed number of 26 trials whose format was identical to the practice trials described above (**Figure 4.2(a)** to **(d)**; **Figure 4.3(a)** to **(c)**) in which the SOA in the non-simultaneous pair of sounds was determined according to the Psi method (described below). To maintain participants' attention and motivation, every five experimental trials were followed by a catch trial in which the SOA in the non-simultaneous pair of sounds was fixed at 400 ms. To further motivate the participant to attend the task and gain more sweets, a screen showing the number of sweets accumulated so far was displayed after each correct response (**Figure 4.3(d)**). At the end of the task, the participant was informed of the total number of sweets they had won.

Figure 4.3

Synchrony Perception task: practice/experimental trial procedure



Note: in both the practice and experimental trials, the pairs of sounds made by the green and blue boxes were presented sequentially, after which the participant was asked which box contained the sweet (a). In the above example, the synchronous pair was played first (i.e. paired with the green box). Therefore, if the blue box was chosen its contents would be revealed as stones (b), and if the green box was chosen its contents would be revealed as a sweet (c). In the experimental trials only, a correct response was followed by a screen displaying the number of sweets accumulated so far (four in the above example) (d).

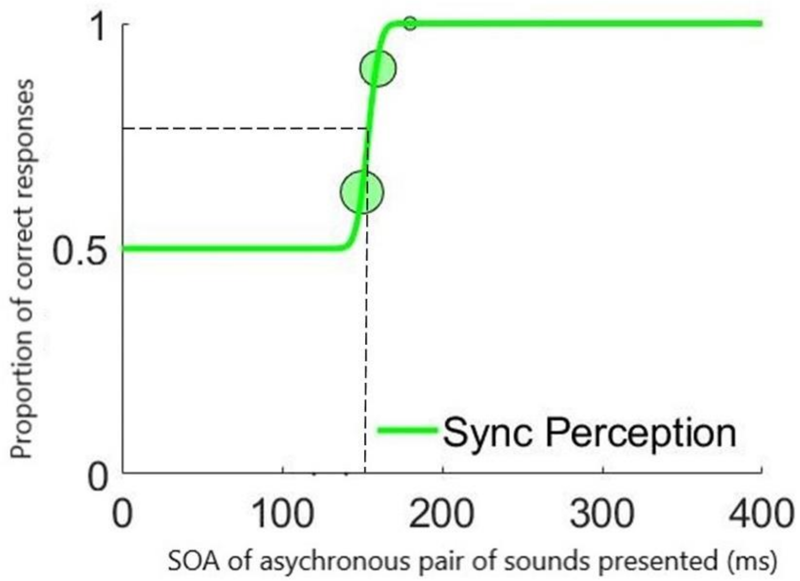
Temporal parameters. In each trial, there was a variable ISI between the presentation of the simultaneous and non-simultaneous pairs of sounds, of between 1.4 and 1.6 s. In the three demonstration trials, the SOAs in the non-simultaneous pairs of sounds were 600, 370 and 300 ms respectively. In the practice and experimental trials, the SOAs in the non-simultaneous pair of sounds were determined on a trial-by-trial basis by the Psi method (Kontsevich & Tyler, 1999). The Psi method is a Bayesian adaptive procedure which updates its estimate of the participant's likely threshold on a trial-by-trial basis, based on performance on all previous trials. Thus, broadly speaking, a correct response on one trial would lead to a decrease in the estimated threshold and thus a decrease in the SOA presented on the next trial. Similarly, an incorrect response would tend to lead to an increase in the SOA presented on the next trial.

Calculation of output variable. To calculate participants' Synchrony Perception threshold, i.e. the threshold at which they could detect whether sounds were simultaneous or not, psychometric functions (PFs) based on a Cumulative Gaussian distribution were fitted to each participant's data using the Palamedes Toolbox (Prins & Kingdom, 2018) in MATLAB, where lapse rate was fixed at 0.03 and guess rate at 0.5. Based on psychophysical methods (Kingdom & Prins, 2010), the threshold was calculated as the SOA, in ms, between sounds at which performance was at 75% correct (50% was chance performance) (**Figure 4.4**).

Data exclusions were determined by visual inspection of the PFs, i.e. instances where no psychometric function could be fit to the data points and therefore no threshold could be determined computationally from the PF.

Figure 4.4

Example of plot used to determine an individual's Synchrony Perception threshold



Note: Individual data points indicate proportion of correct responses at actual SOAs presented. Chance performance is indicated by a proportion of correct responses of 0.5. A fitted curve allowed estimation of the SOA at which the proportion of correct responses would be expected to be 0.75, i.e. the individual's Synchrony Perception threshold. In the above example, the dotted line indicates the individual participant's estimated threshold value of 154 ms.

4.2.2.2 Motor tasks

The two motor tasks, which measured Spontaneous Motor Tempo (SMT) and Motor Synchrony, were adapted from a subsection of the Beat Alignment Test (Iversen & Patel, 2008) and initially delivered via Presentation (Neurobehavioral Systems, Inc.) (*n* = 10), following correspondence with the authors and adapted from their original code. For practical reasons, they were later re-programmed in PsychoPy3 (Peirce et al., 2019) and administered via its online platform Pavlovia (pavlovia.org) (*n* = 74). The Presentation and Psychopy versions used identical task stimuli and procedure.

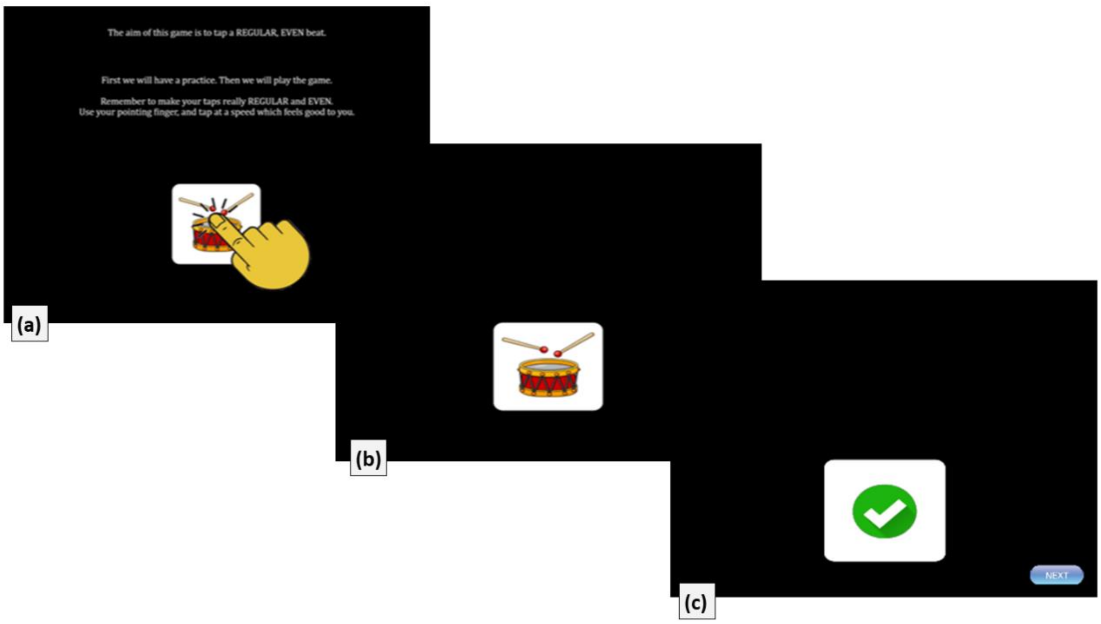
Both the SMT and Motor Synchrony tasks were tapping tasks completed on an iPad. In both tasks, participants tapped on an image of a drum displayed on the iPad screen, using the index finger of their dominant hand. Tapping did not initiate any sound other than that generated by contact between the participant's finger and the screen. All task instructions were displayed on screen and read aloud by the researcher. The researcher controlled the pace of progress through the task using a 'NEXT' button displayed at the bottom of the screen. The SMT task was completed first, so that the rate of participants' un-paced tapping was not influenced by the tempos of the isochronous stimuli presented in the Motor Synchrony task.

4.2.2.2.1 SMT task (un-paced tapping)

Task procedure. The task instructions were delivered (**Figure 4.5(a)**) then replaced on screen by an image of a drum (**Figure 4.5(b)**), on which participants tapped. There was a practice trial that ended when the researcher was satisfied that the task instruction had been understood, followed by a 20 s experimental trial. To signal the end of each trial, the image of the drum was replaced by an image of a tick (**Figure 4.5(c)**).

Figure 4.5

SMT task procedure



Note: Task instructions (a) read: '*The aim of this game is to tap a REGULAR, EVEN beat. First we will have a practice. Then we will play the game. Remember to make your taps really REGULAR and EVEN. Use your pointing finger and tap at a speed which feels good to you.'* The instructions were replaced by an image of a drum on which participants tapped (b), first in a practice trial and then in a 20 s experimental trial. In each case an image of a tick indicated that the trial had ended (c).

Calculation of SMT output variable. Based on reported SMTs in the age range of the current sample of between 300 and 456 ms (Drake et al., 2000; Fitzpatrick et al., 1996; McAuley et al., 2006; Provasi & Bobin-Bègue, 2003), inter-response intervals (IRIs) of greater than 1500 ms were assumed to represent periods during which participants paused their tapping, and were therefore excluded from analysis. The mean of all other IRIs was calculated to obtain a value representing each participant's SMT.

4.2.2.2.2 Motor Synchrony task (synchronised tapping)

Participants were required to tap synchronously with auditory stimuli that consisting of isochronous tones (440 Hz). First, an example stimulus and task instructions were presented (**Figure 4.6(a)** and **(b)**). Next, there was a practice trial in which the instructions were replaced by an image of drum (**Figure 4.6(c)**), on which the participant tapped for 15 s with a series of tones with an interstimulus interval (ISI) of 600 ms. The image of the drum was replaced by an image of a tick to signal the end of the trial (**Figure 4.6(d)**). Participants were informed that the pace of the stimulus would change (**Figure 4.6(e)**), following which there were three experimental trials (**Figure 4.6(f**)) of 15 s duration with stimulus ISIs of 350 ms, 600 ms and 850 ms presented in random order. The intertrial interval (ITI) was 1 s. An image of a tick signalled the end of experimental trials (**Figure 4.6(g)**).

Figure 4.6

Motor Synchrony task procedure

Note: The first part of the task instructions (a) read: '*Now we are going to play another tapping game! This time, you will hear some BEEPS. We want to see how well you can tap along and MATCH the beeps. Tap the speaker to hear what the beeps will sound like*.' Tapping the speaker initiated five isochronous tones of 440Hz with ISI 600 ms. This could be repeated as required. The second part of the task instructions (b) read: '*Tap along with the beeps on the drum. Keep going until you see the green tick. Are you ready?*'. A practice trial followed (c) in which participants tapped with a 15 s stimulus of 600 ms ISI. A tick signalled the end of the trial (d). A further instruction read: '*Well done! Let's have another go. This time, the beeps may get faster or slower. Always try to match the beeps EXACTLY. Keep going until you see the green tick again. Are you ready?'* (e). There were three 15 s experimental trials with ITI 1 s, in which isochronous tones with ISIs of 350, 600 and 850 ms were presented in random order. Participants again tapped on the image of the drum (f) until it was replaced by an image of a tick to signal the end of the trials (g).

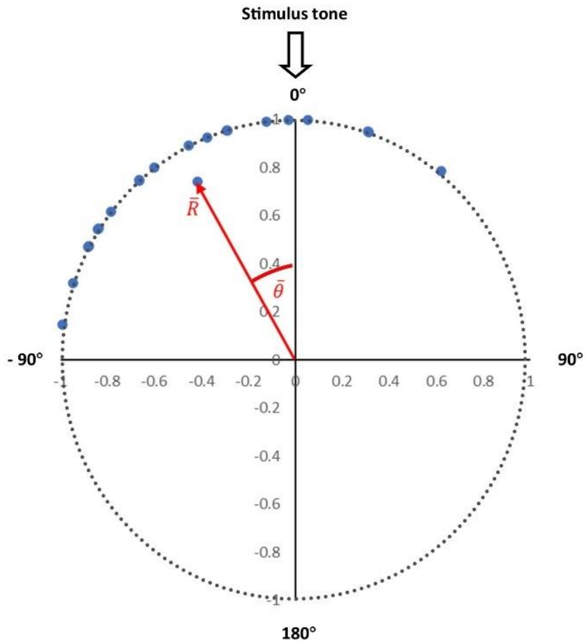
Calculation of Motor Synchrony output variables. In order to ensure participants had sufficient time to adjust their rate of tapping to the stimulus tempo (see e.g. Repp & Su, 2005;

Puyjarinet et al., 2017), response taps occurring less than 3 s after the onset of the external stimulus were disregarded. For the remaining 12 s in each trial, the extent to which participants synchronised with the external stimulus was assessed using circular statistics (Fisher, 1995; Mardia et al., 2000), an approach that has been used previously to quantify synchronisation with an external stimulus (e.g. Kirschner & Tomasello, 2009; Launay et al., 2013; Puyjarinet et al., 2017). This method is particularly appropriate when tapping is highly variable, because individual taps need not be assigned to individual stimulus tones (Kirschner & Tomasello, 2009; Pecenka & Keller, 2011). It gives rise to two variables that reflect components of synchronisation ability: (i) <u>stability of entrainment</u>, i.e. the consistency with which tapping IRI reflects the IOI provided by the stimulus tempo; (ii) <u>accuracy of entrainment</u>, i.e., mean proximity of tapping to the 'beat' provided by the stimulus tempo.

Stability and accuracy were calculated using the following steps. First, each ISI was converted to a circular scale (i.e. ranging from 0 to 360°) with each stimulus tone located at 0°. Each response tap was assigned a position on the circumference of the circle representing its angular deviation from the onset of the stimulus tone. For example, in a trial with ISI 600 ms, a tap that followed a particular stimulus tone by 150 ms would be assigned a position of 90° on the circle; a tap preceding a particular stimulus tone by 100 ms would be assigned a position of 300°. Second, the radius of the circle was assigned a value of 1 and each point on the circle was converted to Cartesian co-ordinates. To summarise tapping performance across the whole trial, the mean of all resulting *x,y* co-ordinates was used to calculate a mean vector (Fisher, 1995; Kirschner & Tomasello, 2009), with length $\bar{R}$ and direction $\bar{\theta}$ (**Figure 4.7**).

Figure 4.7

Example schematic of tapping during an individual Motor Synchrony trial



Note. The dotted circle represents the ISI of the stimulus tones, with the onset of each stimulus tone fixed at 0°. Each blue dot represents a single tap, with its angular distance from 0° representing its temporal deviation from the stimulus tone. After converting the location of each 'tap' to Cartesian co-ordinates with the radius of the circle set at 1, taps were summarised using a mean vector with length $\bar{R}$ (values between 0 and 1) and angular distance, $\bar{\theta}$. For the purposes of analysis, $\bar{\theta}$ was expressed in terms of the smallest absolute angular distance from the stimulus tone, such that values ranged between 0° and 180°. Higher $\bar{R}$ values indicate higher stability; lower $\bar{\theta}$ values indicate higher accuracy. In the above example $\bar{R}$ = 0.85; $\bar{\theta}$ = 30°.

<u>Stability of entrainment</u> was indicated by the length of the vector ($\bar{R}$). Tapping which was random in relation to the stimulus tone IOI would result in individual points uniformly distributed around the circle and thus an $\bar{R}$ of close to 0. The higher the stability of tapping in relation to the stimulus tempo, the higher the concentration of individual points at one location on the circumference of the circle, and therefore the higher the value of $\bar{R}$. Tapping that perfectly reproduced the stimulus tempo would result in all points concentrated at a single location on the circle and thus an $\bar{R}$ of 1.

Rayleigh's test (Fisher, 1995; Kirschner & Tomasello, 2009) was used to assess whether tapping was significantly entrained to the stimulus tempo. Rayleigh's test assesses the distribution of points around the circumference of the circle, with a null hypothesis of random distribution, indicating a lack of entrainment to the stimulus tempo. By contrast, where points are sufficiently concentrated in one location on the circumference of circle, such that the null hypothesis can be rejected, it can be inferred that tapping tempo was significantly influenced by – i.e. entrained to – the stimulus tempo.

<u>Accuracy of entrainment</u> was represented by the size of the angle $\bar{\theta}$, i.e. the shortest absolute angular distance from 0°: for example, a mean angular direction of 200° would be expressed as a $\bar{\theta}$ of 360 – 200 = 160°. Thus, $\bar{\theta}$ had a potential range of 0° to 180°, with a $\bar{\theta}$ of 0° indicating a mean tap simultaneous with the stimulus tones, and a $\bar{\theta}$ of 180° indicating a mean tap equidistant in time between two stimulus tones.

In summary, the extent to which participants were able to synchronise tapping with each external stimulus was represented by two components: <u>stability</u> (represented by vector length, $\bar{R}$, with higher values indicating higher stability) and <u>accuracy</u> (represented by angular distance from the 'beat' provided by the stimulus, $\bar{\theta}$, with lower values indicating higher accuracy).

Overall ability to synchronise can be thought of as a function of both accuracy and stability of entrainment, together with the range of tempos over which synchrony can be achieved. Therefore, principal components analysis (PCA) was used to combine accuracy ($\bar{\theta}$) and stability ($\bar{R}$) scores across tempos were into a single variable reflecting overall ability to synchronise with external stimuli (Overall Motor Synchrony Score).

4.2.2.3 Questionnaire measures

Caregivers reported on participants' levels of emotional and behavioural difficulties, autistic traits, and symptoms of inattention/hyperactivity, via the Strengths and Difficulties Questionnaire (Goodman, 1997) (SDQ), the Autism Spectrum Quotient (Children's Version) (AQ-Child) (Auyeung et al., 2008), and the Attention and Activity Section of the Development and Well-Being Assessment (Goodman, Ford, Richards, et al., 2000) (DAWBA(AAS)) respectively. Full details of each measure are reported in Chapter 3.

4.2.2.4 Statistical analysis

Data were collated in Microsoft Excel and imported into IBM SPSS version 25.0 for statistical analysis.

Questionnaire data. Questionnaires with >10% of items missing were excluded, on the basis that a proportion of missing data greater than 10% is likely to result in a biased analysis (Bennett, 2001). For the AQ-Child there were 11 participants (out of 101 for whom data was available) with <10% missing data. Little's Missing Completely at Random (MCAR) analysis (Little, 1988) indicated that these data were missing completely at random ($\chi 2(480) = 514.98$, $p = .13$). Missing item scores were replaced by the mean value of the available items in the same subscale. No participant had incomplete data for the SDQ or DAWBA(AAS).

Motor Synchrony task. One-way repeated measures ANOVAs were used to compare (1) stability of entrainment across tempos (2) accuracy of entrainment across tempos. Correlations assessed the relations between stability of entrainment and SMT, and between stability and accuracy of entrainment across tempos.

Associations between task performance and questionnaire measures. Correlations were used to investigate performance on the SMT, Synchrony Perception and Motor Synchrony tasks with age, parent-reported levels of difficulties, autistic traits and levels of inattention/hyperactivity, as well as the relations between performance on each task. T-tests were used to assess gender differences in performance on experimental tasks and in scores on questionnaire measures. Compliance with assumptions for parametric testing was investigated and non-parametric statistics used where appropriate. Bonferroni-corrected significance values were used where applicable.

4.3 Results

4.3.1 Sample Characteristics[3]

Of the 110 participants who completed one or both of the experimental tasks, mean scores on the SDQ were consistent with 'high' levels of conduct and hyperactivity problems, 'slightly raised' emotional and peer problems and 'low' prosociality. Mean total difficulties were in the 'very high' range. Mean AQ-child scores were just above the cut-off for high likelihood of autism (**Table 4.1**).

The proportion of participants beyond the cut-off point for risk of psychopathology on the SDQ (total difficulties) was 73%, and the proportion of participants with a high likelihood of autism on the AQ-child was 59%. By contrast, 17% of participants were in the 'close to average' range on the SDQ (total difficulties) measure (i.e. their scores were comparable

[3] Although both Chapter 3 and the current study drew on a sub-sample of NDAU participants, the sample in the current study was both smaller and only partially overlapping with the sample in Chapter 3. Therefore, sample characteristics were examined separately in the current study.

with those of 80% of a population sample) and 4% scored below the reported mean AQ-child score for TD children (Auyeung et al., 2008).

Increasing levels of difficulties/traits in one domain was associated with increasing levels of difficulties/traits in the other two, with medium to large effect sizes (SDQ/AQ-Child: $r_s(98) = .50$, $p < .001$; SDQ/DAWBA(AAS): $r_s(109) = .49$, $p < .001$; AQ-Child/DAWBA(AAS): $r_s(101) = .25$, $p = .01$). There were no significant gender differences in total scores on any of the three parent-report measures.

Table 4.1

Descriptive statistics for parent-report questionnaires

Measure	Subscale	Mean *(SD)*	Min-max; cut-off
SDQ	*N*	*110*	
	Emotional	**4.9** *(2.8)*	0-10; 5
	Conduct	**4.8** *(2.6)*	0-10; 4
	Hyperactivity	**8.4** *(2.3)*	0-10; 8
	Peer	**3.8** *(2.1)*	0-10; 4
	Prosocial	**5.9** *(2.6)*	0-10; 6
	TOTAL DIFFICULTIES	**21.7** ***(6.8)***	**0-40; 17**
AQ- Child	*N*	*101*	
	Social Skills	**15.2** *(6.2)*	0-30
	Attention Switching	**19.1** *(6.0)*	0-30
	Attention to Detail	**16.2** *(5.9)*	0-30
	Communication	**18.8** *(5.5)*	0-30
	Imagination	**13.5** *(5.5)*	0-30
	TOTAL	**82.7** ***(22.7)***	**0-150; 76**
DAWBA (AAS)	*N*	*110*	
	Inattention	**11.9** *(5.6)*	0-18
	Hyperactivity/Impulsivity	**12.7** *(5.9)*	0-18
	TOTAL	**24.6** ***(11.0)***	**0-36**

Note. SDQ= Strengths and Difficulties Questionnaire; AQ-Child = Autism Spectrum Quotient (Children's Version); DAWBA(AAS) = Development and Well-Being Assessment (Attention and Activity Section). Higher scores indicate higher levels of difficulty, save for on the SDQ prosocial subscale, on which higher scores indicate higher prosociality. Quoted SDQ 'cut-off' scores represent a 'high' level of difficulty (ie in the 90th+ percentile at a population level). *N*=number of participants for whom questionnaire data was included in analysis. For the SDQ and DAWBA(AAS) data was available for all 110 participants; for the AQ-child, N=101 because there were 9 participants for whom the questionnaire was not completed.

4.3.2 Synchrony Perception

The data of 25 participants (16 boys; m_{age} = 6 years 6 months; *s.d.* = 11.0 months) were excluded because no perceptual threshold could be calculated, as no PF could be fit to the data points. Lack of fit resulted either from inconsistent responding, or from the fact that participants could not reliably differentiate between synchronous and asynchronous stimuli even at the highest SOAs presented. The final sample consisted of 68 participants (51 boys; M_{age} = 6 years 10 months; *SD* = 11.7 months). Those who were excluded from the final analysis did not differ from those included, by gender ($\chi^2(1) = 0.08$, $p = .77$) or age ($t(89) = 1.06$, $p = .29$).

Synchrony Perception thresholds ranged between 31 and 341 ms (*M* = 192 ms; *SD* = 95 ms) (**Figure 4.8**). There was a significant negative association between age and Synchrony Perception threshold $r_s(68) = -.39$, $p = .001$ (**Figure 4.9**), i.e., participants' ability to detect (a)synchrony improved with age. Median Synchrony Perception Thresholds did not differ significantly by gender (boys = 198 ms; girls = 215 ms; $U = 441.5$; $z = 0.11$, $p = .91$).

Synchrony Perception Threshold was not significantly associated with autistic traits ($r_s(61) = -.05$, $p = .72$) or levels of inattention/hyperactivity ($r_s(67) = -.19$, $p = .12$). There was a significant negative association between Synchrony Perception Threshold and total emotional and behavioural difficulties ($r_s(68) = -.25$, $p = .04$), suggesting that those with higher overall difficulties displayed increased perceptual acuity, i.e. the opposite relation to that hypothesised. However, the relation between total difficulties and perceptual acuity was no longer significant after controlling for the effect of age ($r_{s(partial)}(65) = -.15$, $p = .23$). Together, these relations suggest that there were age-related increases in both overall difficulties and in perceptual acuity, rather than a direct relation between levels of difficulties and perceptual acuity.

Figure 4.8

Synchrony Perception task: distribution of Synchrony Perception thresholds

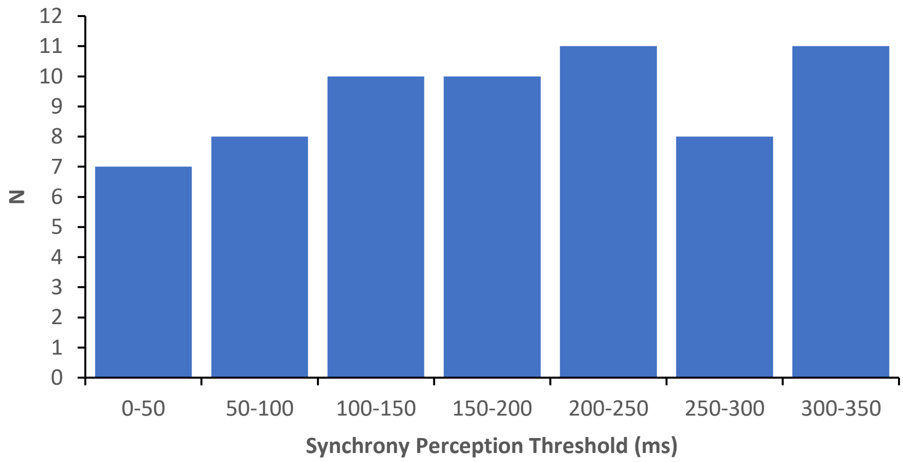
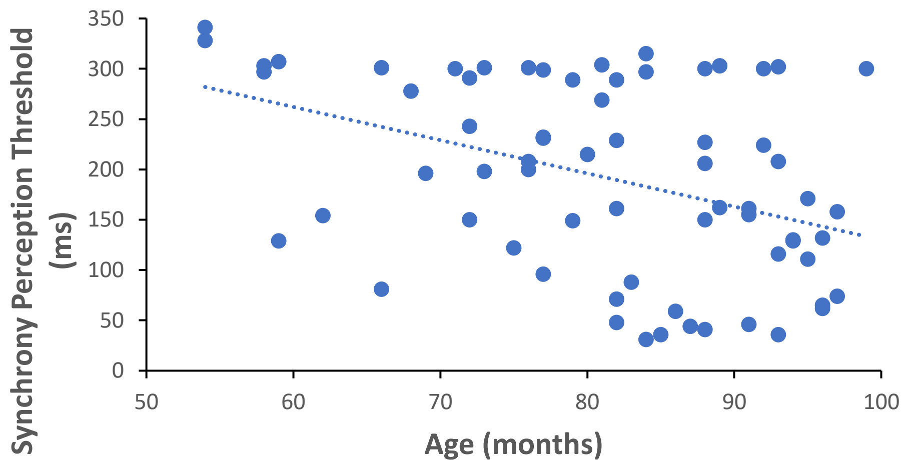


Figure 4.9

Synchrony Perception task: association between Synchrony Perception threshold and age



4.3.3 Motor tasks

Because a small proportion of participants (10 of 84) completed the motor tasks via a different software platform (Presentation) to the majority (PsychoPy/Pavlovia), the data were visually inspected for notable differences in performance in the two groups. As none were observed, data from both platforms were analysed together.

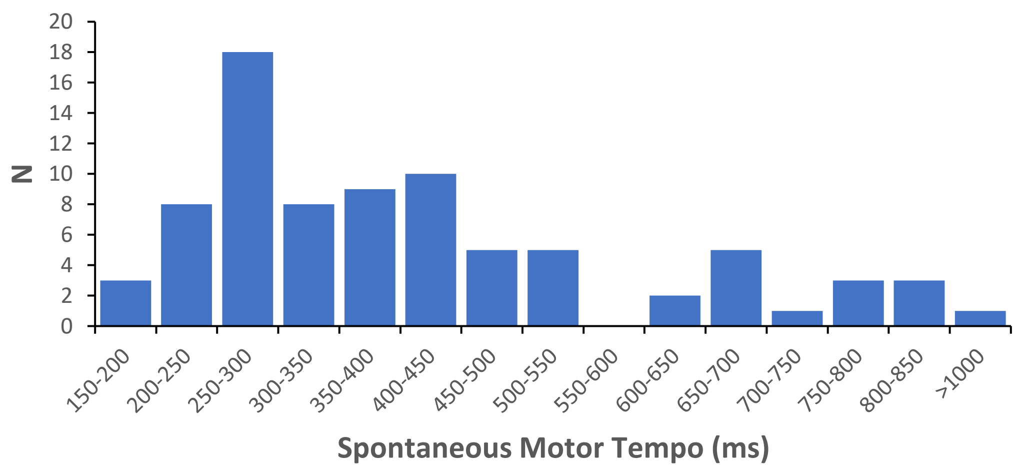
4.3.3.1 SMT

Of the 84 participants who completed the Motor Synchrony task, 80 also completed the SMT task. SMTs could not be calculated for two participants (one produced an insufficient number of taps, and the other tapped a non-isochronous rhythm). The number of participants for whom SMT data was available was therefore 78 (63 boys; M_{age} = 6 years 8 months; SD= 12 months).

Across the whole sample, SMTs ranged between 192 and 1013 ms (*M* = 407 ms; *SD* = 178 ms) (**Figure 4.10**). Mean SMTs for boys (399 ms) and girls (440 ms) did not differ significantly, $t(76) = 0.80$, $p = .43$. SMT was not significantly associated with age ($r_s(78) = 0.10$, $p = .40$).

Figure 4.10

SMT task: distribution of mean SMTs



4.3.3.2 Motor Synchrony

Eighty-one participants completed all three trials, and three participants completed either one (*n*=1) or two (*n*=2) trials only. For those who completed all three trials, 88% significantly entrained their tapping to one or more stimulus tempo (i.e. obtained significant $\bar{R}$ values in at least one trial). A third of participants significantly entrained their tapping to all three stimulus tempos (i.e. obtained significant $\bar{R}$ values for all three trials) (**Table 4.2**).

Table 4.2

Motor Synchrony task: numbers of tempos to which participants successfully entrained

N of tempos successfully entrained to	N of participants	Percentage of participants
0	10	12%
1	19	24%
2	25	31%
3	27	33%
TOTAL	81	100%

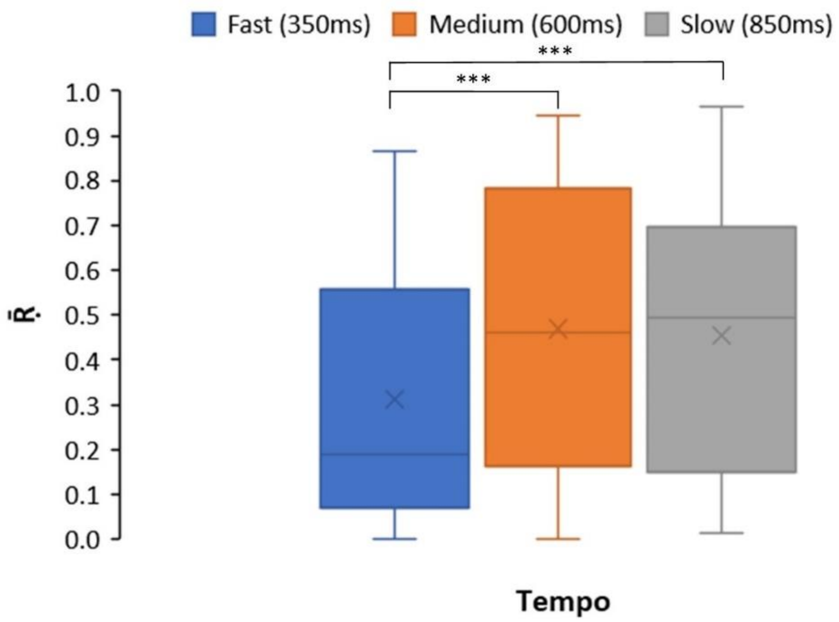
4.3.3.2.1 Stability of entrainment by tempo

Significant $\bar{R}$ values connoted significant entrainment to the stimulus tempo. According to this criterion, 48% of participants significantly entrained to the fast stimulus tempo (350ms ISI) and 69.5% and 66.3% of participants entrained to the medium (600ms ISI) and slow (850ms IOS) tempos respectively.

Greater stability of entrainment was indicated by higher $\bar{R}$ values. Average $\bar{R}$ values and their distributions at each tempo are shown in **Figure 4.11**. A one-way repeated measures ANOVA with tempo (fast; medium; slow) as the independent variable indicated a main effect of tempo on stability of entrainment ($\bar{R}$), $F(2,160) = 11.64$, $p < .001$, $\eta^2 = .13$. Bonferroni-corrected pairwise comparisons indicated that stability of entrainment was significantly higher in both the medium (p < .001) and slow (p < .001) conditions compared to the fast condition. Stability of entrainment did not differ significantly between the medium and slow conditions (p >.99).

Figure 4.11

Motor Synchrony task: stability of entrainment ($\bar{R}$) by tempo



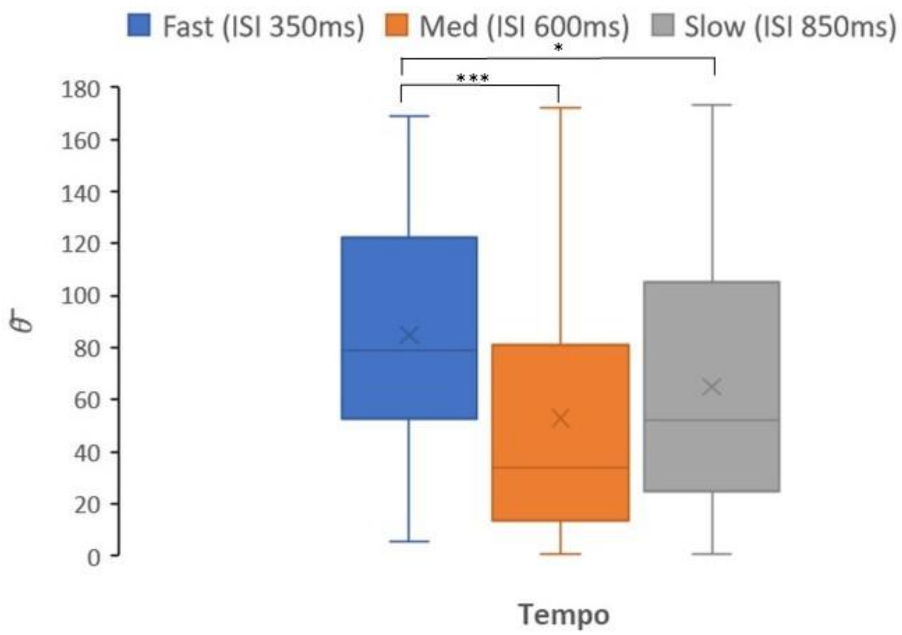
Note. Cross indicates mean $\bar{R}$; horizontal line indicates median $\bar{R}$.
*** p <.001

4.3.3.2.2 Accuracy of entrainment by tempo

Greater accuracy of entrainment was indicated by lower $\bar{\theta}$ values. Average $\bar{\theta}$ values and their distributions at each tempo are shown in **Figure 4.12**. A one-way repeated measures ANOVA with tempo (fast; medium; slow) as the independent variable indicated a main effect of tempo on accuracy of entrainment ($\bar{\theta}$), $F(2,160) = 11.06$, $p < .001$, $\eta^2 = .12$. Reflecting the same pattern as seen for stability of entrainment (above), Bonferroni-corrected pairwise comparisons indicated that tapping was entrained significantly more accurately in both the medium (p < .001) and slow (p = .03) conditions compared to the fast condition, but accuracy of entrainment did not differ significantly between the medium and slow conditions (p =.10).

Figure 4.12

Motor Synchrony Task: accuracy of entrainment ($\bar{\theta}$) by condition



Note. Cross indicates mean $\bar{\theta}$; horizontal line indicates median $\bar{\theta}$.
* p <.05 *** p <.001

4.3.3.2.3 Relation between SMT and stability/accuracy of entrainment

Table 4.3 shows the association between the distance between a participant's SMT and the stimulus tempo on the one hand and stability/accuracy of entrainment on the other. For the medium and slow tempos, proximity of participants' SMT to the stimulus tempo was not significantly associated with stability ($\bar{R}$) or accuracy ($\bar{\theta}$) of entrainment. For the fast tempo, proximity to SMT was not associated with accuracy of entrainment. However, there was a small effect size for the association between increased distance between stimulus tempo and SMT and increased stability of entrainment, at a level close to significance (p = .051) (**Figure 4.13**).

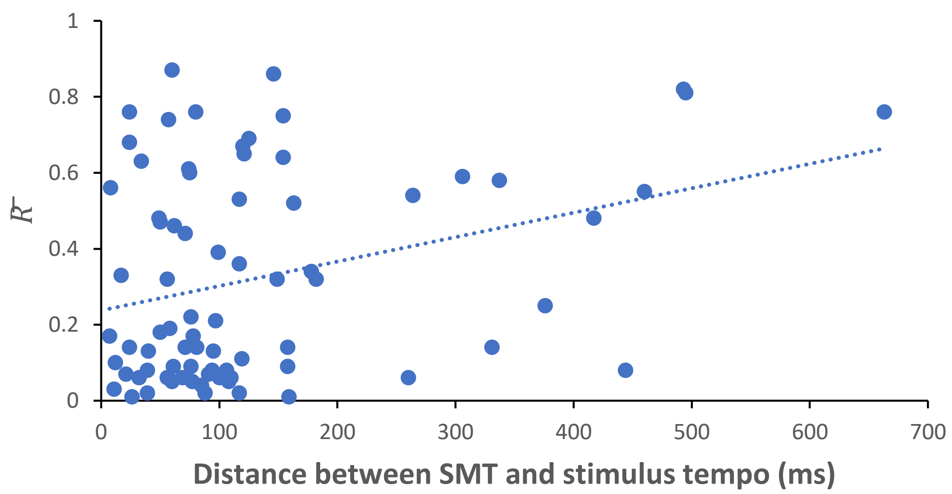
Table 4.3

Relation between stability/accuracy of entrainment by tempo and SMT

Tempo	Measure of entrainment	Association with distance from SMT: r_s *(p)*
Slow (850ms ISI)	Stability ($\bar{R}$)	0.008 (.95)
	Accuracy ($\bar{\theta}$)	–0.04 (.73)
Medium (600ms ISI)	Stability ($\bar{R}$)	0.07 (.57)
	Accuracy ($\bar{\theta}$)	–0.02 (.90)
Fast (850ms ISI)	Stability ($\bar{R}$)	0.22 (.051)
	Accuracy ($\bar{\theta}$)	–0.16 (.16)

Figure 4.13

Motor Synchrony Task: relation between proximity of SMT to stimulus tempo and stability of entrainment at the fast tempo (350ms IOI)



4.3.3.2.4 *Relations between stability and accuracy of entrainment*

The associations between stability ($\bar{R}$) and accuracy ($\bar{\theta}$) of entrainment at each tempo are set out in **Table 4.4**. For the medium and slow tempos, there were medium to large associations between stability and accuracy of entrainment. For the fast tempo, stability of entrainment was significantly associated with a majority of measures of entrainment at other tempos, but accuracy of entrainment was not related to other measure.

Table 4.4

Motor Synchrony Task: Relations between stability and accuracy of entrainment at each tempo

	Fast $\bar{R}$	Fast $\bar{\theta}$	Med $\bar{R}$	Med $\bar{\theta}$	Slow $\bar{R}$	Slow $\bar{\theta}$
Fast $\bar{R}$	-	-	-	-	-	-
Fast $\bar{\theta}$	–0.19	-	-			
Med $\bar{R}$	**0.32****	-	-	-	-	-
Med $\bar{\theta}$	–0.10	0.00	**–0.47*****			
Slow $\bar{R}$	**0.33****	0.01	**0.53*****	-	-	-
Slow $\bar{\theta}$	**–0.29****	-0.06	**–0.58*****	**0.50*****	**0.51*****	-

Note. More accurate Motor Synchrony is reflected in higher $\bar{R}$ values (higher concentration of tapping at a particular point in the ISI) and lower $\bar{\theta}$ values (closer proximity of mean tap to stimulus tap); thus negative correlations between $\bar{R}$ and $\bar{\theta}$ indicate that better performance on one is associated with better performance on the other.
* p <.05 ** p<.01 *** p <.001

4.3.3.2.5 Overall Motor Synchrony Score

A composite score summarising each participant's overall performance on the Motor Synchrony task ability was created using PCA. It was originally intended to enter all six Motor Synchrony variables (i.e. stability ($\bar{R}$) and accuracy ($\bar{\theta}$) for all three tempos) in the PCA However, one variable – $\bar{\theta}$ for the fast tempo – was excluded, for two reasons. First, a high proportion of participants (52%) did not significantly entrain their tapping to the fast stimulus tempo. Because their tapping was random relative to the beat provided by the stimulus tempo, the angular distance of the mean tap from the beat was not a meaningful measure for these participants. Secondly, and presumably relatedly, $\bar{\theta}$ values at the fast tempo were unrelated to all other measures of Motor Synchrony, in contrast to other measures of Motor Synchrony, on which better performance was moderately or strongly associated (**Table 4.4** above). Thus, the remaining five Motor Synchrony variables were retained for PCA.

The Kaiser-Meyer-Olkin (KMO) measure was 0.77, with individual KMO measures between 0.75 and 0.87, indicating 'middling' to 'meritorious' values (Kaiser, 1974). Bartlett's test of sphericity was significant ($p < .001$) suggesting that the data was suitable for factorisation. PCA generated one component with an eigenvalue greater than one, which explained 53.2% of the total variance. Visual inspection of the scree plot also indicated an inflection point at one component. The single component score resulting from the PCA was conceptualised as a measure of participants' overall ability to synchronise with a (non-social) external stimulus (Overall Motor Synchrony Score).

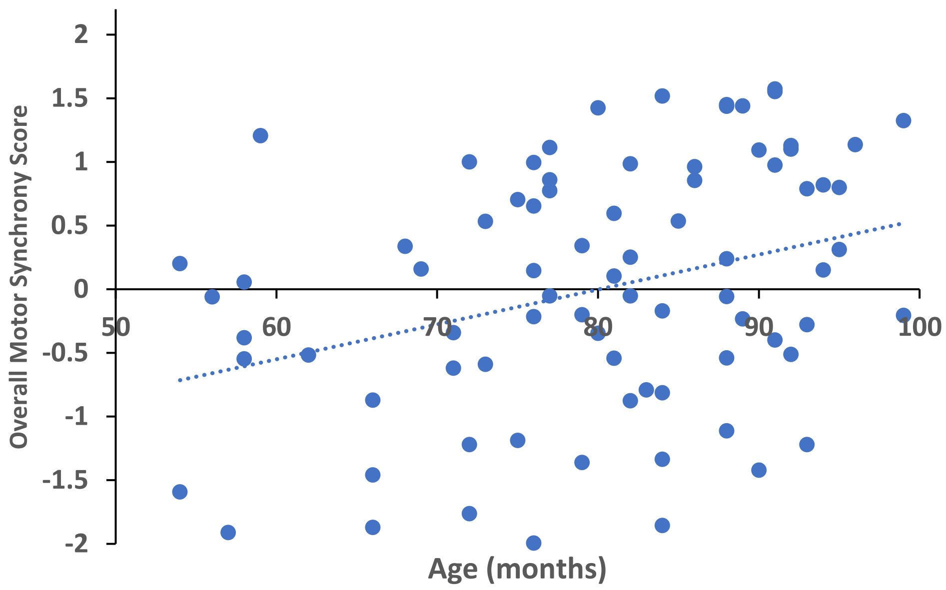
Further, repeating the PCA with the sixth (fast tempo $\bar{\theta}$) variable included yielded two factors with the original five variables loading onto one factor and the $\bar{\theta}$ (fast tempo) loading onto a second factor, suggesting that the five-variable approach was the most appropriate way to reflect participants' overall ability to synchronise their tapping movements with an external stimulus.

4.3.3.2.6 Relations between Overall Motor Synchrony Score and other variables

Participants' motor synchrony abilities, represented by their Overall Motor Synchrony Score, were significantly positively associated with age, $r(81) = 0.32$, $p = .005$ (**Figure 4.14**), but did not differ significantly between boys ($m = 0.004$; $SD = 0.99$) and girls ($m = – 0.02$, $SD = 1.08$), $t(79) = 0.07$, $p = .94$.

Figure 4.14

Motor Synchrony task: Relation between Motor Synchrony abilities and age



There was no significant association between Overall Motor Synchrony Score and overall levels of emotional and behavioural difficulties ($r(81) = 0.01$, $p = .90$), autistic traits ($r(73) = -0.01$, $p = .90$) or levels of inattention/hyperactivity ($r(81) = 0.11$, $p = .32$).

4.3.4 Relation between Synchrony Perception and Motor Synchrony

There was a significant negative association between Synchrony Perception Threshold and Overall Motor Synchrony Score, $r(50) = -0.28$, $p = .047$, although the association was not significant when controlling for the effect of age, $r_{partial}(47) = -0.20$, $p = .17$.

4.4 Discussion

Differences in temporal perception and in motor behaviour are commonly observed across atypical development, and potentially implicated in atypically developing children's experiences of IS (Chapter 1, section 1.6.2). However, there is limited evidence of fundamental, synchrony-specific abilities in such children, as tasks typically include multisensory and/or social confounds. This chapter investigated basic perceptual and motor synchrony in a sample of children with EE&BDs, together with potential behavioural correlates of these abilities. There was considerable heterogeneity both in the ability to detect temporal synchrony (Synchrony Perception task) and in the ability to synchronise movement with an external stimulus (Motor Synchrony task). Abilities in both domains increased with age but did not differ by gender, and were unrelated to children's total levels of emotional and behavioural difficulties, autistic traits, and ADHD traits.

4.4.1 Synchrony Perception

This was the first study to explore the perception of synchrony in a group of children with EE&BDs. On average, participants required an SOA of 192 ms to reliably detect asynchrony in non-social, auditory stimuli. No threshold value could be obtained for 27% of participants who completed the task, because they did not succeed in consistently differentiating between synchrony and asynchrony at any of the SOAs presented. The reason for this may have included a lack of understanding of the task instructions, or fluctuating levels of attention during the task. Another possibility is that the actual perceptual thresholds of these participants far exceeded the largest SOAs presented (300 ms). If this were the case, then the 'true' mean threshold within the sample would be higher than the observed mean of 192 ms.

Even so, a mean threshold of 192 ms is substantially higher than the thresholds at which children aged 7 to 14 years, with and without ADHD, were able to distinguish between synchronous and asynchronous pairs of pure tones (15 and 27 ms respectively) (Breier et al., 2003). There are multiple differences between this and the current study that may explain the higher threshold in the current study. First, the sample in the study by Breier et al. was older than that in the present sample, and would therefore be expected to demonstrate superior performance as a result of age-related improvements in temporal acuity. Second, the study by Brier et al. used pure tones, whereas the current study used complex auditory stimuli which, although non-social, were designed to better resemble the kinds of sounds encountered during day-to-day social interactions. The onset and offset of the stimuli used in the current study may have been less distinct and thus asynchrony may be relatively more difficult to detect at lower SOAs. Second, in contrast to the 2IFC paradigm in the current study, the study by Brier et al. used a four-interval, two-alternative forced choice paradigm. Specifically, four stimuli were presented successively, with the first and last always consisting of synchronous pairs of tones and either the second or third pair of tones consisting of an asynchronous pair. Thus, there were three 'control' stimuli and one target stimulus, as compared to one control and one target in the current study. The larger number of repetitions of the 'control' stimulus in the study by Brier et al. may have made detection of the target stimulus easier, although less comparable to everyday situations in which individuals might encounter (a)synchrony, where multiple 'comparator' stimuli are not typically available.

Aside from the study by Brier et al. discussed above, most studies have measured children's perceptions of the relative timing of auditory events using ToJ tasks, i.e. tasks which assess the threshold at which participants can reliably determine the order in which tones are presented. For example, typically developing 5-year-olds displayed a threshold of 132 ms (Berwanger et al., 2004), and children aged 5 to 12 years displayed a threshold of just under 200 ms (Stevenson et al., 2018) via auditory ToJ tasks. Autistic and non-autistic children aged 8 to 17 years obtained auditory ToJ thresholds of 108 and 73 ms respectively (Kwakye et al.,

2011) and children with and without ADHD, aged 6 to 11 years, had ToJ thresholds of 420 and 92ms respectively (Cardy et al., 2010). The mean threshold in the current study (192 ms) is higher than the thresholds obtained in almost all of the typical samples in these ToJ studies, even though the participants in the current study were not required to make a ToJ, only to detect asynchrony. Thus, on average, the perception of synchrony in children with EE&BDs is likely less accurate than that of their TD counterparts.

In addition to average performance, it is important to consider individual differences in performance within the sample. Previously, a degree of heterogeneity in auditory temporal perception has been observed in TD children. For example, Berwanger et al. (2004), noted that thresholds of 39 and 109 ms were both within one standard deviation of the mean ToJ threshold of 9-year-old participants. The data from the present study suggest an even greater level of heterogeneity in synchrony perception abilities in children with EE&BDs. In the current study, a threshold of 97 ms was only one standard deviation below the mean and a threshold of 287 ms was only one standard deviation above the mean, with these two values likely representing a substantial difference in functional perceptual experience. Further, at one extreme, 10% of participants obtained thresholds of less than 50 ms, which is comparable to temporal order judgment thresholds observed in typical adults (Berwanger et al., 2004; Kanabus et al., 2002). At the other extreme, 16% of participants for whom threshold values could be calculated had a threshold that exceeded 300 ms. Thus, it is possible that both enhanced and substantially reduced synchrony perception is present in children with EE&BDs.

4.4.2 SMT

The mean SMT of 407 ms was comparable to SMTs of TD children of similar ages who completed a similar free-tapping or -clapping task, which ranged across studies between 300 and 456 ms (Drake et al., 2000; Fitzpatrick et al., 1996; McAuley et al., 2006; Provasi & Bobin-Bègue, 2003). The lack of any age effects were consistent with evidence from studies that found no significant differences in the SMTs of older children with and without ADHD (Rubia et al., 2003; Tiffin-Richards et al., 2004). Taken together, it is unlikely that SMT is an area of divergence between children with and without EE&BDs. Rather, SMT may represent a common experience for typically and atypically developing children.

4.4.3 Motor Synchrony

Performance on the simple and repetitive, non-social motor synchrony task used in the current study was highly variable. While a large majority of participants were able to synchronise their finger tapping with an external stimulus at one or more of the tempos presented, only a third of participants were able to synchronise their tapping at all three tempos. Although few previous studies have reported on within-group individual differences, variation in motor synchrony abilities identified in the present study are in line with another study that found heterogenous synchronised finger-tapping abilities in children with ADHD, only a third of whom performed within the range of TD comparators (Puyjarinet et al., 2017).

Across the current sample, entrainment was the least successful at the fastest stimulus tempo (350 ms), with less than half of participants able to entrain their rate of tapping. Both accuracy and stability of entrainment was significantly better at the medium and slow tempos. This pattern of findings was contrary to the prediction that motor synchrony would be highest at the tempo closest to participants' SMT, i.e. the fastest (350 ms) tempo, which was closest to the mean SMT of 407 ms. One possible explanation is that a substantial majority of participants' SMT were close to 350 ms (see **Figure 4.10**), such that there was minimal variation in proximity to SMT within the current sample. Variation attributable to other sources of individual difference may have outweighed variation attributable to proximity to SMT in explaining variation in performance on the task.

Another factor potentially contributing to participants' difficulties in synchronising with the fastest stimulus may be the speed with which they process external stimuli. In previous studies, children with ADHD (Shanahan et al., 2006; Walg et al., 2017) and, to a lesser extent, autistic children (Kramer et al., 2020; Mayes & Calhoun, 2007) displayed slower processing speeds relative to children without those conditions. It has previously been suggested (Noreika et al., 2013) that slower processing speeds may account for the fact that children with ADHD tapped more slowly than those without ADHD when synchronising with fast stimulus tempos (Pitcher et al., 2002) but did not differ when synchronising with slower paced stimuli (Rubia et al., 2003; Zelaznik et al., 2012). Similarly, given high levels of ADHD traits and autistic traits within the present sample, relatively slow processing speeds within the sample may have been responsible for participants' relative inability to synchronise with the fastest stimulus tempo. However, such an explanation was not directly evidenced in the present study, as processing speeds were not assessed.

4.4.4 Relations between Synchrony Perception/Motor Synchrony and age

Performance on both the Synchrony Perception and Motor Synchrony tasks was significantly positively associated with age, suggesting that the synchrony-related perceptual and motor skills of children with EE&BDs increase between the ages of 4 and 8 years. In relation to Synchrony Perception, an age-related increase in auditory perceptual acuity is broadly consistent with evidence of increasing sensitivity to audio-visual (a)synchrony throughout childhood and adolescence, in typically developing samples (Hillock-Dunn & Wallace, 2012; Lewkowicz, 1996; Wang & Yang, 2018), autistic children (Feldman et al., 2018) and children with dyslexia (Wang & Yang, 2018). In relation to Motor Synchrony, age-related improvements reflect those observed in previous studies in TD (Carrer et al., 2022; Drake et al., 2000; McAuley et al., 2006; Monier & Droit-Volet, 2019) and autistic children (Tryfon et al., 2017) children as well as those with ADHD (Ben-Pazi et al., 2006). Thus while the synchrony-related perceptual and motor abilities of typically and atypically developing children may differ in absolute terms, evidence from the current study suggests that both undergo age-related improvements in both domains during middle childhood.

4.4.5 Relations between Synchrony Perception/Motor Synchrony and emotional and behavioural difficulties/behavioural traits

Contrary to the original hypothesis, neither Synchrony Perception nor Motor Synchrony were related to overall levels of emotional and behavioural difficulties, autistic or ADHD traits. In relation to Synchrony Perception, a range of studies have found evidence of higher auditory perceptual thresholds, at a group level, in a variety of neurodivergent conditions including autism (Kwakye et al., 2011), ADHD (Cardy et al., 2010; Fostick, 2017) and developmental dyslexia (Ben-Artzi et al., 2005; Fostick & Revah, 2018; Hairston et al., 2005;

Laasonen et al., 2001; Pasquini et al., 2007). In relation to Motor Synchrony, basic motor synchrony was less accurate in autistic than non-autistic groups (Morimoto et al., 2018; Vishne et al., 2021) and in participants with ADHD than in comparators (Hove et al., 2017; Noreika et al., 2013; Zelaznik et al., 2012), as assessed with similar basic finger tapping tasks. In the current study, the lack of association between levels of difficulty and diagnostic traits on the one hand and perceptual and motor synchrony suggest that previously observed group difference may have been driven by factors other than those directly captured by trait-based measures.

Further, evidence of reduced synchrony perception and motor synchrony in neurodivergent populations is by no means ubiquitous. A number of studies have found no group differences in auditory temporal processing (Breier et al., 2003; Poole et al., 2022; Stevenson et al., 2014; Zhou et al., 2022) and basic motor synchrony (e.g. Tryfon et al, 2017; Honisch et al., 2021; Kaur et al., 2018; Edey et al., 2019). Such mixed findings as to group differences may stem from the presence of greater variability in perceptual and motor synchrony in neurodivergent compared to neurotypical groups, rather than an association between perceptual and motor synchrony and levels of difficulty/diagnostic traits *per se*. Indeed, the current finding that Synchrony Perception and Motor Synchrony abilities were unrelated to inattention/hyperactivity is in line with evidence of a dissociation between timing difficulties and other traits associated with ADHD, specifically, inhibitory control and delay-related difficulties (Sonuga-Barke et al., 2010).

A caveat to the conclusion that perceptual and motor synchrony are unrelated to levels of difficulties/diagnostic traits relates to the profile of the sample used in the current study. Notably, most participants exhibited high levels of overall difficulties and/or were at elevated likelihood of autism/ADHD. Only a small minority of children in the current sample with had low levels of total difficulties, autistic traits, or ADHD consistent with TD (see 'Sample Characteristics' above). It may be that an even broader sample, i.e. incorporating a larger proportion of TD children, would have detected an association between perceptual and motor synchrony abilities and overall levels of difficulties/autistic traits/inattention and hyperactivity. However, the current findings suggest that both synchrony perception and motor synchrony abilities vary independently from core diagnostic traits in children with EE&BDs.

4.4.6 Conclusion

Overall, the Synchrony Perception and Motor Synchrony tasks presented in the current study were appropriate for capturing the fundamental, synchrony-specific perceptual and motor abilities of children with EE&BDs. The findings revealed considerable variation both in perceptual and motor synchrony abilities within the sample. Abilities in both domains improved with age, but varied independently of parent-reported levels of emotional and behavioural difficulties, and autistic and ADHD traits. As set out in Chapter 1, variation in perceptual and motor synchrony abilities, likely influences the real-world experiences of IS in children with EE&BDs, and thus variation in their sensitivity to its social effects. The final experimental chapter (Chapter 5) will draw on the data previously presented on sensitivity to the affiliative effects of IS (Chapter 3) and perceptual and motor synchrony (Chapter 4) and will explore the potential relations between social sensitivity to IS and perceptual and motor synchrony and in children with EE&BDs.

Chapter 5

Interpersonal Synchrony and Affiliation in Children with Emerging Emotional and Behavioural Difficulties: Component Processes

5.1 Introduction

In Chapter 2, TD children judged synchronous social partners as higher in affiliation than asynchronous partners, i.e. they displayed social sensitivity to IS. In Chapter 3, the effect of IS on the affiliation judgements of children with EE&BDs was reduced at a group level, although there was also evidence of individual differences in whether and to what extent IS had such an influence. Variation in social sensitivity to IS was not related to any of the potential behavioural correlates examined, i.e. total level of difficulties, autistic traits, and ADHD traits (Chapter 3). This chapter takes an alternative approach to explaining variation in social sensitivity to IS. It draws on the idea that IS is the combined product of processes in the perceptual, motor, and socio-cognitive domains (Bowsher-Murray, Gerson, et al., 2022; Delaherche et al., 2012; Trainor & Cirelli, 2015), each of which may operate differently across atypical development (Chapter 1, section 1.6). It seeks to explore transdiagnostic perceptual, motor and socio-cognitive correlates of social sensitivity to IS in children with EE&BDs. The roles of three potential component processes are considered: synchrony perception; motor synchrony; and the ability to make mental state inferences, i.e. theory of mind (ToM) (Frith & Frith, 2003; Premack & Woodruff, 1978).

5.1.1 Synchrony perception

To make social judgements based on IS, synchrony between partners must be perceived (Lakens, 2010; Novotny & Bente, 2022; Oullier et al., 2008; Trainor & Cirelli, 2015). As described in Chapter 1 (section 1.6.2.1), atypical time processing, including less accurate perception of the relative timing of events, has been observed across atypical development. In the current sample of children with EE&BDs, there was substantial variation in perceptual sensitivity to auditory (a)synchrony (Chapter 4). Children with relatively low perceptual sensitivity to (a)synchrony may be less likely to perceive differences between synchronous and asynchronous social interactions, and thus be less able to use such information to judge affiliation between partners. Indeed, lower perceptual sensitivity to (a)synchrony may have led to a disruptions to IS over the course of development (Zhou et al., 2022), and thus to reduced opportunity for an association between IS and affiliation to arise at all. Accordingly, the first aim of this chapter is to explore whether children's sensitivity to (a)synchrony at a perceptual level is associated with their social sensitivity to IS.

5.1.2 Motor synchrony

IS emerges via the temporal alignment of partners' motor behaviour, meaning motor function is likely to be an important contributor to IS (Georgescu et al., 2020; Trainor & Cirelli, 2015). Differences in motor timing, including differences in synchronising motor movements with external stimuli have been observed across atypical development (see Chapter 1, section 1.6.2.2). In Chapter 4, children with EE&BDs displayed considerable variation in basic motor synchrony abilities, both in terms of the accuracy with which synchrony was achieved and in the range of tempos over which synchronisation occurred. The relation between motor abilities and rates of IS has been explored in autistic people, although not in other neurodivergent populations, with mixed results. Some studies have found a positive association between motor abilities and observed levels of IS in autistic groups (Brezis et al., 2017; Fitzpatrick et al., 2017a), but others have found no such association (Kaur et al., 2018; Koehler et al., 2021; Noel, De Niear, et al., 2018). Notably, however, studies assessing the link between motor skills and IS production tend to employ general measures of motor skills, or assess motor skills that are not synchrony specific (Bowsher-Murray, Gerson, et al., 2022). It is possible that reduced motor synchronisation specifically – rather than motor difficulties in general – lead to reduced levels of IS during interactions. Reduced experience of IS may, in turn, mean reduced opportunities for individuals to come to associate IS with affiliation. Therefore, a second aim of this chapter is to investigate the association between basic motor synchrony abilities and the extent to which IS has affiliative effects in children with EE&BDs.

5.1.3 Theory of Mind

ToM is a core component of social cognition. Difficulties with ToM are well documented in autistic populations (Happé, 2015; Tager-Flusberg, 2007), and have also been associated with other neurodivergent conditions (Baribeau et al., 2015; Korkmaz, 2011; Maoz et al., 2019; Pineda-Alhucema et al., 2018; Uekermann et al., 2010). There is also evidence of a relation between ToM and IS. For example, those with higher ToM displayed higher levels of IS (Dai et al., 2018; Koehne, Hatri, et al., 2016; Novembre et al., 2019), and those who engaged in synchronous interactions also displayed an increased tendency to consider the mental states of others, relative to those who engaged in asynchronous interactions (Baimel et al., 2018). ToM may similarly be relevant to the processes by which IS generates affiliative effects, such that a reduced ability to make inferences about mental states may be a barrier to making IS-based judgements of affiliation (see Chapter 1, section 1.6.2.3). Therefore, a third aim of this chapter is to investigate whether variation in children's ToM abilities is a further factor that explains variation in social sensitivity to IS in children with EE&BDs. Given evidence of dissociation between cognitive and affective ToM abilities in neurodivergent populations (Chapter 1, section 1.6.2.3) as well as in children drawn from the NDAU sample (Howe-Davies, 2020), this chapter will consider separately the relations between social sensitivity to IS and cognitive, affective and overall ToM abilities.

5.1.4 Witnessed vs experienced IS

The relative contributions of perceptual, motor and ToM abilities to the affiliative effects of IS may differ depending on whether IS is witnessed or experienced. For example, judging affiliation from witnessed IS does not require motor activity, but motor behaviour is an integral component of experienced IS. Thus, motor synchrony abilities may be more closely linked to affiliation judgements in experienced than witnessed IS. Relatedly, affiliation judgments based on witnessed IS require an appraisal of the mental states of others, but those based experienced IS primarily requires the identification of one's own state of mind. Thus, ToM (as it relates to understanding the minds of others) may be more closely linked to affiliation judgements for witnessed IS, relative to experienced IS.

5.1.5 The current study

This chapter explores the extent to which sensitivity to synchrony as a marker of affiliation in children with EE&BDs can be explained by variation in synchrony perception, motor synchrony, and ToM abilities. Social sensitivity to IS was measured using the Witnessed and Experienced IS tasks described in Chapters 2 and 3. Potential component abilities were measured using the Synchrony Perception and Motor Synchrony tasks described in Chapter 4, together with a four-item ToM battery, in which each task was based on established paradigms assessing false belief understanding (Baron-Cohen et al., 1985; Coull et al., 2006; Wellman & Liu, 2004). Performance on the Synchrony Perception, Motor Synchrony and ToM tasks were each expected to explain a proportion of the variance in the affiliative effects of IS. It was anticipated that the relative importance of each factor may differ depending on whether IS was witnessed or experienced.

5.2 Method

5.2.1 Participants

Participants were children from the NDAU sample who completed one or both of the Witnessed and Experienced IS tasks, as described in Chapter 3. The numbers of participants for whom data was also available on the Synchrony Perception, Motor Synchrony and ToM tasks are summarised in **Table 5.1**. Different numbers of participants completed each task because of time constraints and/or participant engagement during the testing sessions.

Table 5.1

Number of participants by task

Task	N Total	(male/female ratio)	Age M	(SD)
Witnessed IS	**136**	(101/35)	6 y 7 mo	(12 mo)
Experienced IS	**150**	(110/40)	6 y 7 mo	(12 mo)
Synchrony Perception	**68**	(51/17)	6 y 9 mo	(12 mo)
Motor Synchrony	**81**	(67/14)	6 y 6 mo	(11 mo)
ToM	**154**	(113/41)	6 y 6 mo	(12 mo)

5.2.2 Materials and procedure

The data were collected during the same two-day testing sessions described in Chapter 3 (see section 3.2.2).

5.2.2.1 Synchrony-related tasks

The Witnessed and Experienced IS tasks were those described in Chapters 2 and 3 and the Synchrony Perception and Motor Synchrony tasks were those described in Chapter 4.

Outcome variables. As described in Chapter 3, participants' social sensitivity to both witnessed and experienced IS was quantified using synchrony difference scores, i.e. the difference between affiliation scores assigned in the fully synchronous condition (partners tapped both simultaneously and regularly) and the fully asynchronous condition (partners tapped neither simultaneously nor at regular intervals).

As described in Chapter 4, individual participants' perceptual sensitivity to synchrony was quantified via their threshold score on the Synchrony Perception task, i.e. the SOA (in ms) at which they could reliably distinguish synchronous and asynchronous auditory stimuli. As further described in Chapter 4, motor synchrony abilities were quantified using composite standardised scores ('Overall Motor Synchrony Score') on the Motor Synchrony task, which reflected participants' accuracy and stability when synchronising their finger tapping with a series of isochronous auditory tones at a range of tempos.

5.2.2.2 Theory of Mind

Participants completed four scripted ToM tasks. As summarised in **Table 5.2**, there were three first-order ToM tasks ("X thinks that….") and one second-order task ("X thinks that Y thinks that…") (Perner & Wimmer, 1985). One task measured affective ToM (i.e. inferences about feelings/emotions) and three measured cognitive ToM (i.e. inferences about thoughts/beliefs) (Shamay-Tsoory & Aharon-Peretz, 2007).

Table 5.2

Summary of constructs measured by each ToM task

Task order	Task	Affective/ Cognitive	First/second order	Adapted from
1	Belief-emotion	Affective	First	Wellman and Liu (2004)
2	Unexpected location	Cognitive	First	Baron-Cohen et al. (1985)
3	Unexpected contents	Cognitive	First	Wellman and Liu (2004)
4	Unexpected action	Cognitive	Second	Coull et al. (2006)

In each task, a scenario was presented via props/puppets/dolls and narrated by the researcher, and the participant responded verbally to a series of questions. Tasks were completed in a fixed order as follows:

1. Belief-emotion (first order/affective): the participant was shown a 'Coco Pops' box and a teddy. Coco Pops were said to be Teddy's '*favourite snack.*' Teddy went '*to play*' and was put out of sight. The researcher opened the box and showed its contents – small white rocks – to the participant, commenting that there are '*really rocks inside, and no Coco-Pops*.' The box was closed and Teddy was brought back. The researcher said: '*Teddy has never ever seen inside this box. Now here comes Teddy. Teddy's back and its snack time. Let's give Teddy this box. So, how does Teddy feel when he gets this box?'* (target question). The box was opened and Teddy 'looked' inside. The participant was asked '*How does Teddy feel* after *he looks inside the box?*' (emotion control question). The participant 'passed' the task if they answered the target and emotion control questions correctly.

2. Unexpected location (first order/cognitive): two dolls, 'Max' and 'Sally' were introduced, along with a covered basket and a box with a closed door. Max put a ball into the covered basket then left. Sally retrieved the ball from the basket, put it into the box, and closed the box door. Sally left, and then Max returned. The participant was asked: "*Where will Max look* *for his ball?*" (target question); and then "*Where is the ball really?*" and "*Where did Max put his ball in the beginning?"* (control questions). The participant 'passed' the task if they answered all three questions correctly.

3. Unexpected contents task (first order/cognitive): the participant was shown a closed Smarties tube. To avoid possible carry over effects from the first task, they were asked what they thought was inside the tube. If their reply was substantially different to 'Smarties' (e.g. 'rocks'), they were asked what was '*usually*' inside a Smarties tube. All participants' answers (e.g. 'Smarties'; 'sweeties') indicated they understood what the tube would typically be expected to contain. The tube was opened to reveal that it contained pens, and the lid was replaced. A tiger puppet was then introduced: '*Tiger has been down here sleeping, He hasn't seen what is inside the tube*.' The participant was asked: '*What does Tiger think is inside the tube?*' (target question); and '*Did Tiger see inside the tube?*' (memory/control question). The participant 'passed' the task if they answered both questions correctly.

4. Unexpected action task (second order/cognitive): the participant was shown a child's bedroom set-up containing two beds with covers, a playmat ad a small cupboard with a closed door (**Figure 5.1**). Two figures were placed in the scene: 'Alex', seated on the playmat, and 'Nick', who held a teddy. Nick placed his teddy under the cover of one of the beds. A third figure, 'Mum', entered the room and asked Nick to brush his teeth. Nick and Mum left together. Alex retrieved the teddy from the bed '*to hide it in the cupboard*.' The cupboard was opened and the teddy placed inside. Alex was seated facing the open cupboard. Nick returned and stood behind Alex. The researcher commented: "*Nick comes back and sees Alex hiding in the teddy in the cupboard. But Alex doesn't see Nick.*" Nick left, the cupboard was closed, and Alex returned to the playmat. Nick returned again and the participant was asked: ‘*Where does Alex think Nick will look for the teddy?”* (target question) and then asked ‘*Why does Alex think Nick will look for the teddy* [in the bed]*?*’ (justification question). Appropriate answers to the justification question would include ‘Because that’s where he left the teddy’; ‘Because she doesn’t know he saw her hiding it’ etc. There followed three further comprehension/control questions: ‘*Does Nick know that the teddy is in the cupboard?*”; “*Does Alex know that Nick saw her hide the teddy?*’; and ‘*Where will Nick look for the Teddy?*’. The participant ‘passed’ the task if they answered all four questions correctly and provided an appropriate answer to the justification question.

Figure 5.1

Theory of Mind: second order task set up

Note. Figures L-R: ‘Mum’, ‘Nick’ and ‘Alex’. Nick places his teddy under the covers of one of the beds and leaves the room. Alex moves the teddy from the bed to the cupboard but, without her knowing, Nick sees her doing so. To assess participants’ second order false belief understanding, they are asked where Alex thinks Nick will look for the teddy and to justify their answer. Three control questions probe their understanding of the story.

Outcome variables. Participants received a score of 1 for each ToM task they 'passed', yielding an Affective ToM score of 0 or 1, a Cognitive ToM score between 0 and 3 and a Total ToM score between 0 and 4.

5.2.2.3 Statistical analysis

Data were collated in Microsoft Excel and imported into IBM SPSS version 25.0 for statistical analysis. Compliance with assumptions for parametric testing was investigated. For all measures other than Affective ToM, correlations were used to investigate the relations between task performance and age, and t-tests were used to compare performance by gender for each task. For Affective ToM, which had a binary outcome variable, t-tests were used to assess whether those who passed and failed differed significantly in age, and Chi-square tests were used to assess whether performance differed by gender.

Correlations investigated associations between Synchrony Perception, Motor Synchrony, Total ToM, and social sensitivity to witnessed/experienced IS. Additionally, the relations between Affective and Cognitive ToM and social sensitivity to witnessed/experienced IS were investigated separately. T-tests were used to compare the Witnessed and Experienced IS scores of those who did and did not pass the Affective ToM task. Similarly, due to limited variance across the three Cognitive ToM tasks, participants were split into two groups according to whether they passed all Cognitive ToM tasks, i.e. displayed robust Cognitive ToM, or passed fewer than three tasks. Then, t-tests were used to compare Witnessed and Experienced IS difference scores across the two groups (i.e. participants with robust Cognitive ToM vs rest of sample).

Bonferroni-corrected significance values were used where applicable. Multiple regression analyses were planned to assess the extent to which Synchrony Perception, Motor

Synchrony and ToM abilities explained variation in social sensitivity to IS. However, regression analyses were not ultimately carried out because correlational analyses revealed no evidence of a relation between the putative component processes and social sensitivity to IS on the other.

5.3 Results

Performance on the Witnessed and Experienced IS tasks was described in Chapter 3, and performance on the Synchrony Perception and Motor Synchrony tasks was described in Chapter 4.

5.3.1 Theory of Mind

Of the 154 participants who completed at least one ToM task, all 154 completed the Affective ToM task, of whom 144 also completed the three Cognitive ToM tasks. Of those who completed all four ToM tasks, 92.4% passed one or more tasks, and 22.2% passed all four (**Table 5.3**).

Table 5.3

ToM: distribution of number of tasks passed

N of tasks passed	N of participants	Percentage of participants
0	11	8%
1	19	13%
2	42	29%
3	40	28%
4	32	22%
TOTAL	144	100%

As set out in **Table 5.4**, 73% of participants passed the Affective ToM task. The mean Cognitive ToM Score (out of 3) was 1.73 (*SD* = 0.97) and the mean Total ToM score (out of 4) was 2.44 (*SD* = 1.19). Those who passed the Affective ToM (m_{age} = 6 y 7 mo) were slightly older than those who did not (m_{age} = 6 y 3 mo), although the difference was not significant ($t(152) = 1.71$, $p = 0.09$). However, there was a significant positive association between age and Cognitive ToM score (r = .40, $p < .001$) as well as between age and Overall ToM score (r = .37, $p < .001$). There were no gender differences in the proportion of participants who passed the Affective ToM task ($\chi^2(1) = 0.80$, $p = .37$), nor in Cognitive ToM score ($t(142) = 0.54$, $p = .58$) or Total ToM score ($t(142) = 0.86$, $p = .39$).

Table 5.4

ToM: proportion of participants who passed each task

Task	Affective/cognitive	First/second order	Percentage of participants passing
Belief-emotion	Affective	First	73%
Unexpected location	Cognitive	First	62%
Unexpected contents	Cognitive	First	81%
Unexpected action	Cognitive	Second	33%

5.3.2 All tasks: descriptive statistics

Descriptive statistics for the Witnessed IS, Experienced IS, Synchrony Perception, Motor Synchrony and ToM tasks are summarised in **Table 5.5**.

Table 5.5

Descriptive statistics for all tasks

Task	N	Measure	Mean	SD	Range	Min-max
Witnessed IS	136	Difference score	0.10	0.81	–2.00 – 3.00	–3 to 3
Experienced IS	150	Difference score	–0.02	0.81	–2.50 – 2.25	–3 to 3
Synchrony Perception	68	Threshold (ms)	192	95	31 – 341	0 to N/A
Motor Synchrony	81	Overall Motor Synchrony Score	0.00	1.00	–2.10 – 1.57	N/A
Affective ToM	154	No of tasks 'passed'	N/A	N/A	0 – 1	0 to 1
Cognitive ToM	144	No of tasks 'passed'	1.73	0.97	0 – 3	0 to 3
Total ToM	144	No of tasks 'passed'	2.44	1.19	0 – 4	0 to 4

Note. For **Witnessed** and **Experienced IS**, 'Difference score' = difference in affiliation ratings following fully synchronous compared to fully asynchronous interactions (Chapter 3). **Synchrony Perception** 'Threshold' = threshold (in ms) at which participants could reliably distinguish synchronous and asynchronous non-social auditory stimuli (Chapter 4); **Motor Synchrony** = 'Overall Motor Synchrony Score' = standardised composite score reflecting accuracy and stability with which participants could synchronise finger taps with isochronous tones across three tempos. **ToM:** no mean score for Affective ToM is shown as scoring was binary (pass/fail). IS = interpersonal synchrony; ToM = theory of mind.

5.3.3 Relations between task performance and age and gender

Synchrony Perception, Motor Synchrony and Total ToM scores were all significantly associated with age, suggesting an age-related improvement in each of these three abilities. Sensitivity to Witnessed and Experienced IS were not significantly associated with age. Performance did not differ by gender on any of the tasks (**Table 5.6**).

Table 5.6

Relations between task performance and age and gender

Task	N	Association w /comparison by age (r/t)	Comparison by gender (t/ χ^2)
Witnessed IS	136	–0.01	0.55
Experienced IS	150	–0.02	1.06
Synchrony Perception	68	**–0.41****	0.08
Motor Synchrony	81	**0.31****	0.07
Affective ToM	154	1.71	0.80
Cognitive ToM	144	**0.40*****	0.54
Total ToM	144	**0.37*****	0.86

Note. Pearson correlations were used to test association with age for all variables save for Affective ToM, for which t-tests assessed whether those who passed/failed differed by age. The negative association between Synchrony Perception score and age reflects lower perceptual thresholds (i.e. higher perceptual acuity) in older participants. T-tests were used for all gender comparisons save for Affective ToM, for which a Chi-square test was used. IS = interpersonal synchrony; ToM = theory of mind.
* p <.05; **p<.01; ***p<.001.

5.3.4 Correlations between performance on individual tasks

As shown in **Table 5.7**, better synchrony perception was significantly associated with better ToM abilities, including when age was controlled for. More accurate motor synchrony was significantly associated with better synchrony perception and increased ToM abilities, but neither association remained significant when age was controlled for. Sensitivity to witnessed and experienced IS was not significantly associated with performance on any other task (**Table 5.7**).

Table 5.7

Correlations between performance on all tasks

	Synchrony Perception	Motor Synchrony	ToM	Witnessed IS
Motor Synchrony	**–0.28***	-		
	(–0.20)			
ToM	**–0.36****	**0.25***	-	
	(–0.28*)	*(0.18)*		
Witnessed IS	0.05	0.06	–0.04	-
	-	-	-	-
Experienced IS	0.02	0.1	–0.07	–0.09
	-	-	-	-

Note. Figures not in brackets = Pearson's correlations; figures in brackets = partial correlations ($r_{partial}$) controlling for age. IS = interpersonal synchrony; ToM = theory of mind.
* p <.05; **p<.01; ***p<.001.

5.3.5 Affective and Cognitive ToM and social sensitivity to IS: group comparisons

Finally, as shown in **Table 5.8**, Witnessed and Experienced IS difference scores did not differ between those who did and did not pass the Affective ToM task. Although the Witnessed and Experienced IS scores of those who passed all three Cognitive ToM were somewhat higher than those of the rest of the sample, the difference was not significant.

Table 5.8

Comparison of difference scores on Witnessed and Experienced IS task, by ToM performance

ToM measure	Witnessed /Experienced IS	Difference scores: (group n); m (SD)				Comparison of mean difference scores	
		High ToM group		Low ToM group		*t*	*p*
Affective	Witnessed	(95)	0.08 (0.82)	(34)	0.08 (0.85)	**0.004**	.99
	Experienced	(101)	0.03 (0.82)	(38)	0.05 (0.79)	**0.53**	.60
Cognitive	Witnessed	(32)	0.19 (0.68)	(89)	0.07 (0.86)	**0.71**	.48
	Experienced	(34)	0.18 (0.80)	(102)	0.05 (0.82)	**1.41**	.16

Note. For Affective ToM, 'High' vs 'Low' ToM groups = passers vs non-passers; for Cognitive ToM, 'High' vs 'Low' ToM groups = robust passers (i.e. passed all three tasks) vs rest of sample. IS = interpersonal synchrony; ToM = theory of mind.

5.4 Discussion

This chapter explored whether variation in social sensitivity to IS could be explained by variation in three processes that potentially contribute to children's experience and understanding of IS: synchrony perception, motor synchrony, and ToM understanding. In a sample of 4 to 8-year-olds with EE&BDs, abilities in all three domains increased significantly with age. However, there was no evidence of a relation between abilities in any of the three domains and children's sensitivity to IS as a marker of affiliation.

5.4.1 Synchrony perception and social sensitivity to IS

Children in the current sample displayed considerable variation both in their perceptual sensitivity to synchrony in a non-social context (Chapter 4), as well as in sensitivity to IS as a marker of affiliation (Chapter 3). However, findings from the current chapter revealed no evidence of a relation between the two. The lack of association was surprising, given that being able to detect synchrony at a perceptual level is logically necessary for it to induce affiliative effects. It also seems plausible, at a theoretical level, that the more sensitive children are to IS at a perceptual level, the greater the opportunities, over the course of development, for an IS-affiliation association to arise.

In the current study, the degree of asynchrony in the Witnessed and Experienced IS tasks was considerable, i.e. in the order of hundreds rather than tens of milliseconds (see Chapter 2). Such large asynchronies were used deliberately, as the task was designed to probe social sensitivity to IS in the absence of perceptual confounds. However, it may be that synchrony perception abilities play a greater role when affiliative effects are derived from day-to-day experiences of IS, in which the degree of IS may be more subtle and/or variable. Similarly, day-to-day experiences of IS likely involve more complex perceptual processing. Unlike the current study, in which synchrony perception was assessed using relatively simple uni-sensory, auditory stimuli, 'real world' IS involves processing a variety of complex multisensory stimuli. Thus, it may be that basic synchrony perception (as assessed here) is not related to social sensitivity to IS, but more complex perceptual processing plays a greater role.

Alternatively, it may be that very tight temporal coupling between cues is not required in order for IS to generate affiliative effects. If this were the case, highly accurate perceptual synchrony abilities would not confer a particular advantage in detecting socially relevant levels of IS, and thus a relation between perceptual synchrony and sensitivity to the social effects of IS would not be expected. This possibility is discussed further at **5.4.3** below.

5.4.2 Motor synchrony and social sensitivity to IS

In the current study, variation in children's abilities to synchronise simple motor movements with an auditory stimulus was similarly unrelated to their social sensitivity to IS. This finding was contrary to the hypothesis that increased basic motor synchrony would be associated with increased social sensitivity to IS, potentially because better motor synchrony is likely to lead to increased experience of IS and its affiliative effects over the course of development.

It may be that basic motor synchrony abilities, as assessed in the current study, are not directly related to social sensitivity to IS, but that more complex synchrony-related motor abilities play a role. For example, because the stimuli in the Motor Synchrony task were isochronous, participants were not required to monitor, predict or adapt their motor behaviour to changes in the stimulus. This was a deliberate aspect of the task design: pared down tasks were constructed in order to isolate basic motor processes (see Chapter 3). However, monitoring, prediction and adaptation are believed to contribute to successful motor synchronisation in more naturalistic contexts (Cacioppo et al., 2014; Delaherche et al., 2012; Keller et al., 2014), and each may be impaired in atypical development (Cannon et al., 2021; Gowen & Hamilton, 2013; Granner-Shuman et al., 2021; Kaiser et al., 2015; Kasten et al., 2023; Vishne et al., 2021). Similarly, the Motor Synchrony task required a simple, isolated motor movement (finger tapping), whereas IS often entails a range of fine and gross motor movements, as well as intra-personal co-ordination (Bloch et al., 2022; Bloch et al., 2019). The ability to synchronise may differ in the presence of such additional motor demands.

A further possible explanation for the lack of an observed association between motor synchrony and social sensitivity to IS may lie in the distinction between intentional and spontaneous motor synchrony. In the current study, participants were explicitly instructed to synchronise, whereas synchronisation during day-to-day social interactions is rarely instructed and may be unintentional (Oullier et al., 2008; Schmidt & Richardson, 2008). While both intentional and spontaneous IS may be reduced in atypical development (see e.g. Amrani & Golumbic, 2020; Fitzpatrick et al., 2016, although cf. Problovski et al., 2021) each is thought to arise from distinct neuropsychological processes (Keller et al., 2014; Problovski et al., 2021) and there is some evidence that they are differentially affected in atypical development (see Chapter 1, section 1.5.2). Therefore, children's abilities to synchronise when instructed to do so, as in the current study, may not be closely related to the extent to which they intentionally or spontaneously synchronise during their day-to-day interactions.

Overall, although the current study found no evidence of a relation between basic motor synchrony and social sensitivity to IS, it remains to be seen whether motor synchrony in different or more complex contexts relates to sensitivity to the social effects of IS. Similarly, the contribution of spontaneous motor synchrony, as opposed to intentional and instructed synchrony, should be investigated further.

5.4.3 A threshold for affiliative effects?

An alternative possible reason for the observed lack of association between perceptual/motor synchrony and social sensitivity to IS lies in the possibility that the degree of synchrony present in an interaction is not linearly related to the magnitude of affiliative effects (Cross et al., 2016). Rather, there may be a 'threshold' amount of synchrony that triggers positive social consequences (Tarr et al., 2018), or a threshold beyond which no additional affiliative effects occur. If increasingly precise synchronisation does not affect social outcomes beyond a certain threshold, then neither perceptual nor motor synchrony abilities that exceed the threshold would be required for affiliative effects to be reliably experienced. Consequently, social sensitivity to IS would not increase in proportion to increases in perceptual acuity and/or motor synchrony.

There is some support for the proposition that the affiliative effects of IS do not increase beyond a 'threshold' degree of synchrony. Levels of bonding (Howard et al., 2021; Wilson & Gos, 2019), trust (Launay et al., 2013) and co-operation (Cross et al., 2016) were all higher following synchronous tapping/computer-based interactions, relative to asynchronous ones. However, in the same studies, there was no association between higher levels of synchronisation and increased positive social effects (Cross et al., 2016; Howard et al., 2021; Launay et al., 2013; Wilson & Gos, 2019). Against this, however, other studies *have* found evidence of a positive relation between levels of synchrony and positive social outcomes. The degree of synchrony between partners who tapped with a visual metronome was positively associated with levels of affiliation (Hove & Risen, 2009), as did the degree of synchrony between participant tapping and the sounds attributed to their partner (Launay et al., 2014). Similarly the degree of visual synchrony between children's tapping and that of their partner was positively associated with feelings of closeness (Howard et al., 2021). These studies support the converse argument: if the degree of synchrony matters to affiliation, then so too would the ability to perceive and produce increasing levels of IS. Overall, it remains unclear whether a threshold exists at which IS generates affiliative effects; at what level such threshold might be; and how it relates to individual differences in children's perceptual and motor synchrony abilities.

5.4.4 Theory of mind and social sensitivity to IS

As with Synchrony Perception and Motor Synchrony, the ToM abilities of children within the current sample were highly variable. Although TD children typically acquire explicit first order ToM abilities around the age of 4 to 5 years (Apperly & Butterfill, 2009; Callaghan et al., 2005; Happé & Frith, 2014), a small proportion (8%) of the current sample of 4- to 8-year-olds with EE&BDs were unable to pass any of the first-order tasks, and the overall pass rate for the first-order ToM tasks was 72%. At the other extreme, however, roughly a fifth of the sample (22%) displayed robust ToM abilities, passing all four ToM tasks, including the second-order ToM task. This subset of the sample thus demonstrated ToM abilities broadly in line with those of TD children aged 6 to 7 years (Miller, 2009; Osterhaus & Koerber, 2021).

ToM abilities within the current sample were also significantly positively associated with age. This finding is in line with increasing ToM abilities during middle childhood in TD (Hughes & Devine, 2015; Osterhaus & Bosacki, 2022) and autistic children (Happé, 1995; Steele et al., 2003), as well as a different NDAU subsample of children with EE&BDs (Howe-Davies et al., 2022).

However, the current study found no evidence of a relation between ToM abilities and sensitivity to IS. This finding was contrary to the hypothesis that the two would be positively associated, because affiliation judgements necessarily entail making inferences about the mental states of social partners. One possible explanation is that the type of mental state understanding assessed in the current study may differ from that engaged when making IS-based affiliation judgements. For example, there is evidence of a partial dissociation between the neurobiological mechanisms underpinning affective and cognitive ToM (Dvash & Shamay-Tsoory, 2014; Shamay-Tsoory & Aharon-Peretz, 2007). Judging affiliation between social partners based on IS is an assessment of the socio-emotional state of others, and is therefore potentially more closely aligned with affective than cognitive ToM. Although the current study measured both affective and cognitive ToM, only one of the four ToM tasks related to affective ToM. Further, the Affective ToM task had a binary outcome measure and there was an uneven number of participants who passed vs did not pass (112 vs 42). Thus, only a limited amount of variability in affective ToM abilities was reflected in the data. It may be that a more sensitive measure of affective ToM would disclose a relation between ToM and social sensitivity to IS.

Previous research has also drawn a distinction between socio-cognitive ToM (i.e. the ability to make and verbalise explicit judgements about cognitive or affective states) and social-perceptual ToM (i.e. implicit inferences about mental states from non-verbal cues) (Apperly & Butterfill, 2009; Frith & Frith, 2008; Tager-Flusberg & Sullivan, 2000). This ‘two process’ account is supported by evidence of distinct developmental trajectories for each (Meinhardt-Injac et al., 2018; Meinhardt-Injac et al., 2020). While the tasks in the current study probed socio-cognitive ToM, IS-based affiliation judgements are implicit judgements based on non-verbal cues. Thus, they may be more closely aligned with socio-perceptual

ToM abilities. Tasks that measure spontaneous ToM (e.g Senju et al., 2012; Onishi & Baillargeon, 2005) or otherwise rely more heavily on interpretation of non-verbal cues, may provide a more direct measure of the mental state understanding abilities that contribute to social sensitivity to IS.

Finally, the ability to 'pass' explicit ToM tasks such as the ones used in the current study is closely aligned with a range of other skills, including language abilities, reasoning, and inhibitory control (Chevallier et al., 2014; Meinhardt-Injac et al., 2018). Such skills were not measured directly in this study. However, it is likely that there was considerable heterogeneity in each within the current sample, given that children were recruited based on a wide variety of teacher-identified emotional and behavioural difficulties, rather than a relatively narrow set of diagnostic criteria (Chapter 1, section 1.7.2). High levels of variation in relation to the additional task demands may have obscured the association between children's core mental state understanding and their social sensitivity to IS.

Overall, while the current study found no evidence of a relation between ToM abilities and social sensitivity to IS in children with EE&BDs, future research should probe the relation further using tasks that target affective ToM specifically and/or implicit mental state understanding.

5.4.5 Future directions

In the current study, children were explicitly directed to attend to perceptual synchrony, produce motor synchrony, as well as to assess the mental states of others. However, their tendency to engage each of these abilities during day-to-day interaction, particularly in the presence of competing social and/or sensory demands, may vary. Thus, future studies could examine the contributions of children's spontaneous synchrony perception/motor synchrony/ToM to their social sensitivity to IS.

Further, the processes examined in the current study are not the only factors that contribute to children's experiences of IS. In particular, children's patterns of social attention likely influence whether and how IS is experienced (Bowsher-Murray, Gerson, et al., 2022; Fulceri et al., 2018), and therefore its social relevance. For example, atypical patterns of social visual attending in atypical development (see e.g. Jones & Klin, 2013; Riby et al., 2013; Vabalas & Freeth, 2016; Zhao et al., 2021; Frazier et al., 2021; Braithwaite et al., 2020) may disrupt both the experience of IS and its use as a social cue. While the use of auditory-only stimuli in the current study meant that its influence was (intentionally) excluded, social visual attention is thus a further potential component process that influences how children with and without EE&BDs experience and interpret IS.

Lastly, the current study examined the direct relations between perceptual, motor and ToM abilities on the one hand and social sensitivity to IS on the other. However, the influence of these factors may be primarily indirect, that is, they may affect social sensitivity to IS via their influence on the experience of IS over time. Therefore, to further understand how different aspects of IS interrelate, it would be helpful for future research to measure directly the extent to which participants synchronise during naturalistic interactions. This would allow for exploration of the relation between the component processes examined here and the levels of IS children display, as well as the relation between displayed levels of IS and sensitivity to IS as a marker of affiliation.

5.4.6 Conclusion

The current study investigated the contributions of three basic abilities to social sensitivity to IS, namely, synchrony perception, motor synchrony and ToM. Abilities in each domain varied considerably within the sample, but there was no evidence of an association between either of the three constructs and social sensitivity to IS. The findings suggest that basic synchrony perception, basic motor synchrony and ToM abilities, at least as assessed in the current study, do not contribute to social sensitivity to IS in children with EE&BDs. However, a range of other processes may be relevant to children's interpretations of IS, including basic perceptual and motor skills in visual or multisensory modalities; more complex perceptual/motor functioning; mentalising abilities based on non-verbal cues; and/or spontaneous engagement of each component process. Further research should also explore the role of social attention and children's tendency to display IS during naturalistic interactions, in order to better understand the factors that contribute to children's use of IS as a social cue.

Chapter 6

General Discussion

6.1 Overview

IS influences TD children's feelings of affiliation and prosocial behaviour towards their social partners, as well as informing their understanding of the social relationships of others (Cirelli, 2018; Rauchbauer & Grosbras, 2020). However, little is known about the factors that account for the association between IS and its positive social outcomes (Cirelli, 2018; Hu et al., 2022; Rabinowitch, 2020; Wan & Zhu, 2022). Further, although challenges with social communication are common in neurodivergent populations (Lense et al., 2021; Mikami et al., 2019; Missiuna et al., 2014), the social significance of IS for atypically developing children is unknown (Bowsher-Murray et al., 2023; Michael et al., 2020). Variation in the social effects of IS is potentially driven by a number of processes known to operate atypically across neurodivergent populations, including temporal perception (Casassus et al., 2019; Falter & Noreika, 2014; Meilleur et al., 2020; Zheng et al., 2022), motor behaviour (Gooch et al., 2014; Goulardins et al., 2017; Hudry et al., 2020; Kilroy et al., 2022; Zampella et al., 2021), and mental state understanding (Bora & Pantelis, 2016; Happé, 2015; Nikolić et al., 2019; Poletti & Adenzato, 2013).

The overarching aim of this thesis was to describe and explain the contribution of IS to the social experiences of typically and atypically developing children. Chapter 2 sought to identify the temporal properties of IS that influence the affiliation judgements of TD children, and to understand why they had such an effect. Chapter 3 investigated whether the social effects of IS differed in children with EE&BDs, and whether children's degree of social sensitivity to IS was associated with a particular set of diagnostic traits. Chapters 4 and 5 investigated variation in three processes that likely contribute to how children with EE&BDs experience IS, namely, synchrony perception, motor synchrony, and ToM. Chapter 5 additionally explored the relations between these component processes and social sensitivity to IS in children with EE&BDs.

6.2 Summary of findings

In Chapter 2, both simultaneity and temporal regularity within witnessed interactions positively influenced TD children's assessments of partner affiliation. The effects of simultaneity and regularity were both mediated by children's subjective perceptions of the 'togetherness' of partners' actions. Taken together, these findings indicated that the affiliative effects of IS in TD children emerge via the presence of temporal interdependence between partners, which includes but is not limited to simultaneity. However, when TD children themselves experienced IS via an interaction with limited social context, no affiliative effects were observed.

In Chapter 3, findings indicated that the social effects of IS were limited in children with EE&BDs. In the sample as a whole, there was no significant relationship between witnessed IS and perceived affiliation. However, effects differed by gender, with affiliation judgements being positively influenced by regularity in boys and by simultaneity in girls, but not vice versa. For experienced IS, there was a tentative albeit non-significant pattern of evidence suggesting that children with EE&BDs felt more affiliated with partners whose actions were regular, relative to partners whose actions were either simultaneous or temporally unpredictable. Both when witnessing and experiencing IS, children's social sensitivity to IS was unrelated to their overall levels of emotional and behavioural difficulties, autistic traits, and ADHD traits.

In Chapters 4 and 5, there was evidence of considerable heterogeneity in synchrony perception, motor synchrony, and ToM abilities of children with EE&BDs. Taken together with the existing literature in relation to TD children, the evidence indicated some areas of commonality between children with and without EE&BDs. For example, the sample as a whole demonstrated comparable SMTs to those reported in TD children of a similar age (Drake et al., 2000; Fitzpatrick et al., 1996; McAuley et al., 2006; Provasi & Bobin-Bègue, 2003). In relation to synchrony perception, motor synchrony and ToM, there was evidence of difficulties in each of the three domains. Yet, a substantial proportion of children with EE&BDs demonstrated abilities broadly in line with those reported in typical samples (Berwanger et al., 2004; Cardy et al., 2010; Kanabus et al., 2002; Kwakye et al., 2011; Fitzpatrick et al., 1996; Provasi & Bobin-Bègue, 2003 Miller, 2009; Osterhaus & Koerber, 2021). Consistent with previous findings in TD children (Hillock-Dunn & Wallace, 2012; Lewkowicz, 1996; McAuley et al., 2006; Monier & Droit-Volet, 2018; Osterhaus & Koerber, 2021), abilities in all three domains increased with age. Synchrony perception, motor synchrony and ToM abilities were all unrelated to children's levels of emotional and behavioural difficulties, autistic traits, and ADHD traits.

In Chapter 5, synchrony perception, motor synchrony, and ToM abilities of children with EE&BDs were found to be unrelated to their sensitivity to the social effects of IS. Findings suggested that basic synchrony perception, basic motor synchrony and ToM abilities, at least as assessed in this thesis, do not contribute to social sensitivity to IS in children with EE&BDs.

6.3 Implications of findings

Overall, the studies presented in this thesis further the understanding of how IS informs the social experiences of TD children and children with EE&BDs.

6.3.1 Theoretical implications

Chapter 2 replicated previous findings that IS influences TD children's social judgements when they witness interactions between others (Abraham et al., 2022; Cirelli et al., 2018; Fawcett & Tunçgenç, 2017). It also extended these findings by providing evidence of the specific temporal properties that contribute to effects, which in turn shed light on why IS has affiliative effects in children. Much of the previous literature had assumed that the degree of simultaneity between partners was responsible for the affiliative effects of IS (Dignath et al., 2018; Hove & Risen, 2009; Rauchbauer & Grosbras, 2020; Tarr et al., 2015). However, the independent manipulation of simultaneity and temporal regularity in Chapter 2 demonstrated that both properties contributed to TD children's perceptions of partner affiliation, by influencing their perceptions of 'togetherness' between partners. Thus, it can be concluded that children's perceptions of IS-related affiliation arise from temporal organisation and co-ordination between partners, not just from simultaneity of action. The findings in Chapter 2 were also the first evidence of an age-related increase in social sensitivity to IS. The effect was driven specifically by an age-related increase in the effect of regularity, suggests that temporal regularity may become increasingly important to affiliation for TD children as they get older.

The findings from Chapter 2 also have implications for our understanding of the conditions that are necessary and sufficient for IS to generate affiliative effects. The findings suggest that such conditions differ depending on whether IS is witnessed or experienced. For witnessed IS, brief and socially lean interactions that were auditory-only were sufficient to generate affiliative effects, supporting the conclusion that temporal qualities of an interaction themselves are a significant social heuristic for TD children when they witness IS. When children experienced equivalent interactions for themselves, however, no affiliative effects were observed. In light of consistent previous findings that experienced IS has positive effects on affiliation in TD children (Rauchbauer & Grosbras, 2020; Trainor & Cirelli, 2015), the null effect was likely a result of the particular experimental paradigm used. Affiliative effects may have been lacking because partner presence/engagement was not sufficiently salient, and/or because sensorimotor matching of visual cues is required for affiliative effects to occur (Howard et al., 2021). Researchers seeking to induce affiliative effects via experienced IS should ensure that experimental paradigms include both these factors. Further, although more research is needed to establish which particular aspects of social interaction are relevant and necessary for experienced IS to bring about affiliative effects, the findings are a tentative indication that in-person settings may be particularly important for the development of children's peer relationships.

The findings from Chapter 3 provided the first evidence of the social significance of IS for atypically developing children. Although a direct comparison with the TD children in Chapter 2 was not possible, there was less evidence of the social effects of IS in children with EE&BDs, suggesting that the social relevance of IS is likely to be greater in TD children than in children with EE&BDs. The likely differential social significance of IS has implications for social communication between neurotypes. For example, in a neurotypical dyad, one partner may express a positive disposition towards the other (Brambilla et al., 2016; Miles et al., 2010; Zhao et al., 2015) or desire to affiliate with them (Asher et al., 2020; Paxton & Dale, 2013; Tschacher et al., 2014) by initiating IS (see Chapter 1, section 1.3.2). In response, the other neurotypical partner is likely to experience feelings of affiliation, leading them to contribute to and maintain IS, and so on, in a mutually reinforcing affiliative cycle (Gvirts & Perlmutter, 2020; Hoehl et al., 2021). By contrast, in a mixed neurotypical/divergent dyad, the neurodivergent partner may not experience IS as socially significant. Consequently, they are less likely to engage in the co-creation of IS and/or experience its positive effects. In a mixed dyad, the neurotypical partner may perceive the neurodivergent partner as socially disinterested, potentially leading to a diminution of both IS and affiliation via the opposite cyclical relationship. Thus, variation in the social significance of IS across neurotypes may be conceptualised as a specific manifestation of the 'double empathy problem' (Milton, 2012), whereby a particular construct forms part of the social reality of one neurotype but not another, resulting in mismatched communication styles and mutual difficulty in social understanding (Morrison et al., 2020). Relatedly, the reduced significance of IS for neurodivergent individuals may be one reason why autistic people do not display higher levels of IS with autistic compared to non-autistic social partners (Georgescu et al., 2020), but do report greater affiliation with autistic partners, relative to non-autistic partners (Crompton et al., 2020a). Reduced IS is less likely to be a barrier to affiliation in autistic dyads, who likely co-create affiliative relationships in other ways (Heasman & Gillespie, 2019; Rifai et al., 2022; Williams et al., 2021).

Chapters 4 and 5 found evidence of considerable variation in basic synchrony perception abilities, motor synchrony, and ToM in children with EE&BDs. In each domain, many children demonstrated significant challenges, highlighting the presence of considerable functional difficulties – and therefore potentially substantial support needs – in many children with no formal neurodivergent or other diagnosis. However, difficulties were by no means ubiquitous. Some children demonstrated temporal perception abilities comparable to those reported in neurotypical adults; many were able to demonstrate accuracy and flexibility in motor synchronisation and around a third demonstrated robust ToM abilities comparable with TD children at the upper end of the age range of the current sample. Overall, there was a wide variation in children's perceptual, motor and ToM abilities. These findings add to evidence of heterogeneity in functioning in children with EE&BDs (Ameis, 2017; Astle et al., 2022; Mareva et al., 2019; Márquez-Caraveo et al., 2021), and underscore the need for a dimensional approach to understanding the processes that contribute to children's functional difficulties.

Finally, the key finding from Chapter 5 was that neither basic synchrony perception, basic motor synchrony, nor ToM explained variation in social sensitivity to IS. Thus, alternative factors that explain reduced social sensitivity to IS in children with EE&BDs should be explored. Suggested approaches are considered in more detail at **6.5** ('Areas for further research') below.

6.3.2 Practical implications

The finding that both simultaneity and regularity promote affiliation in TD children (Chapter 2), together with the likely importance of social presence/partner engagement, has implications for understanding and shaping the sorts of day-to-day activities in which IS may influence affiliation. In addition to obviously synchronised activities such as singing and dancing (where the same actions are performed at the same time), temporal co-ordination within other activities may also have affiliative effects. For example, turn taking games and other forms of temporal predictability in play- or classroom-based activities may also be relevant for promoting affiliation in children. Thus, efforts to promote wellbeing, at the forefront of current priorities for schools in England and Wales (Neagle et al., 2018;

Newlove-Delgado et al., 2021), could incorporate specific activities that foster opportunities for temporal co-ordination via partner co-operation. Simple rhythmic activities of this sort may provide a brief and cost-effective way of promoting rapport between peers as well as between peers and educators.

Equally, however, the finding that children with EE&BDs may not experience IS as socially relevant as TD children has implications for rapport-building activities based on rhythmic co-ordination. Educators should be mindful that such activities may be less effective for atypically developing pupils than for TD pupils. Thus, there is also a need to establish alternative approaches to fostering rapport that are effective across neurotypes. Relatedly, differences in the social effects of IS are a specific instance of differing socio-communicative behaviour in typically and atypically developing children. As such, they underscore the importance of helping all children to understand and accommodate such differences in the classroom (see e.g. Alcorn et al., 2021).

Finally, the findings in this thesis also have implications for interventions that aim to increase levels of behavioural IS in atypically developing children, as a means of enhancing their social skills (e.g. Landa et al., 2011; Srinivasan et al., 2015; Koehne et al, 2016; Yoo & Kim, 2018; Daniel et al., 2022). First, the substantial variation in basic perceptual synchrony, motor synchrony and socio-cognitive skills in children with EE&BDs seen in Chapters 4 and 5 are relevant. While some children with EE&BDs may have the basic perceptual and motor skills to benefit from such an intervention, other may experience basic perceptual and motor difficulties that would be a barrier to increased IS. Second, the findings from Chapter 3 suggest that the underlying social significance of IS may be reduced or absent in children likely to be offered such an intervention. If so, they are likely to lack the motivation to act with IS, particularly outside the context of the intervention. Further, even if levels of IS are increased and maintained by intervention, the lack of affiliative consequences may mean the benefits to the children themselves are limited. To increase the chances that rapport-building interventions will be effective, a greater understanding of the ways in which atypically developing children establish rapport, as well as shared mechanisms for establishing rapport across neurotypes, is required.

6.4 Strengths and limitations

6.4.1 Strengths

A particular strength of this thesis was its use of a suite of four bespoke and complementary IS-related tasks. The social, perceptual, and motor content of the four tasks were either closely matched or the subject of manipulation. For example, the two social tasks (Witnessed and Experienced IS) were both based on tapping interactions between children using the same auditory and visual stimuli, with the only material difference being whether the participant listened to an interaction between partners (Witnessed IS) or took part in the interaction themselves (Experienced IS). Thus, meaningful comparisons could be drawn between the pattern of findings in each task. Similarly, the Synchrony Perception task used the same auditory stimuli as the Witnessed IS and Experienced task, and the Motor Synchrony task used a tapping paradigm comparable to that in the Experienced IS task. The closely matched nature of the tasks meant that unmeasured variance due to irrelevant task demands was minimised.

Similarly, the tasks were designed so that, as far as possible, confounding factors that may have affected the interpretation of results were excluded. For example, in both the Witnessed and Experienced IS tasks, partner interactions were conveyed via a single, auditory modality, and 'partners' were pictured so that their faces were not visible. This meant that the task targeted children's social judgements directly, excluding potential confounds arising from factors known to operate differently across neurotypes, such as multisensory processing (de Boer-Schellekens et al., 2013; Francisco et al., 2017; Kwakye et al., 2011; Panagiotidi et al., 2017) and patterns of social visual attention (Braithwaite et al., 2020; Frazier et al., 2021; Hedger & Chakrabarti, 2021). Similarly, potential motor confounds (Gooch et al., 2014; Goulardins et al., 2017; Hudry et al., 2020; Kilroy et al., 2022; Zampella et al., 2021) were excluded from the Witnessed and Experienced IS task, because neither depended on the participant's ability to produce accurate motor synchrony. Rather, the Witnessed IS task required no motor behaviour, and in the Experienced IS task levels of IS between the participant and their 'partner' were experimentally manipulated. Overall, therefore, the Witnessed and Experienced IS tasks were well placed to assess the IS-based social judgements of both typically and atypically developing children.

A further strength of the thesis was its use of a transdiagnostic, dimensional approach. Although most research into IS in non-TD samples has focussed on autistic people, there is also emerging evidence of reduced IS in other neurodivergent populations, together with evidence of transdiagnostic differences in temporal perception, motor synchrony, and ToM abilities (see Chapter 1, section 1.6.2). Thus, it was important to investigate the effects of IS outside the confines of traditional diagnostic categories. A purely group-based approach would have been unable to address the question as to whether reduced perceptual and motor synchrony, or social sensitivity to IS were unique to the set of diagnostic traits under consideration. By contrast, a transdiagnostic approach allowed for the conclusion that each process may be of general relevance to the social experiences of atypically developing children. Further, it highlighted the presence of a variety of functional difficulties in children with no formal diagnosis. Overall, a transdiagnostic approach allowed for more robust and contextual conclusions about variation in the synchrony-related processes under consideration.

A final strength of this thesis was the use of a functionally recruited sample (Astle et al., 2022) of children experiencing emotional and/or behavioural difficulties at school. Because inclusion in the study was not dependent on meeting a diagnostic threshold, or on meeting only a single diagnostic threshold, the evidence obtained was inclusive and representative of individual differences that may arise in atypically developing children. It is particularly important to understand the experiences of children with emerging difficulties, so that support needs can be identified and addressed at an early stage (Conroy & Brown, 2004; Humphrey & Wigelsworth, 2016; Newman, 2012). Yet, children with functional difficulties but without a formal diagnosis represent a large but generally understudied and under-resourced group (National Assembly for Wales Children Young People and Education Committee, 2018, 2020). This thesis thus contributed to the understanding of the varied perceptual, motor, and social experiences of children, and thus potential support needs, of children in this relatively neglected population.

6.4.2 Limitations

As outlined in the previous section, the suite of tasks developed for use in the current thesis were carefully designed to isolate fundamental synchrony-related abilities and to exclude the influence of a range of potential confounds. However, this high degree of experimental control also gave rise to a potential limitation in terms of the generalisability of findings. For example, social sensitivity to IS and perceptual and motor synchrony were all assessed using auditory stimuli that were highly rhythmical in nature. However, children's day-to-day experiences of IS can also occur visually (between partners' limbs, posture, facial expressions etc), cross-modally (e.g. nodding with a partner's speech) and via stimuli which are themselves multisensory in nature (e.g. with a partner whose speech and gestures are co-ordinated with each other). Similarly, while some of children's everyday social interactions are characterised by rhythmical co-ordination (e.g. clapping games; walking in step), others will have a less obvious temporal structure that varies over time (Mayo & Gordon, 2020; Tronick & Cohn, 1989). The presence or magnitude of atypical synchrony perception (Falter & Noreika, 2014; Kwakye et al., 2011; Meilleur et al., 2020) and motor synchrony (Edey et al., 2019; Morimoto et al., 2018) in neurodivergent populations may differ depending on the modality under consideration, or the degree of adaptation/responsiveness to external stimuli required (Kasten et al., 2023; Vishne et al., 2021). Thus, it remains to be seen whether findings from the current thesis, including the effects of simultaneity and regularity on affiliation in TD children, and the differential social effects of IS in typical and atypical samples, generalise to other modalities and temporal structures.

Second, although an exploration of gender effects was not an aim of this thesis, the data disclosed some evidence of gender differences in the social effects of IS in children with EE&BDs. However, there was a substantial gender imbalance in the NDAU sample, as a consequence of the fact that schools referred far more boys than girls for assessment. Together with the heterogeneity in the nature and severity of difficulties for which participants were referred to the NDAU, the relatively small number of girls in the sample mean that the gender differences found in the data are not necessarily generalisable to other girls with EE&BDs. Further, a more gender-balanced sample may have led to different findings as to the relations between sensitivity to IS and diagnostic traits (Chapter 3) and other experimental measures (Chapter 5). Although it was not possible to make firm conclusions about role of gender in the interpretation of IS in the current thesis, it is possible that there are underlying gender differences in the way children with EE&BDs experience IS. For example, there is some evidence that autistic females display higher levels of IS than autistic males (Paolizzi et al., 2022), which is consistent with broader evidence that autistic girls are more likely than autistic boys to display typical patterns of non-verbal behaviour (Hiller et al., 2014; Lai et al., 2015). Therefore, future research into the social significance of IS for atypically developing individuals should aim to account for the potential moderating role of gender in its research design and analysis.

A third limitation concerns the conditions under which the TD group completed the Witnessed and Experienced IS tasks. Due to Covid-19 restrictions on in-person testing during 2020-21, the TD group completed the task online in their own homes. While caregivers were asked to assist children to complete the task and to minimise distractions, the extent to which participants were attending to the task and complying with task instructions could not be monitored directly. Thus although the lack of social context/partner presence invoked by the Experienced IS task remains the most likely explanation for the null finding in that task (see Chapter 2), it is also possible that increased noise in the data as a result of testing conditions was a contributing factor. Had the TD group carried out the task under the same, lab-based conditions as the children with EE&BDs, affiliative effects may have been observed. This possibility has implications for the interpretation of the Experienced IS data in children with EE&BDs (Chapters 3 and 5). On one hand, it may be that for both groups, the social context/partner presence conveyed by the Experienced IS task was generally insufficient to evoke affiliative effects. Alternatively, the lack of effect in children with EE&BDs may have resulted, at least in part, from their relative insensitivity to IS as a social cue. Inconsistent testing conditions across the two groups make it difficult to evaluate which interpretation is more appropriate.

Finally, a further consequence of Covid-related restrictions and ongoing uncertainty in relation to in-person testing meant that the range of tasks completed by the TD sample (Witnessed and Experienced IS only) was narrower than that completed by children with EE&BDs (who additionally completed the Synchrony Perception, Motor Synchrony, and ToM tasks). Together with the differing conditions under which the two groups completed the tasks, this meant the scope for making between-group comparisons was limited. Importantly, it also meant that when exploring the extent to which variation in component processes related to variation in social sensitivity to IS (Chapter 5), only children with EE&BDs could be included. The inclusion of data from both TD children and children with EE&BDs in this analysis would have maximised the chances of observing an association between perceptual and motor synchrony and ToM on the one hand, and social sensitivity to IS on the other.

6.5 Areas for further research

This thesis provides the first evidence that IS is of limited social significance for children with EE&BDs. Given that IS fosters social relationships throughout the lifespan in neurotypical populations (Cross et al., 2019; Mogan et al., 2017, Rennung & Göritz, 2016), future research should investigate the social significance of IS in older neurodivergent populations, both with and without a formal neurodivergent diagnosis. Building on the evidence presented in this thesis in relation to basic auditory IS, the significance of IS in neurodivergent populations should also be explored using visual and multisensory stimuli. Further, in line with recent moves to increase the ecological validity of assessments of behavioural IS in neurodivergent populations (Georgescu et al., 2020; Koehler et al., 2021; Ragone et al., 2022), the social significance of IS for neurodivergent individuals should also be assessed in the context of naturalistic social interactions.

Further research is also required to establish the processes that contribute to variation in social sensitivity to IS. For example, although the current thesis found no relation between basic motor synchrony and social sensitivity to IS, other aspects of motor behaviour may contribute to differences in IS. While the isochronous nature of the stimuli used meant that neither action prediction nor adaptive motor behaviour were required for successful synchronisation to occur, both are likely to play a role in IS (Konvalinka et al., 2010; Sacheli et al., 2021; Shamay-Tsoory et al., 2019; Vesper et al., 2013), and both may be aspects of atypical motor behaviour in neurodivergent populations (Chambon et al., 2017; Gvirts Probolovski & Dahan, 2021; Hudson et al., 2021; Vishne et al., 2021). Similarly, aspects of ToM other than those assessed in this thesis may play a role in social sensitivity to IS. While the tasks used focussed on children's explicit cognitive and affective ToM abilities, other types of atypical mental state understanding, such as the interpretation of non-verbal cues (Ames & Jarrold, 2009; Georgescu et al., 2014), may be more closely associated with reduced social sensitivity to IS.

The contribution of factors that were not assessed in the current thesis should also be explored. In particular, children's social sensitivity to IS may relate to differences in their patterns of social attention. Picking up on the presence of IS within an interaction likely requires not only general orienting towards social stimuli (Richardson et al., 2007; Rösler et al., 2017) but flexible and dynamic attending (Johnson et al., 2016) to relevant aspects of the interaction such as facial expressions and limb movements (Fulceri et al., 2018; Khoramshahi et al., 2016). Atypical patterns of social attention in neurodivergent individuals (see e.g. Jones & Klin, 2013; Riby et al., 2013; Vabalas & Freeth, 2016; Zhao et al., 2021; Frazier et al., 2021; Braithwaite et al., 2020) may therefore play a key role in the extent to which they are socially sensitive to IS.

While the current thesis focussed on the extent to which IS promotes positive social outcomes in children with EE&BDs, research in neurotypical populations indicates a bidirectional and mutually reinforcing relation between IS and social outcomes (Gvirts & Perlmutter, 2020; Hoehl et al., 2021; Tschacher et al., 2014). Thus, to gain a fuller understanding of the relation between IS and affiliation across neurotypes, it is also necessary to establish whether social contextual factors influence levels of IS displayed by atypically developing children.

Overall, it is important to continue to explore the social significance of IS in neurodivergent populations, so as to understand the ways in which social behaviour may differ between neurotypes. However, the likely dissociation between IS and social bonding for atypically developing children also highlights the need for research into ways in which social affiliation *does* come about in neurodivergent populations (Heasman & Gillespie, 2019; Morrison et al., 2020). For example, emerging research suggests that the extent to which information is efficiently exchanged (Crompton et al., 2020a) and feelings of shared experience (Crompton et al., 2020b) are important in establishing rapport and bonding for many autistic adults. Similar research into the ways in which atypically developing children forge affiliative bonds may ultimately lead to new ways of understanding and supporting their social experiences.

6.6 Conclusion

This thesis aimed to explore how IS contributes to the social experiences of typically and atypically developing children. It presented novel findings as to the temporal properties of IS that influence the affiliation judgements of TD children (Chapter 2), suggesting that temporal co-ordination in general, rather than simultaneity of action in particular, promotes affiliation in this population. Thus, IS may be relevant to social bonding via a wide range of interactions, and may be a simple and effective way of promoting affiliation in educational settings. By contrast, IS was of limited social relevance for children with EE&BDs (Chapter 3). As this was the first investigation of the social significance of IS in children with EE&BDs, further research is required to confirm whether its social significance is reduced in other neurodivergent populations, and whether findings generalise across sensory modalities and levels of perceptual, motoric and social complexity. However, the likely differential social significance of IS for typically and atypically developing children can be thought of as a specific manifestation of the 'double empathy problem' (Milton, 2012), thus helping to explain the challenges with social communication commonly experienced by children with EE&BDs. In Chapter 4, there was considerable heterogeneity in the basic perceptual and motor synchrony abilities of children with EE&BDs, underscoring the need for a dimensional approach to understanding functional difficulty as well as the presence of potential support needs in children with no formal neurodivergent diagnosis. In Chapter 5, findings indicated that the basic synchrony perception, motor synchrony, and ToM abilities of children with EE&BDs were unrelated to their sensitivity to the social effects of IS. Further research is required to establish the factors that explain reduced social sensitivity to IS in children with EE&BDs. Equally, however, it will be important for future research to establish a greater understanding of alternative means by which atypically developing children can be supported to build social bonds.

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