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Beyond simultaneity: Temporal interdependence of behavior is key to affiliative effects of interpersonal synchrony in children

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A B S T R A C T

Interpersonal synchrony (IPS) is the temporal coordination of behavior during social interactions. IPS acts as a social cue signifying affiliation both when children witness IPS between others and when they experience it themselves. However, it is unclear which temporal qualities of IPS produce these effects and why. We hypothesized that both the simultaneity and temporal regularity of partners' actions would influence affiliation judgments and that subjective perceptions of IPS ("togetherness") would play a role in mediating these relations. In two online tasks, children aged 4 to 11 years listened to a pair of children tapping (witnessed IPS; *n* = 68) or themselves tapped with another child (experienced IPS; *n* = 63). Tapping partners were presented as real, but the sounds attributed to them were computer generated so that their temporal relations could be experimentally manipulated. The simultaneity and regularity of their tapping was systematically manipulated across trials. For witnessed IPS, both the simultaneity and regularity of partners' tapping significantly positively affected the perceived degree of affiliation between them. These effects were mediated by the perceived togetherness of the tapping. No affiliative effects of IPS were found in the experienced IPS condition. Our findings suggest that both the simultaneity and regularity of partners' actions influence children's affiliation judgments when

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witnessing IPS via elicited perceptions of togetherness. We conclude that temporal interdependence—which includes but is not limited to simultaneity of action—is responsible for inducing perceptions of affiliation during witnessed IPS.

Introduction

Interpersonal synchrony (IPS) refers to the temporal coordination of activity during social interaction (Bernieri et al., 1988; Delaherche et al., 2012; Feldman, 2007), which manifests via a range of behaviors, including gesture, gaze, and vocalization (Feldman, 2007). IPS is the complex product of a range of perceptual, social, and motoric processes (Bowsher-Murray et al., 2022), although rudimentary temporal coordination of social behavior begins to emerge from the earliest days of life (Condon & Sander, 1974; Dominguez et al., 2016). Over the course of early development, IPS is believed to promote a range of positive social and emotional outcomes, including self-regulation, empathy, and secure attachment (Evans & Porter, 2009; Feldman, 2007; Harrist & Waugh, 2002).

In addition to scaffolding relations with primary caregivers, infants and older children are influenced by IPS when evaluating social relationships within their wider social environment (Hoehl et al., 2021; Rauchbauer & Grosbras, 2020). From early on in development, IPS acts as a social cue signifying affiliation, with evidence that infants (Fawcett & Tunçgenç, 2017) and children (Abraham et al., 2022) infer greater levels of affiliation between social partners they witness interacting synchronously ("witnessed IPS") compared with those they observe acting asynchronously. Relatedly, experiencing IPS within an interaction ("experienced IPS") precipitates a range of consequences that are important in fostering social relationships. For example, experienced IPS increases children's perceived similarity to, and closeness with, their partner (Rabinowitch et al., 2015) and promotes bonding (Tarr et al., 2015). There is also evidence that experienced IPS promotes prosocial behaviors in children (Kirschner & Tomasello, 2010; Rabinowitch & Meltzoff, 2017; Tunçgenç & Cohen, 2018). IPS has been shown to induce affiliative effects in infants as young as 12 months (Tunçgenç et al., 2015) and endures as an important component of social cognition into adulthood (Cross et al., 2019; Mogan et al., 2017; Rennung & Göritz, 2016).

Although the social significance of both witnessed and experienced IPS is well documented in both children and adults, much less is known about *how* such positive social effects come about (Cirelli, 2018; Hu et al., 2022; Rabinowitch, 2020; Wan & Zhu, 2022). Two (largely untested) 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 behaviors co-occur in time) is critical (Dignath et al., 2018; Rauchbauer & Grosbras, 2020). The second proposal is that IPS 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) suggests that the affiliative effects of IPS depend on simultaneity of partner action. Indeed, much of the existing literature has assumed that simultaneity of action is an essential property of IPS (e.g., Hove & Risen, 2009; Howard et al., 2021; Tarr et al., 2016). 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, both simultaneity and regularity would lead to affiliative effects because they both provide a shared temporal framework (Demos et al., 2012; Kirschner & Tomasello, 2010; 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.

Disentangling the effects of simultaneity and regularity based on existing empirical research is challenging. Typically, studies have not 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., Fawcett & Tunçgenç, 2017; Lang et al., 2017; Rabinowitch & Meltzoff, 2017; Tarr et al., 2018; Tunçgenç et al., 2015). There is some evidence that in-phase synchrony (i.e., partners at the same point of the movement cycle at the same time) and anti-phase synchrony (i.e., partner movements always at opposite points of the movement cycle) can have equally positive effects on affiliation (Cirelli et al., 2014; Cross et al., 2016; but cf. Wiltermuth, 2012). Because in-phase synchrony is characterized by simultaneous and regular movements, and anti-phase synchrony is characterized by non-simultaneous but regular movements, one interpretation of these findings is that partners' temporal regularity—not simultaneity—underpins the affiliative effects in both cases (Cirelli et al., 2014; Cross et al., 2016; Wan & Zhu, 2022). However, other studies that manipulated temporal proximity between partners during regular interactions (e.g., Dignath et al., 2018; Lakens & Stel, 2011; Miles et al., 2009) found that higher temporal proximity (i.e., a smaller phase offset) was associated with higher levels of affiliation. These findings suggest that simultaneity *does* positively influence affiliation, notwithstanding the presence of temporal regularity. Thus, so far as temporally regular interactions are concerned, there is conflicting evidence as to whether simultaneity between partners confers an affiliative benefit. Furthermore, the role of simultaneity in interactions that are *not* characterized by temporal regularity is not addressed by this line of research.

To our knowledge, only two studies have manipulated both simultaneity and regularity independently (Cacioppo et al., 2014; Cirelli et al., 2014), each using a different sample (adults vs. infants) and outcome measure (self-reported perceived affiliation vs. helping behavior). 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). No studies have investigated the separable and combined effects of simultaneity and regularity on children's affiliation judgments beyond infancy. Overall, therefore, the temporal aspects of IPS that are responsible for its observed social effects in children are yet to be established.

It is also currently unknown whether there are developmental differences in sensitivity to the affiliative effects of IPS. Although the affiliative effects of IPS have been well documented in infants, children, and adults, previous studies have tended to examine the effects of IPS within a distinct and narrow age range. Furthermore, such studies have employed a diverse range of paradigms both when manipulating synchrony and when measuring affiliation, with infant studies tending to use behavioral outcome measures (e.g., helping) and studies with older children and adults using self-report. As such, based on the existing literature, it is difficult to assess whether the affiliative effects of IPS differ across development. However, IPS and its affiliative effects are the product of children's developing perceptual, motor, and social communication abilities (Trainor & Cirelli, 2015). Age-related changes have previously been observed during early and middle childhood in synchrony-related perceptual acuity (Hillock-Dunn & Wallace, 2012; Lewkowicz, 1996), in motor synchronization (McAuley et al., 2006; Monier & Droit-Volet, 2018), and in sociocognitive abilities (Rakoczy, 2022; Weimer et al., 2021). Thus, it is possible that sensitivity to the affiliative effects of IPS is also subject to age-related change during this period.

A further, related question concerns *why* IPS provides children with a sense of affiliation between interacting partners. In adults, there is evidence to suggest that subjective perceptions of IPS 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 toward each other (Launay et al., 2013). There is also some evidence that subjectively perceived synchrony mediated the relationship between objective levels of IPS and corresponding social judgments in adults (Hagen & Bryant, 2003; Lakens, 2010). By contrast, previous studies of the effects of IPS in children have focused exclusively on the relation between objective levels of IPS and affiliation. There is no evidence of how children subjectively perceive IPS or how such perceptions relate to their assessments of affiliation between interacting partners. One possibility is that objective and subjective perceptions of IPS are closely aligned in children, with the influence of the former mediated by the latter. Alternatively, the effects of objective IPS in children may be implicit and direct, and wholly or partially independent of their subjectively reported perceptions of IPS.

Finally, it is notable that theoretical accounts of the temporal properties and mechanisms that influence affiliation do not differentiate explicitly between witnessed and experienced IPS. The limited number of empirical studies that have differentiated between simultaneity and regularity and/or explored the role of perceived IPS all have employed paradigms based on experienced IPS. However, witnessed IPS and experienced IPS contribute to social cognition in different ways. Witnessed IPS entails making judgments about others' relationships based on observations of their non-verbal behavior. By contrast, experienced IPS 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 IPS) or generated (in the case of experienced IPS) may differ. For example, when experiencing IPS, the predictability of a partner's actions may reduce cognitive load. Reduced cognitive load is theorized to increase mutual attention, and ultimately affiliation, between partners (Hoehl et al., 2021; Miles et al., 2009). By contrast, someone who merely witnesses IPS is not part of the interaction, meaning that predictability within the interaction will not have the same consequences for the way in which the interaction is processed. Ultimately, a comprehensive account of the relative importance of simultaneity and regularity for affiliation judgments can be established only by examining both witnessed and experienced IPS.

To better understand the processes by which IPS generates affiliative outcomes in children, we investigated the separable effects of simultaneity and regularity on children's affiliation judgments both when witnessing and experiencing IPS. We further investigated the role of children's subjective perceptions of witnessed IPS by assessing the relations between the objective temporal properties of witnessed interactions, the perceived "togetherness" of partners, and affiliation judgments. Children aged 4 to 11 years completed an online activity in which they listened to a series of brief tapping interactions between pairs of children (witnessed IPS) or took part in an equivalent interaction with a series of virtual partners (experienced IPS). In both tasks, the simultaneity and regularity of tapping within each interaction were manipulated across trials. Following each interaction, participants rated affiliation between partners (witnessed IPS) or toward their partner (experienced IPS). Participants also reported whether they perceived witnessed interacting partners to have acted "together" or not. We analyzed the data in two ways. First, in keeping with much of the previous research on the effects of IPS, we compared affiliation ratings following "fully synchronous" interactions (i.e., characterized by both simultaneity and regularity) and "fully asynchronous" interactions (i.e., characterized by neither simultaneity nor regularity) together with a condition in which no interaction was witnessed/experienced. Second, to enable us to tease apart the temporal properties that may contribute to the effects of IPS, we explored the separable effects of simultaneity and regularity on affiliation.

In line with the established effects of IPS, we expected fully synchronous interactions to generate higher affiliation ratings than fully asynchronous interactions. Based on the idea that the affiliative effects of IPS arise from a shared temporal framework, and given that both simultaneity and regularity are aspects of temporal organization, we hypothesized that the presence of both simultaneity and regularity would lead to increased affiliation ratings for both witnessed and experienced IPS. For witnessed IPS, we predicted that both objective simultaneity and regularity would influence perceived IPS; that is, both would increase the likelihood of an interaction being perceived as together. Based on previous findings in adults as to the relation between subjectively perceived IPS and affiliation, we further predicted that perceived togetherness would mediate the relation between objective simultaneity and affiliation ratings. However, because togetherness is not necessarily implied by regularity, we made no predictions as to whether perceived togetherness would be associated with regularity or whether it would mediate the relationship between regularity and affiliation judgments.

Method

Participants

Participants were children aged 4 to 11 years whose caregivers responded to a study advertisement on social media (witnessed IPS task: n = 68, 40 male; M_{age} = 7 years 6 months, SD = 2 years 2 months; experienced IPS 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 IPS task was not available. A total of 19 participants completed both tasks at least a week apart (4 completed the witnessed IPS task first). Post hoc exploration of the data established that there was no effect of task order on performance in the experienced IPS task ($p = .25$). We were unable to explore order effects in the 4 participants who completed the witnessed IPS task first because of the small number of participants potentially affected. No participants had a recognized hearing impairment or diagnosed developmental disorder. Caregivers provided informed consent on participants' behalf. Participants were offered a voucher to compensate them for their time. The project was approved by the Cardiff University School of Psychology research ethics committee.

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 participants. All auditory stimuli were generated using Audacity Version 3.0.2 (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 prerecorded 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 at the bottom right-hand corner of the screen, which participants pressed to trigger delivery of the next element in the task.

Witnessed IPS task

Stimuli. Auditory stimuli of 11.5-s duration were described to participants as interactions in a tapping game played between two children. Of the 10 stimuli, 8 consisted of a series of "taps" generated by a plastic beater striking a glockenspiel (G4; ~392 Hz) and by a finger pressing a piano key (C3; ~131 Hz). The simultaneity and regularity of the "tapping" were manipulated across conditions according to a $2 \times 2 \times 2$ 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 generalizability of any effects.

Stimuli in individual conditions are described in Table 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.

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

The remaining two stimuli consisted of a voice-over that said "We cannot hear the sounds made by this pair" at the onset of the 11.5-s stimulus duration. This meant that participants had no information about the temporal properties of the interaction. Therefore, the remaining two stimuli 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 would respond to questions about each pair. An example pair of children was pictured (Fig. 1A). The glockenspiel and piano notes described above were played and were 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 (Fig. 1B). Children were pictured

Table 1
Temporal relation between glockenspiel and piano notes in tapping interactions in the witnessed interpersonal synchrony task 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.

from behind to ensure that their facial features or expressions did not influence participants' affiliation judgments. Their "names" were drawn from the last 20 names on a list of most popular names 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.

Fig. 1. Witnessed interpersonal synchrony task: Overview of procedure. Participants were told that 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, participants were introduced to two virtual children and told that they would hear the sounds made by the pair shown (B); the audio track (in which simultaneity and regularity were 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, participants rated affiliation between the pair (D) (second affiliation question not pictured). Following presentation of all 10 trials, participants were told that 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 one, participants stated whether the 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 that 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 (Fig. 1C). Immediately afterward, participants rated the level of affiliation between the two children by responding to two questions, presented sequentially, assessing perceived liking and similarity on a 4-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* (Fig. 1D). 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 5 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 perceived IPS. Each pair of children and their associated tapping interaction (if previously heard) were presented again in the same order. Participants were told, "We 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" (Fig. 1E). Participants then reported whether they perceived the sounds as "together" or "not together" (Fig. 1F). Response options remained available until one was selected.

Experienced IPS task

Stimuli. For this task, each 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 (500-ms interstimulus interval [ISI]) or slow (800-ms ISI). Participants' and partners' taps were represented by the piano and glockenspiel notes, respectively, described in the witnessed IPS task above. All partners' taps were in fact computer generated so that their onset, relative to the taps of the participants, could be manipulated across conditions. Partners' taps were either (a) simultaneous with those of the participants, (b) non-simultaneous but at regular intervals from those of the participants, or (c) non-simultaneous and at irregular intervals from those of the participants. There were 2 trials for each condition in which the tempo of the pacing stimulus was either fast or slow. Table 2 contains further details of the temporal relation between participants' and partners' taps within each condition. Similar to the witnessed IPS task, minor deviations (±2% of the beat interval) were introduced so that the interaction would more closely resemble a real-life experience.

For irregular tapping, the latency of the partners' taps varied quasi-randomly, such that it fitted a normal distribution with a standard deviation of 25% of the beat interval. This ensured that the mean beat interval was the same across all trials of the same tempo and the mean latency between notes was the same across both non-simultaneous trials (i.e., 125 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 participants in the way prescribed by each condition, each participant tap initiated a prerecorded, computer-generated

Table 2
Temporal relation between participant's and partner's tapping across conditions (experienced interpersonal synchrony task).

Condition	Temporal relation
Simultaneous	Partner's taps were simultaneous with participant's taps.
Non-simultaneous/Regular	Partner's taps followed participant's taps 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 taps with a variable latency.

audio file that contained the sound attributed both to the participant's own tap (i.e., a single piano sound) and to that of the 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 participants had no information about the timing of their partners' taps. Participants were informed that they would hear only their own taps.

Procedure. Participants completed 3 practice trials in which they were familiarized with reproducing a series of isochronous beats. For these trials, and following a short video demonstration (Fig. 2A), participants were instructed to "listen to the sound, then copy the pattern it makes" by tapping "at the same speed" as the sound presented. After this, a pacing stimulus as described above was heard. The ISIs of the pacing stimuli were 800, 500, 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 (Fig. 2B). 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 (Fig. 2C).

In the experimental 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" (Fig. 2D). 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 IPS task and was described as the participant's partner for the "round." Eight partner image/name combinations from the witnessed IPS task were chosen at random to be re-used in the current 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, after which the participant responded by tapping on an image of a drum (Fig. 2E), with each tap generating the piano sound described above. Whether or not the partner's tapping was also heard, and if so its timing relative to that of 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 afterward, participants rated their feelings of affiliation toward their partners by responding to two questions, as described in the witnessed IPS task except that they were worded to target the participants' own feelings toward each of their tapping partners (Fig. 2F). As before, response options remained available until one was selected.

All participants were presented with the same 8 experimental trials. Trials were presented in one of two fixed orders counterbalanced across participants. The two fixed orders were constructed such that the first 4 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.

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 from 1 to 4, with higher values indicating greater liking/similarity. For both tasks, scores for Question 1 (liking) and Question 2 (similarity) were positively associated, $r_s(680) = .65$, $p < .001$ (witnessed IPS) and $r_s(504) = .59$, $p < .001$ (experienced IPS). Analyzing scores for Questions 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 scores between fast (500-ms ISI) and slow (800-ms ISI) conditions revealed no significant effect of tempo on affiliation score, $t(67) = 0.16$, $p = .87$ (witnessed IPS) and $t(67) = 0.56$, $p = .58$ (experienced IPS). Therefore, all affiliation scores were 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 analyses of variance (ANOVAs) were used to assess (a) the effect of fully synchronous tapping (i.e., both simultaneous

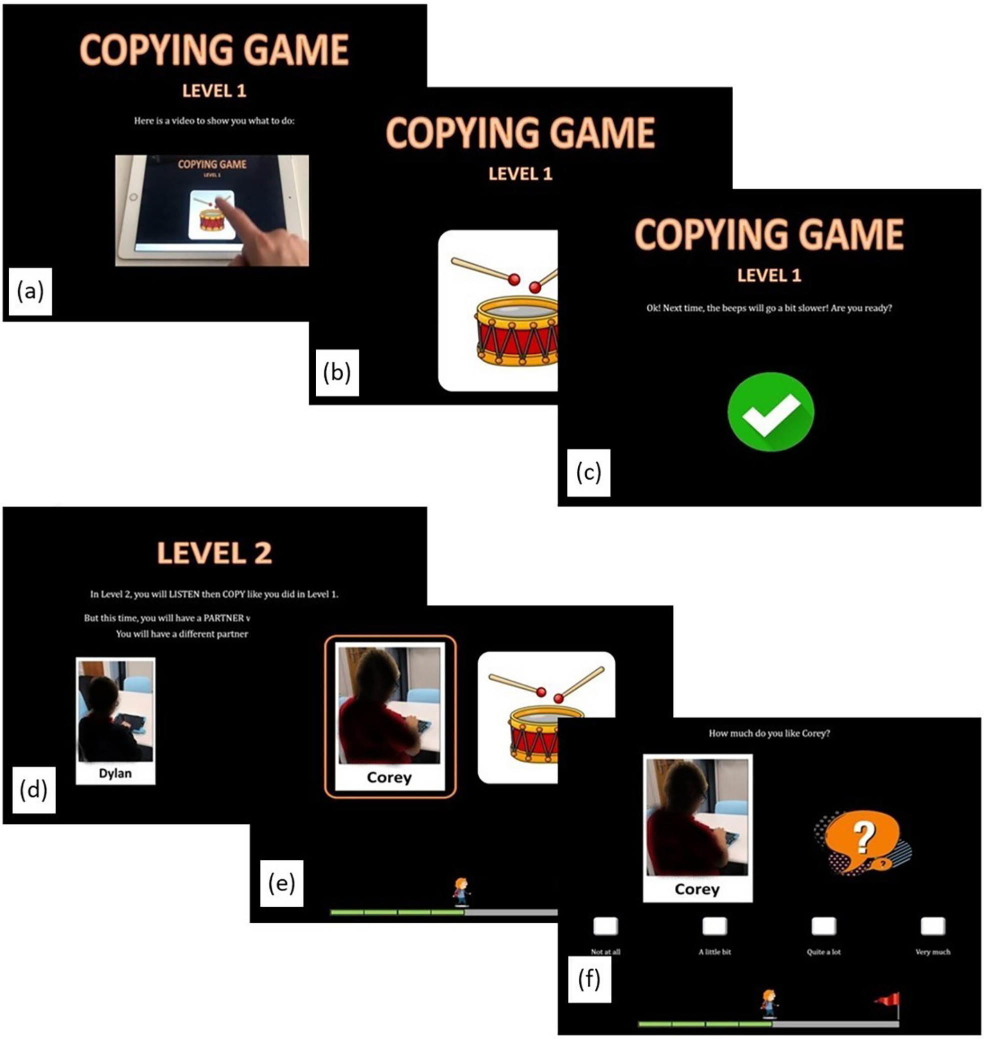

Fig. 2. Experienced interpersonal synchrony task: Overview of procedure. Participants were shown an instruction video demonstrating how to reproduce an isochronous pacing signal (A). Three practice trials followed, in which they reproduced a pacing signal by tapping on an image of a drum (B). A tick indicated completion of each trial (C). Participants were told that they would repeat the activity but that a partner would "be doing it too" (D). There were 8 trials in which the taps of both participants and their partner were heard (with the partner's tapping manipulated for simultaneity and regularity with participants across trials). The partner's image was outlined in orange throughout the tapping portion of the trial to denote the partner's participation (E). Immediately after each partner's interaction, participants rated their feelings of affiliation toward 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.

and regular, as typically conceptualized 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, and (b) the separable effects of simultaneity and regularity on affiliation scores. Bonferroni-corrected post hoc analysis was carried out as appropriate. For witnessed IPS, generalized linear mixed models (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), we then assessed whether the perceived togetherness of an interaction mediated the relations between simultaneity and affiliation scores and between regularity and affiliation scores. Linear mixed models 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 judgments were influenced by (a)synchrony was quantified using difference scores. For each task, "synchrony difference scores" were calculated for the participants 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 judgments. Further difference scores were created to quantify sensitivity to simultaneity (mean score across the two simultaneous conditions minus 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 and 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.

Results

Witnessed IPS

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: (a) fully synchronous tapping (i.e., both simultaneous and regular), (b) fully asynchronous tapping (i.e., neither simultaneous nor regular), and (c) partner tapping not heard, $F(1.75, 117.21) = 57.64$, $p < .001$, $\eta^2 = .46$ (Fig. 3). Post hoc analysis revealed that affiliation scores were significantly higher in the fully synchronous condition than in both the fully

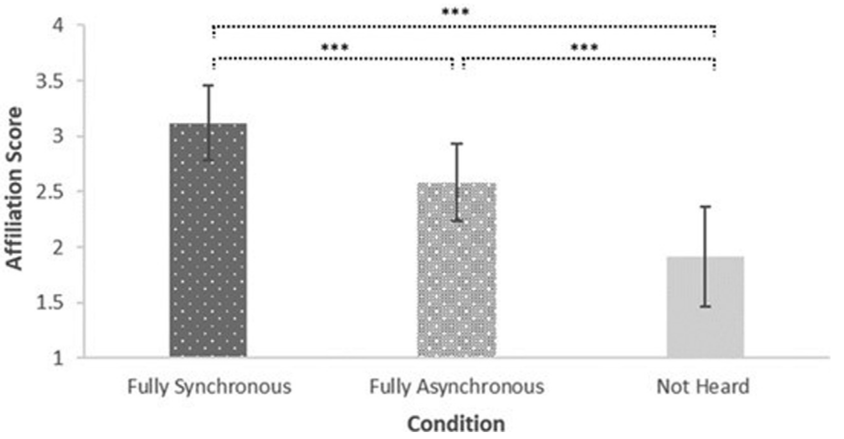

Fig. 3. Witnessed interpersonal synchrony: Effect of fully synchronous tapping on affiliation scores. Fully synchronous: simultaneous and regular tapping; Fully asynchronous: tapping was neither simultaneous nor regular. Minimum score = 1; maximum score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviations. ***$p < .001$.

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).

Individual differences in sensitivity to IPS 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 (Fig. 4).

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, $F(1, 67) = 10.17$, $p = .002$, $\eta^2_p = .13$, 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, $F(1, 67) = 26.86$, $p < .001$, $\eta^2_p = .29$, indicating that regular tapping (M = 3.07, SD = 0.55) attracted significantly higher affiliation scores than irregular tapping (M = 2.73, SD = 0.56) (Fig. 5).

The interaction between simultaneity and regularity was close to significance, $F(1, 67) = 3.33$, $p = .07$, $\eta^2_p = .05$. 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, $t(67) = 1.13$, $p = .26$, $d = 0.14$.

Effect of gender and age

When gender was entered into the ANOVA as a between-participants factor, the interaction between simultaneity and gender, $F(1, 66) = 0.26$, $p = .62$, $\eta^2_p = .004$, the interaction between regularity and gender, $F(1, 66) = 0.28$, $p = .60$, $\eta^2_p = .004$, and the three-way interaction among simultaneity, regularity, and gender, $F(1, 66) = 0.11$, $p = .74$, $\eta^2_p = .002$ all were 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 that the effect of IPS on affiliation scores was age sensitive and driven specifically by increasing sensitivity to regularity with age.

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 (Fig. 6). The effect of simultaneity and

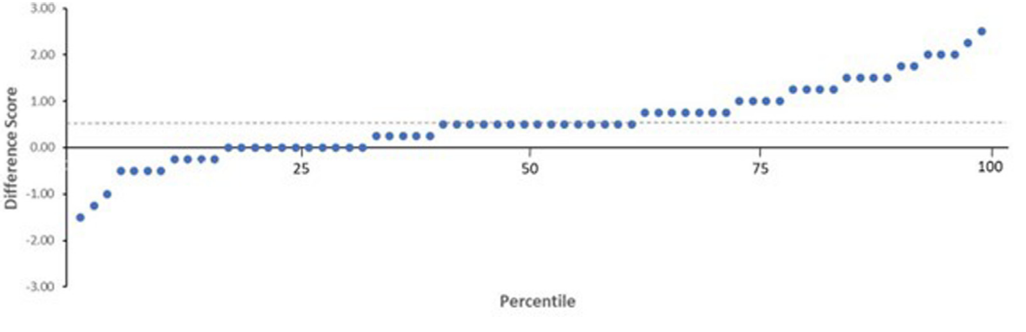

Fig. 4. Witnessed interpersonal synchrony: Difference scores of individual participants. Each data point represents the difference score of an individual participant. Dotted line indicates mean difference score.

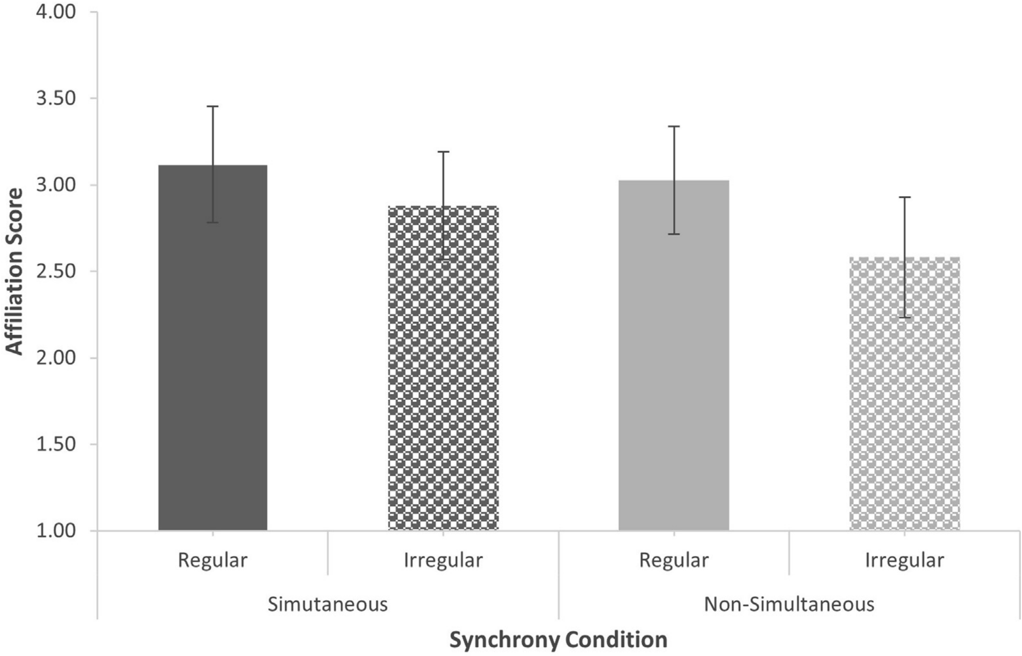

Fig. 5. Witnessed interpersonal synchrony: Mean affiliation scores for each combination of simultaneity and regularity during witnessed interactions. Minimum score = 1; maximum score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviations.

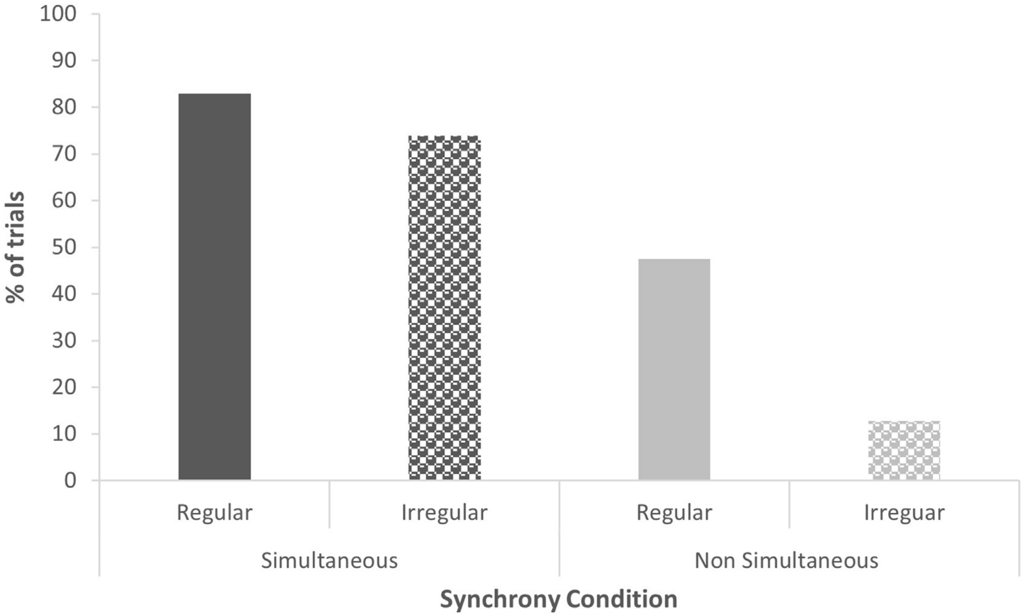

Fig. 6. Witnessed interpersonal synchrony: Percentage of trials in which tapping was perceived as "together" by synchrony condition.

regularity on the likelihood of tapping being perceived as together was investigated using a GLMM with simultaneity, regularity, and a Simultaneity × Regularity interaction term as dummy-coded binary predictor variables and with perceived togetherness as the binary outcome variable. Both simultaneity (β = 3.10, t = 9.31, p < .001) and regularity (β = 1.95, t = 6.12, p < .001) had a significant positive effect on the likelihood of perceiving tapping as together.

Because the 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, but that the presence or absence of regularity did not significantly influence participants' perceptions of the togetherness of simultaneous tapping.

Mediation analyses indicated that perceived togetherness fully mediated the relation between simultaneity and affiliation scores (Fig. 7A) and perceived togetherness partially mediated the relation between regularity and affiliation scores (Fig. 7B) ($z_{\text{Mediation}}$ = 2.53, p = .001).

Experienced IPS

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 (a) partners tapped simultaneously with participants, (b) partners' tapping was fully asynchronous, and (c) partners' taps were not heard, F(1.80, 111.80) = 0.61, p = .53, η^2 = .01 (Fig. 8).

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 (Fig. 9).

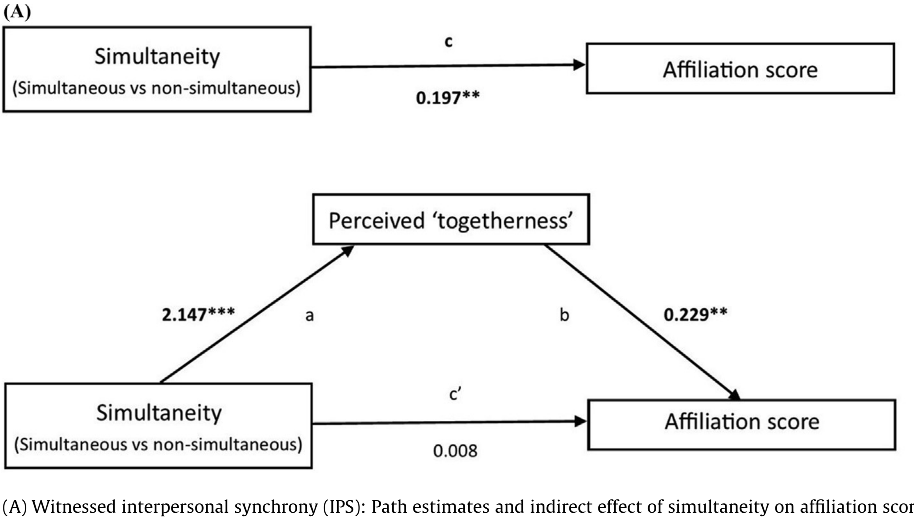

Fig. 7. (A) Witnessed interpersonal synchrony (IPS): Path estimates and indirect effect of simultaneity on affiliation scores. (B) Witnessed IPS: Path estimates and indirect effect of regularity on affiliation scores. Perceived "togetherness" fully mediated the relationship between objective simultaneity and affiliation scores and partially mediated the relationship between objective simultaneity and affiliation scores. Path values are unstandardized regression coefficients. Significant effects are in bold. $^{**}p$ < .01, $^{***}p$ < .001.

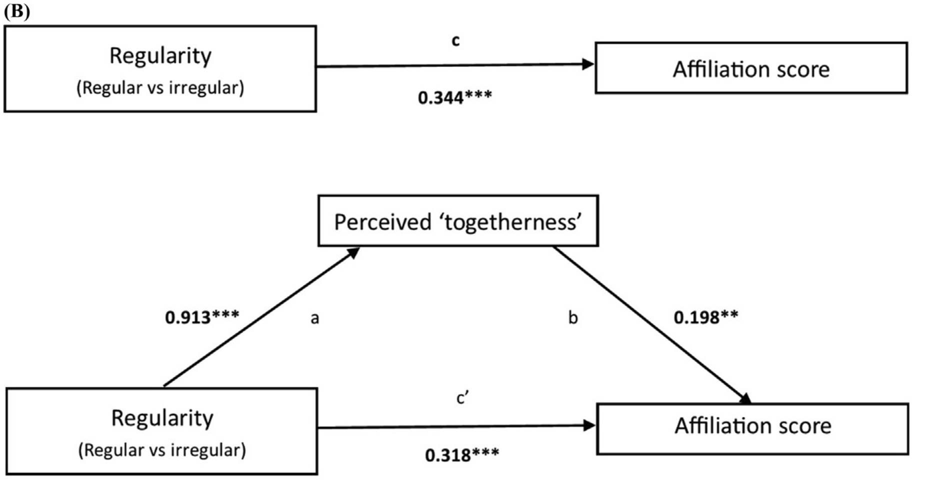

Fig. 7 (*continued*)

The separable effects of simultaneity and regularity on affiliation scores

A further one-way repeated-measures ANOVA compared affiliation scores where (a) partners tapped simultaneously, (b) partners' tapping was non-simultaneous but regular (i.e., at a fixed latency), and (c) partners' tapping was non-simultaneous and irregular (i.e., at a variable latency). Scores were not significantly different between conditions, $F(1.64, 101.53) = 1.65$, $p = .20$, $\eta^2 = .03$ (Fig. 10).

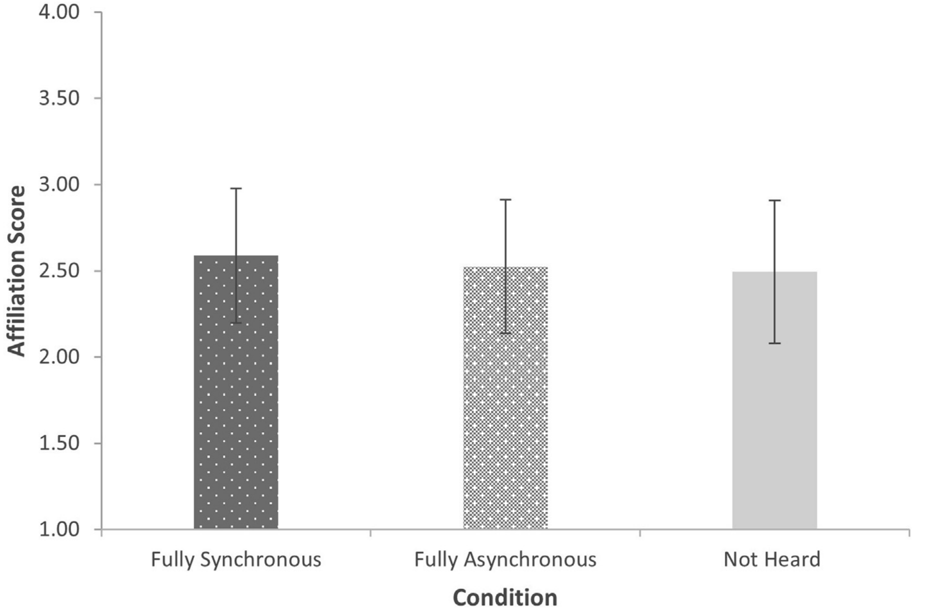

Fig. 8. Experienced interpersonal synchrony: Effect of fully synchronous tapping on affiliation scores. Minimum score = 1; maximum score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviations.

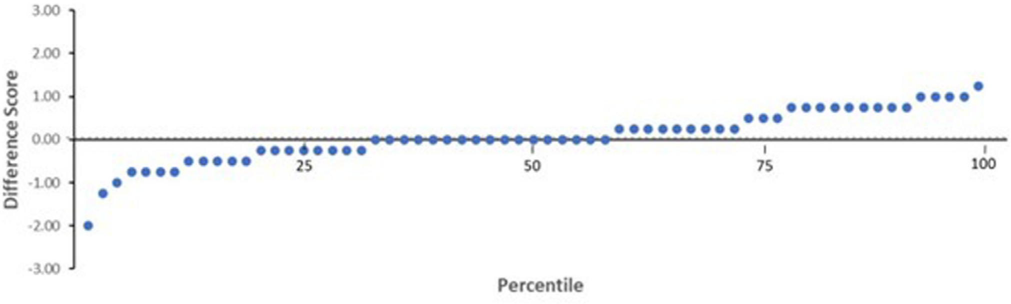

Fig. 9. Experienced interpersonal synchrony: Synchrony difference scores of individual participants. Each data point represents the synchrony difference score of an individual participant. Dotted line (just visible) indicates mean synchrony difference score.

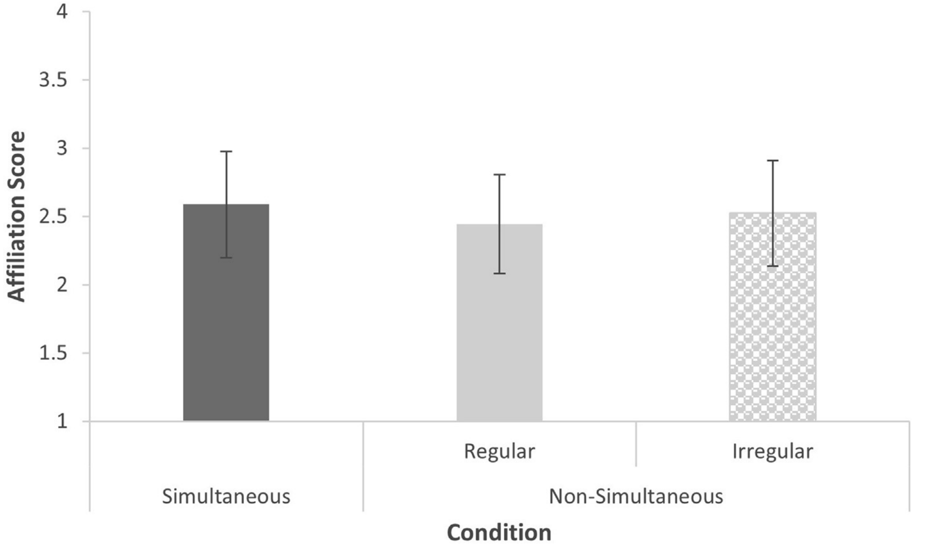

Fig. 10. Experienced interpersonal synchrony: Mean affiliation scores for each combination of simultaneity and regularity. Minimum score = 1; maximum score = 4; higher scores indicate greater affiliation. Regular: partners tapped with fixed latency; Irregular: partners tapped with variable latency. Error bars indicate standard deviations.

Effect of gender and age

When gender was entered into the ANOVA as a between-participants factor, the interaction between gender and synchrony condition was non-significant, $F(1.7, 100.9) = 2.90$, $p = .07$, $\eta_p^2 = .05$, and the effect of the synchrony conditions remained non-significant, $F(1.7, 100.9) = 2.60$, $p = .09$, $\eta_p^2 = .04$. 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: $r(63) = .16$, $p = .22$].

Association between affiliation judgments following witnessed and experienced IPS

For the 19 participants who completed both tasks, the mean synchrony difference score for witnessed IPS was 0.86 ($SD = 0.72$) and the mean synchrony difference score for experienced IPS was 0.37 ($SD = 0.64$). There was no significant association between synchrony difference scores for witnessed IPS and experienced IPS, $r(17) = -.08$, $p = .37$.

Discussion

The affiliative effects of IPS in children have been extensively documented. Much less is known about the mechanisms that translate the objective temporal relations between partners into subjective assessments of their social relationships. In an online study involving both witnessed and experienced IPS, we explored how the temporal properties of IPS influenced the affiliation judgments of 4- to 11-year-old children. Our novel approach examined the separable effects of simultaneity and regularity on children's affiliation judgments and also investigated the mediating effect of perceived "togetherness." We found that the effect of IPS on children's affiliation judgments for witnessed interactions was not uniquely contained in either the simultaneity or regularity of an interaction; rather, both simultaneity and regularity were associated with increased perceived affiliation between partners. Both 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 IPS in children are not limited to interactions characterized by simultaneity but rather emerge via a more generalized assessment of temporal interdependence between partners. By contrast, no affiliative effects of IPS were found in the experienced IPS task. Potential explanations for this finding are discussed further below.

The separable effects of simultaneity and regularity when witnessing IPS

Both simultaneity and temporal regularity positively influenced children's perceptions of affiliation when witnessing IPS. Thus, our findings indicate that the affiliative effects of IPS occur when there is a discernible temporal relationship between partners. Although both simultaneity and temporal regularity fulfill 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. Although 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 led to significantly higher perceived levels of affiliation between partners only 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 organized partners as higher in affiliation than temporally disorganized partners, with both simultaneity and regularity playing a significant role. However, there is a tentative indication that simultaneity may increase affiliation only in the absence of regularity and might 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.

Our principal finding—that both simultaneity and regularity lead to increased perceived affiliation in relation to witnessed IPS—does not support narrower theoretical accounts proposing that the affiliative effects of IPS stem from a perception of similarity that arises specifically when behavior co-occurs in time (e.g., Dignath et al., 2018; Valdesolo & Desteno, 2011). Rather, the influence of *both* simultaneity and temporal regularity supports the broader interpretation whereby children's affiliation judgments 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 cooperation, shared intentionality, and thus affiliation between interacting partners (Kirschner & Tomasello, 2010; Reddish et al., 2013; Wan & Fu, 2019; Wan & Zhu, 2022). However, because we did not directly measure or manipulate perceptions of cooperation or shared intentionality, this element of the proposed pathway is not yet supported by direct evidence.

Developmental differences in the effects of witnessed IPS on affiliation

Within our sample of 4- to 11-year-olds, witnessed IPS had a greater effect on the affiliation judgments of older children compared with younger children. 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 behavior is influenced only by simultaneity, and not by regularity (Cirelli et al., 2014), but that both simultaneity and regularity influenced the affiliation judgments 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 behavior toward their social partners relative to those who acted according to an irregular beat (Wan & Fu, 2019). Taken together with our finding of an increasing influence of regularity during middle childhood, the evidence suggests that the affiliative influence of simultaneity may develop earlier than that of regularity, with the former present during infancy but the latter emerging during 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.

Subjectively perceived togetherness

Both simultaneity and regularity in witnessed IPS influenced children's judgments 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 IPS (e.g., Lakens, 2010; Lang et al., 2017; Launay et al., 2014; Reddish et al., 2013; but cf. Demos et al., 2012). Our study also examined the separable effects of simultaneity and regularity on perceptions of togetherness. We found that objective simultaneity led to significantly higher perceptions of togetherness than non-simultaneity. This finding was not unexpected given that participants were, in effect, instructed to make a simultaneity judgment ("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 judgments 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 and 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; Ismaail et al., 2019; Wightman et al., 1989). 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.

Our findings 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 judgments but partially mediated the relation between regularity and affiliation judgments, suggesting that regularity had both a direct effect and an indirect effect (via perceived togetherness) on children's affiliation judgments. 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, our findings suggest that the affiliation judgments 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. Furthermore, the mediating role of perceived IPS suggests that for children, as for adults, variation in the ability to perceive IPS is likely to lead to variation in the extent to which objective levels of IPS influence social outcomes (Lakens, 2010).

IPS as a social heuristic in children

Our finding that children perceive synchronized partners as higher in affiliation than asynchronous partners is consistent with previous research into the influence of witnessed IPS on children's social judgments (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 an adult engaged side by side in a painting activity using either synchronous or asynchronous movements (Abraham et al., 2022). Ours was a socially "lean" paradigm in comparison; the brief (11.5 s) interactions on which affiliation judgments were based included no visual movement information and minimal social contextual information. Nevertheless, IPS influenced affiliation judgments with medium to large effect sizes. Thus, our study extends previous findings by providing evidence that the temporal structure of an interaction is itself sufficient to influence children's affiliation judgments when witnessing IPS even in the absence of physical congruency or of other visible features of the interaction. Our findings suggest that for children, as for adults (Fessler & Holbrook, 2016; Miles et al., 2009), the temporal properties of interactions are a heuristic for interpreting relationships between other people.

Experienced IPS

The temporal relations between partners had no effect on children's affiliation judgments for experienced IPS. This result contrasts with findings from previous studies in which experiencing IPS elicited affiliative effects in children (e.g., Cirelli et al., 2014; Kirschner & Tomasello, 2010; Rabinowitch et al., 2015; Tarr et al., 2015; but cf. Kirschner & Ilari, 2014). Notably, however, all these studies employed in-person interactions between children or between child participants and an adult researcher. In our task, "partners" were not physically present but instead were represented by photographs and names, and their movements were not visible. For any affiliative effects to arise, children would have needed 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 our witnessed IPS task also employed photographs and auditory-only stimuli. When experiencing IPS, however, the attribution of sounds to the actions of a human partner—and thus any affiliative effect—may further depend on the salience of the partner's "live" involvement in the interaction. We attempted to convey a sense of partner involvement by using the name and picture of a real child and by referring to the partner in task instructions. However, comparable adult studies in which interactions took place via computer button presses (e.g., Cacioppo et al., 2014; Koehne et al., 2016; Launay et al., 2014) 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 our null finding is that our task design did not convey to participants a sufficiently keen sense of a 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. However, because we did not ask participants directly about their beliefs/experience in relation to the partner's participation, we are unable to assess directly the extent to which these factors affected our findings. A further possible explanation for the null finding in the experienced IPS task relates to the absence of movement cues. IPS conveyed only via auditory signals has previously been found to elicit affiliative effects in adults (e.g., Cacioppo et al., 2014; Koehne et al., 2016; Kokal et al., 2011; Launay et al., 2013). However, it is possible that the affiliative effects of experienced IPS 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, we cannot rule out the possibility that some participants experienced a lag between initiating and hearing their own taps because of internet connection/speed issues. This would have been a source of noise in the data, although not one that directly affected the synchrony between participant and partner. Overall, the relative influence of simultaneity and regularity on affiliation judgments in the context of experienced IPS and 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.

Limitations and future directions

Our findings were based on highly rhythmical auditory interactions. Some of children's everyday social interactions are characterized by deliberate or spontaneous rhythmical coordination (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 our stimuli, they are also likely to contain substantial visual content and other forms of social information. It remains to be seen whether our findings in relation to simultaneity, regularity, and perceived togetherness generalize 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 IPS 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 we were unable to monitor directly. However, it is also possible that the variability within difference scores reflects individual differences in children's responsiveness to IPS when judging affiliation between others stemming, for example, from individual differences in perceptual and/or social processing. Further research is required to understand the extent of any such individual differences and the factors that underpin them.

Our study examined affiliative effects of IPS in typically developing children. Yet, differences in rhythm and timing (Lense et al., 2021) and in social cognition (Baribeau et al., 2015; Bora & Pantelis, 2016) have been observed across neurodevelopmental conditions. There is also specific evidence that individuals with attention-deficit/hyperactivity disorder (Problovski et al., 2021), as well as autistic people (Georgescu et al., 2020; Marsh et al., 2013) exhibit reduced IPS. However, there is limited existing research on the affiliative effects of IPS in people with neurodevelopmental conditions, which may be relevant in understanding differences in social functioning in neurodivergent populations.

In addition, our findings have potential implications for the development of IPS-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, IPS-based interventions have largely aimed to induce simultaneity of movement between partners. However, in relation to witnessed IPS at least, our 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.

Finally, the fact that IPS did not influence affiliation in the socially lean paradigm employed in our experienced IPS 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 are 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 well-being in clinical contexts (Wong et al., 2020) as well as supporting social functioning in neurodevelopmental conditions (Jiménez-Muñoz et al., 2022; Stone et al., 2019). Our findings highlight the possibility that, if partner presence and engagement are insufficiently salient in such interactions, the social benefits they are designed to deliver may be reduced or absent. As such, our findings 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).

Conclusion

This is the first study to establish that both the simultaneity and regularity of partners' actions influence children's affiliation judgments when the children witness IPS. Our findings indicate that children judge affiliation between partners according to their temporal interdependence, which includes but is not limited to simultaneity of action. Furthermore, this is the first study to establish the mediating role of children's perceptions of "togetherness" when judging affiliation from witnessed IPS. Importantly, these effects were established in the context of very limited social cues, providing strong support for the importance of temporal structure in influencing children's perceptions of affiliation. By contrast, when children experience IPS, 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 IPS in both typical and neurodivergent development.

Author contributions

Claire Bowsher-Murray: conceptualization, methodology, software, formal analysis, investigation, data curation, writing–original draft, writing–review & editing; Catherine R. G. Jones: conceptualization, methodology, writing–review & editing, supervision; Elisabeth von dem Hagen: conceptualization, methodology, writing–review & editing, supervision.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2023.105669.

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