Beyond Simultaneity: Temporal Interdependence of Behaviour is Key to Affiliative Effects of

Interpersonal Synchrony in Children

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Abstract

Interpersonal synchrony (IS) is the temporal co-ordination of behavior during social interactions. IS acts as a social cue signifying affiliation, both when children witness IS between others and when they experience it themselves. However, it is unclear which temporal qualities of IS produce these effects, and why. We hypothesized that the simultaneity and temporal regularity of partners' actions would each influence affiliation judgements, and that subjective perceptions of IS ('togetherness') would play a role in mediating these relations. In two online studies, children aged 4-11 years listened to a pair of children tapping together (witnessed IS; N=68) or themselves tapped with another child (experienced IS; N=63). Tapping partners were presented as real but were virtual. The simultaneity and regularity of their tapping was systematically manipulated across trials. For witnessed IS, 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 IS were found in the experienced IS condition. Our findings suggest that both the simultaneity and regularity of partners' actions influence children's affiliation judgements when witnessing IS, 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 IS.

Interpersonal synchrony (IS) refers to the temporal co-ordination 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). IS is the complex product of a range of perceptual, social and motoric processes (Bowsher-Murray et al., 2022), although rudimentary temporal co-ordination 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, IS 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 care givers, infants and older children are influenced by IS when evaluating social relationships within their wider social environment (Hoehl et al., 2021; Rauchbauer & Grosbras, 2020). From early on in development, IS 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 IS"), compared to those observed acting asynchronously. Relatedly, experiencing IS within an interaction ("experienced IS") precipitates a range of consequences that are important in fostering social relationships. For example, experienced IS 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 IS promotes pro-social behaviors in children (Kirschner & Tomasello, 2010; Rabinowitch & Meltzoff, 2017; Tunçgenç & Cohen, 2018). IS 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 & Goritz, 2016).

Although the social significance of both witnessed and experienced IS 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), such that the affiliative effects of IS depend upon the simultaneity of partners' actions. 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). Under the second proposal, IS is thought to drive 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). Accordingly, the affiliative effects of IS result from the partners sharing the same temporal framework (Demos et al., 2012; Kirschner & Tomasello, 2010; Wan & Zhu, 2022). Both simultaneity and temporal regularity – whereby partners' actions occur at constant temporal intervals – can provide temporal contingency. This second proposal therefore takes a broader approach, with regularity and simultaneity each leading to affiliative effects. 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. 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. Lang et al., 2017; Tarr et al., 2018; Tunçgenç et al., 2015; Rabinowtich & Meltzoff, 2017; Fawcett & Tunçgenç, 2017). A minority of studies have manipulated the length of the delay between partners' actions, but not its variability (e.g. Miles et al., 2009; Lakens & Stel, 2011; Dignath et al., 2018), such that simultaneity varies across conditions but regularity does not. To our knowledge, only two studies have manipulated both simultaneity and regularity independently (Cacioppo et al., 2014; Cirelli et al., 2014), each using different samples (adults vs infants) and outcome measures (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 effects of simultaneity and regularity on children's affiliation judgements beyond infancy. Overall, therefore, the temporal aspects of IS that are responsible for its observed social effects in children are yet to be established.

A further, related question concerns *why* IS provides children with a sense of affiliation between interacting partners. 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 perceived synchrony mediated the relationship between objective levels of IS and corresponding social judgements in adults (Hagen & Bryant, 2003; Lakens, 2010). By contrast, there is no evidence of how children subjectively perceive IS, or how such perceptions relate to their assessments of affiliation between interacting partners.

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. The limited number of empirical studies that have differentiated between simultaneity and regularity and/or explored the role of perceived IS have all employed paradigms based on experienced IS. However, it is possible that the relative importance of simultaneity and regularity in IS may differ depending on whether IS is witnessed or experienced. Any differences can only be established by examining witnessed and experienced IS separately.

To better understand the processes by which IS generates affiliative outcomes in children, we investigated the separable effects of simultaneity and regularity on children's affiliation judgements, both when witnessing and experiencing IS. We further investigated the role of the perceived 'togetherness' of witnessed interacting partners in affiliation judgements. 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 IS), or took part in an equivalent interaction with a series of virtual partners (experienced IS). In both tasks, the simultaneity and regularity of tapping within each interaction was manipulated across trials. 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.

We hypothesized that the presence of both simultaneity and regularity would lead to increased affiliation ratings for both witnessed and experienced IS. For witnessed IS, we predicted that objective simultaneity would increase the likelihood of an interaction being perceived as together. 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 had no predictions as to whether perceived togetherness would be associated with regularity, or whether it would mediate the relationship between regularity and affiliation judgements.

Material and Methods

Participants

Participants were children aged 4 to 11 years whose caregivers responded to a study advertisement on social media, N = 68 (40 male; M = 7 years 6 months; SD = 2 years 2 months) (witnessed IS task); N = 63 (38 male; M = 7 years 8 months; SD = 1 year 10 months; 65% White, 19% Asian, 13% of multiple ethnic backgrounds, 3% no ethnic background specified) (experienced IS task). 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). 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 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.

Witnessed IS Task

Stimuli. Auditory stimuli of 11.5s 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 (500ms beat interval) or slow (800ms beat interval). 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.

Table 1

Temporal relation between glockenspiel and piano notes in tapping interactions in the witnessed synchrony task for both fast (500ms) and slow (800ms) 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 = 125ms; slow trials = 200ms).
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. They 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. 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 1**). 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 1

Witnessed IS task: example of an introductory trial screen
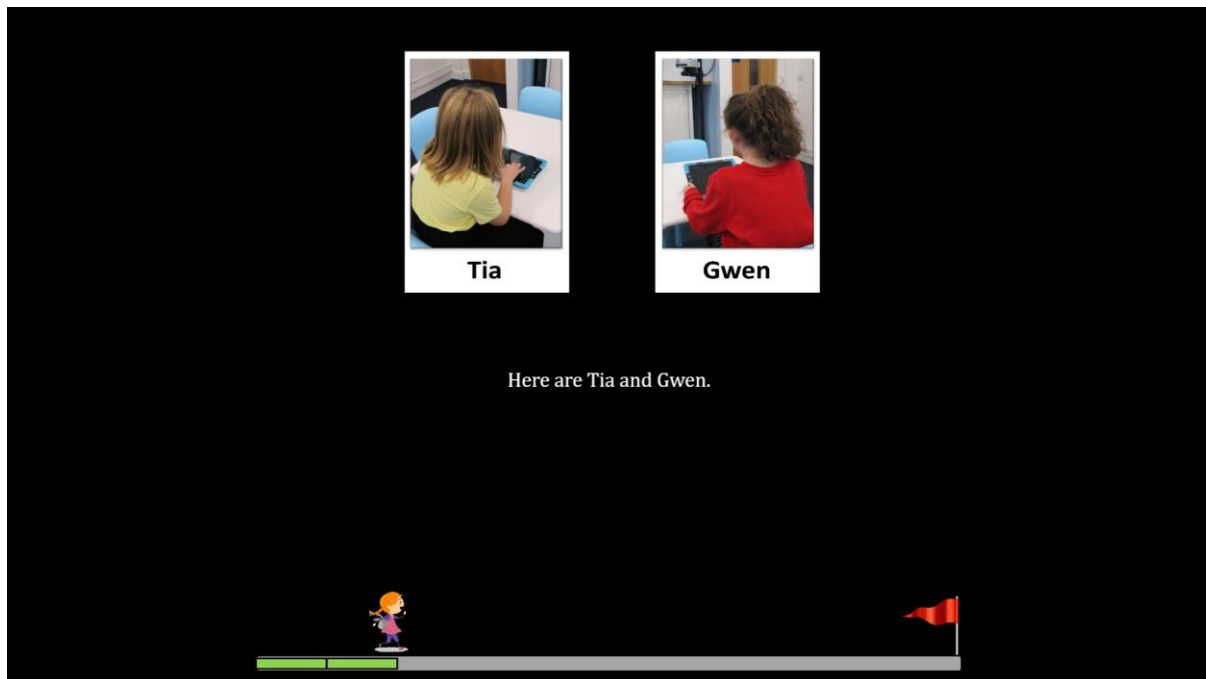
Note. The participant is introduced to two virtual children. Later in the trial they will hear the children 'make some sounds' that are manipulated for their degree of simultaneity and regularity with one another. A figure moving left to right along a path at the bottom of the screen indicates progress through trials.

Participants were told they would hear the sounds made by the pair shown, and one of the

stimuli described above was presented. At the stimulus onset, an orange line forming a frame

around the image of each partner appeared, and then disappeared at the stimulus offset.

Immediately after stimulus offset, 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*'. 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.

Trials were 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 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.*' Participants then reported whether they perceived the sounds as '*together*' or '*not together*'. Response options remained available until one was selected.

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 500ms) or slow (ISI 800ms). 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** 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

Temporal relation between participants' and 'partners'' tapping across conditions (experienced IS task)

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. 125ms (fast) or 200ms (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. 125ms and 200ms 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 familiarized with reproducing a series of isochronous beats. For these trials, and following a short video demonstration, 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 800ms, 500ms and 800ms 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. 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.

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*.' 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**), 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 3s. 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'. As before, response options remained available until one was selected.

Figure 2

Experienced IS task: Example of a trial screen
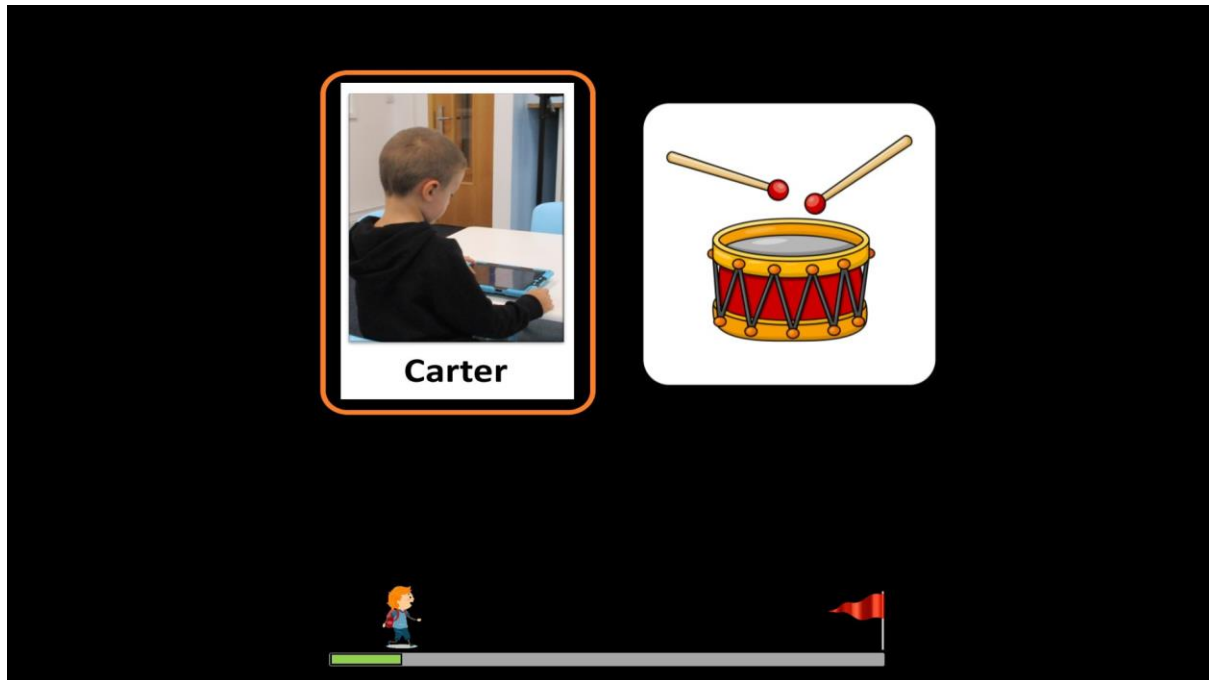
Note. The participant has been told that both they and their partner (Carter, in this example) should listen to a sequence of tones and then copy by tapping. During the tapping portion of the trial, the participant taps on the drum icon. The partner's taps are also heard (depending on the trial). Throughout the tapping portion of the trial, the partner's image is outlined in orange to denote their participation. The partner's tapping is manipulated for simultaneity and regularity with the participant. A figure moving left to right along a path at the bottom of the screen indicates progress through 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.

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). Analyzing 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 scores between fast (ISI 500ms) and slow (ISI 800ms) 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 conceptualized in previous studies) on affiliation scores; 2) the separable effects of simultaneity and regularity on affiliation scores. Bonferroni-corrected post-hoc analysis was carried out as appropriate. The extent to which individual participants' affiliation judgements were influenced by (a)synchrony was quantified using difference scores. For each task, 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. For witnessed IS, Generalized Linear Mixed Models 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 Generalized Linear Mixed Models 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,

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. 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.

Results

Witnessed IS

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 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 3

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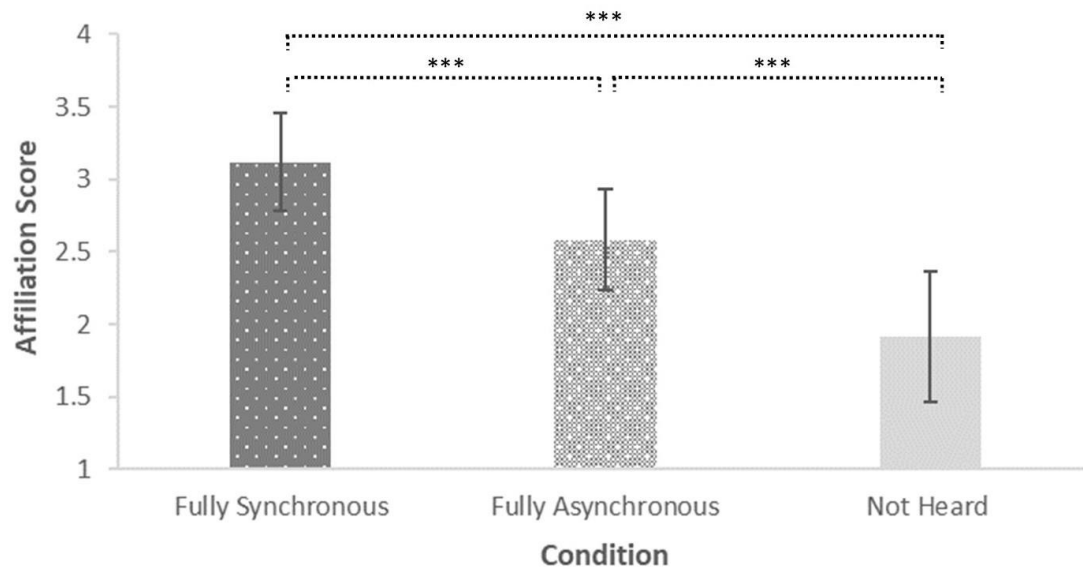
Note. 'Fully synchronous' = simultaneous and regular tapping; 'fully asynchronous' = tapping was neither simultaneous nor regular. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.
*** $p < .001$.

Individual differences in sensitivity to IS when judging affiliation

The mean 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 difference scores (**Figure 4**).

Figure 4

Witnessed IS: difference scores of individual participants
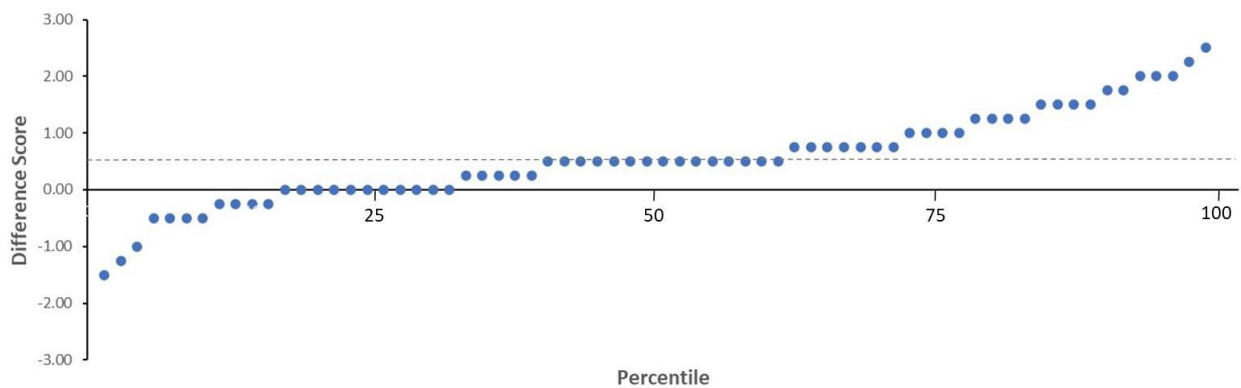
Note. Each data point represents the difference score of an individual participant. Dotted line indicates mean difference score.
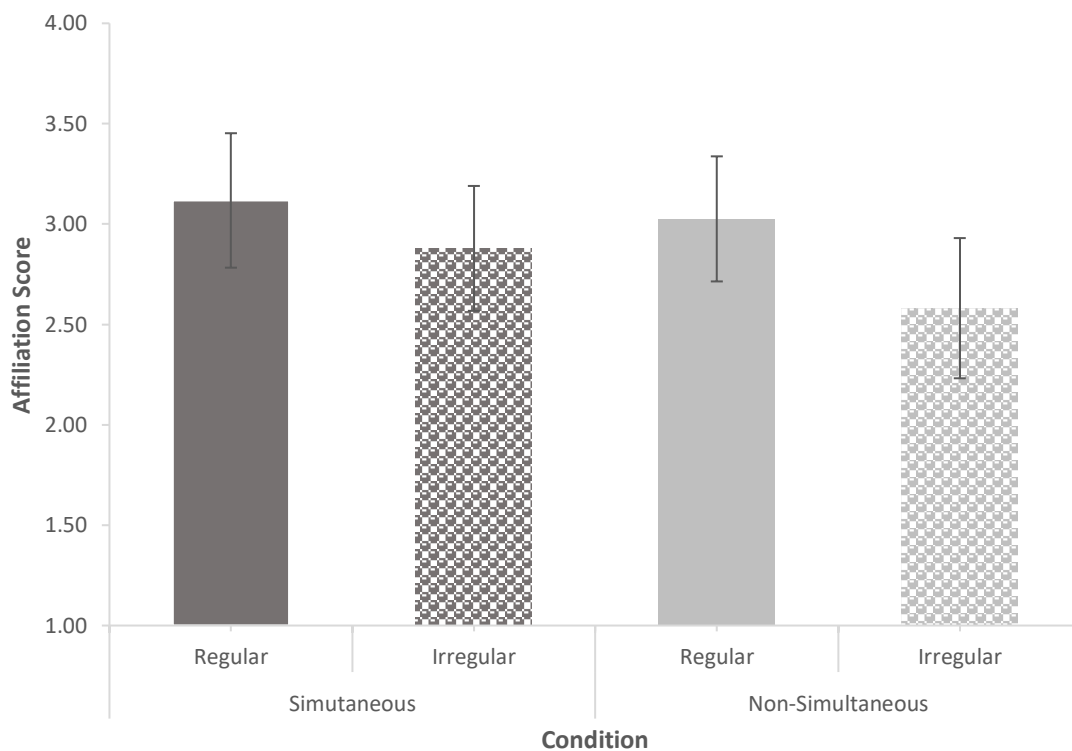
The separable effects of simultaneity and regularity on affiliation scores

A two-way repeated measures ANOVA indicated that there was a main effect of simultaneity on affiliation score, $F(1,67) = 10.17$, $p = .002$, $\eta_p^2 = .13$, 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, $F(1,67) = 26.86$, $p < .001$, $\eta_p^2 = .29$, 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 5**).

The interaction between simultaneity and regularity was close to significance, $F(1,67) = 3.33$, $p = .07$, $\eta_p^2 = .05$. 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 5

Mean affiliation scores for each combination of simultaneity and regularity during witnessed interactions

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

Effect of gender and age

The main effects of simultaneity and regularity remained unchanged when gender was entered into the ANOVA as a between-subjects factor. Sensitivity to synchrony, represented by each participant's difference score, was significantly positively associated with age, $r(68) = .28$, $p = .02$, suggesting that the effect of IS on affiliation scores was age-sensitive.

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 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 6

*Percentage of trials in which tapping was perceived as 'together', by synchrony condition*
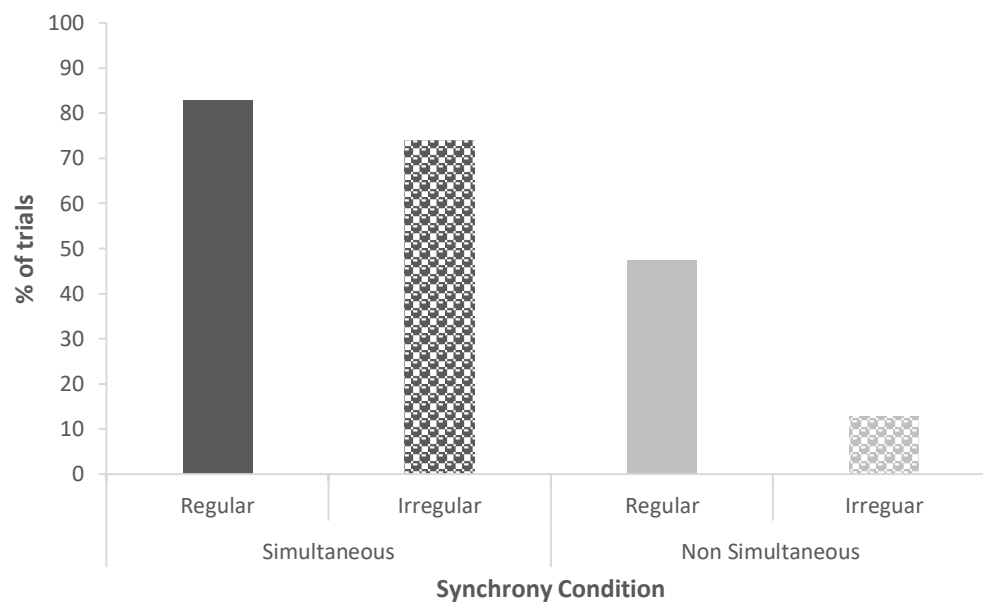
As the interaction term (β = −1.44, *t* = −3.26, *p* = .001) was also significant, the effect of regularity for each simultaneity condition (simultaneous and non-simultaneous) was assessed using two further GLMMs, each with regularity as the single dummy-coded predictor variable. When tapping was non-simultaneous, 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.
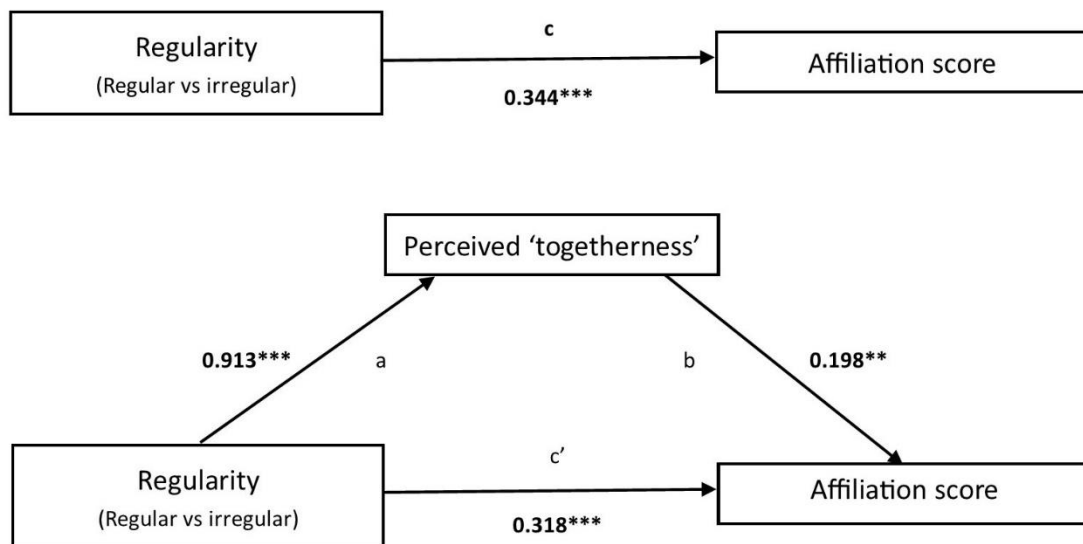
Mediation analyses indicated that perceived togetherness fully mediated the relation between simultaneity and affiliation scores (**Figure 7a**), and perceived togetherness partially mediated the relation between regularity and affiliation scores (**Figure 7b**), $z_{Mediation}$ = 2.53, p = .001.

Figure 7

 (a) *Witnessed IS: Path estimates and indirect effect of simultaneity on affiliation scores*
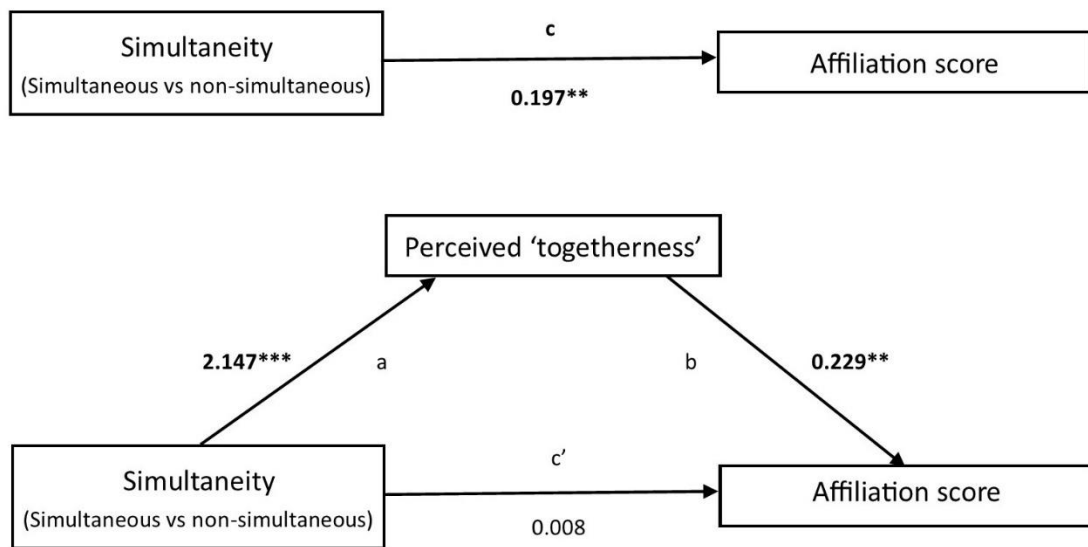
 (b) *Witnessed IS: Path estimates and indirect effect of regularity on affiliation scores*

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 unstandardized regression coefficients. Significant effects are in bold.
** *p* < .01. *** *p* < .001.

Experienced IS

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: (i) partners tapped simultaneously with participants; (ii) partners' tapping was fully asynchronous; and (iii) partners' taps were not heard $F(1.80, 111.80) = 0.61$, $p = .53$, $\eta^2 = .01$) (**Figure 8**).

Figure 8

Mean affiliation scores for experienced interactions by synchrony condition
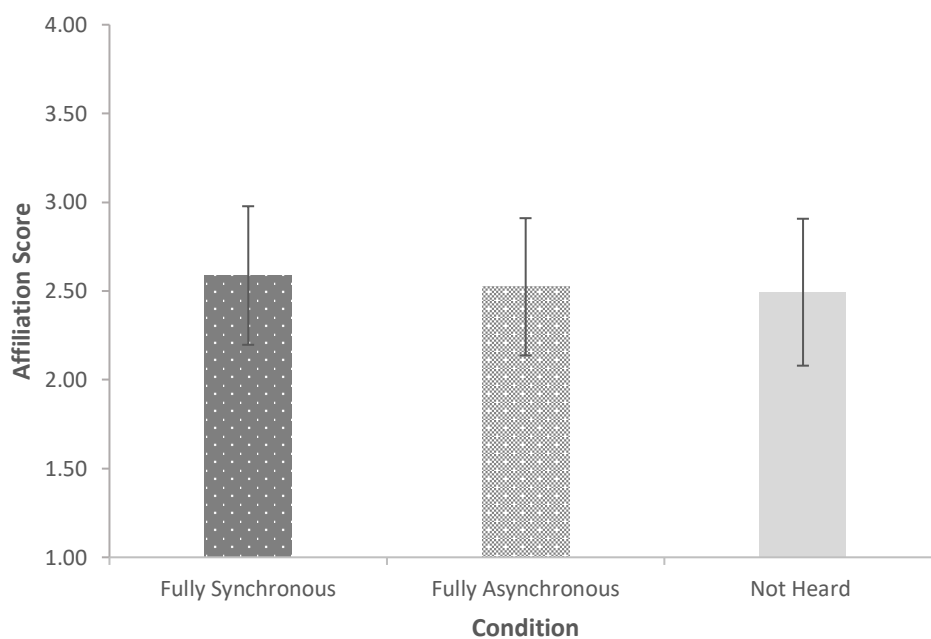

Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Error bars indicate standard deviation.

The mean 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 difference scores (**Figure 9**).

Figure 9

Experienced IS: difference scores of individual participants
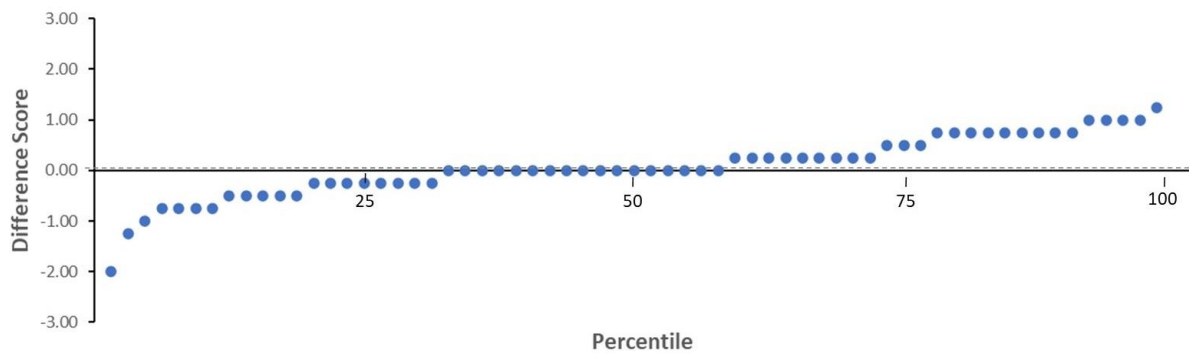
Note. Each data point represents the difference score of an individual participant. Dotted line (just visible) indicates mean difference score.

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 10**).

Figure 10

Mean affiliation scores for each combination of simultaneity and regularity during experienced interactions
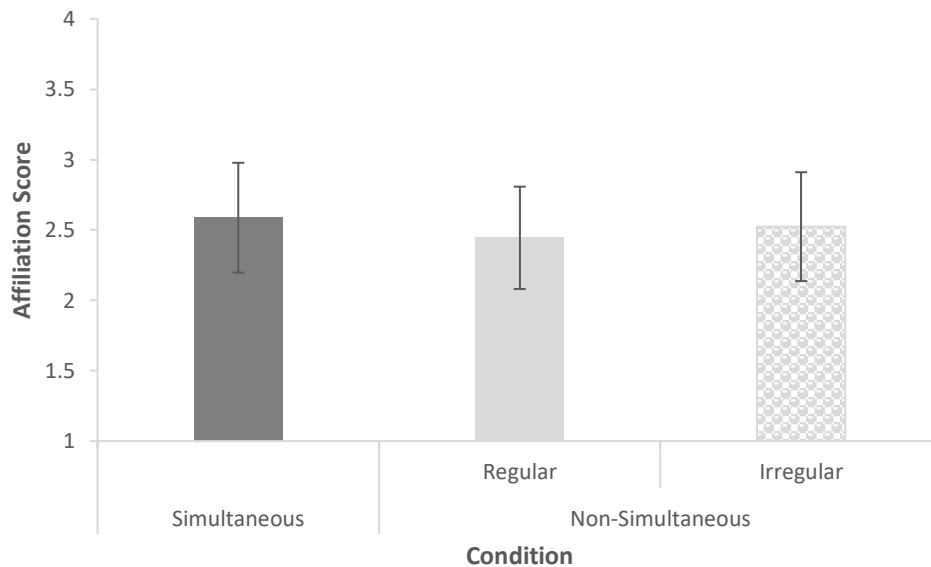
Note. Min. score = 1; max. score = 4; higher scores indicate greater affiliation. Regular = partners tapped with fixed latency; Irregular = partners tapped with variable latency. Error bars indicate standard deviation.

Effect of gender and age

The effects of the synchrony manipulations remained non-significant when gender was entered into the ANOVA as a between-subjects factor. Sensitivity to synchrony, represented by each participant's difference score, was not associated with age, $r(63) = .13$, $p = .31$.

Association between affiliation judgements following witnessed and experienced IS

For the 19 participants who completed both studies, there was no significant association between difference scores for witnessed and experienced IS, $r(17) = −.08$, $p = .37$.

Discussion

The affiliative effects of interpersonal synchrony 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 IS, we explored how the temporal properties of IS

influenced the affiliation judgements of 4-11-year-old children. Our 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'. We found that the effect of IS on

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 perceptions of the 'togetherness' of the interactions they heard. Taken

together, these findings suggest that the affiliative effects of IS in children are not limited to

interactions characterized by simultaneity, but emerge via a more generalized assessment of

temporal interdependence between partners.

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. Our findings thus indicate that the affiliative effects of IS occur when

there is a discernible temporal relationship between partners, with simultaneity and temporal

regularity both fulfilling this criterion.

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 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 only increase affiliation in the absence of regularity, and may not increase affiliation above that engendered by regularity.

Our 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 behavior 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 we did not directly measure or manipulate perceptions of co-operation or shared intentionality, this element of the proposed pathway is not yet supported by direct evidence.

The finding that simultaneity and regularity both positively influenced children's affiliation judgements accords with a similar finding in adults (Cacioppo et al., 2014), but contrasts, in part, with evidence that infants' affiliative behavior is influenced only by simultaneity, and not by regularity (Cirelli et al., 2014). There is some evidence of social sensitivity to temporal regularity in older children: five-year-olds who took part in an interaction governed by a regular beat displayed increased helping behavior towards their social partners, relative to those who acted according to an irregular beat (Wan & Fu, 2019). Taken together, one interpretation of these and our findings is that the affiliative influence of simultaneity develops earlier than that of regularity, with the latter emerging in childhood, not infancy. 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'

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). 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 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 200ms) were substantially beyond the threshold at which young children can detect gaps in auditory stimuli (consistently estimated at less than 50ms: 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.

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 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, our 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.

IS 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 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). Ours was a socially 'lean' paradigm in comparison: the brief (11.5s) 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. Our 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. Our 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.

Experienced IS

The temporal relations between partners had no effect on children's affiliation judgements for experienced IS. 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 our task, '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 our 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. We attempted to convey a sense of partner involvement 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, the most likely explanation for our null finding is that our 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). The relative influence of simultaneity and regularity on affiliation judgements in the context of experienced IS therefore remains an open question. Future research should aim to explore this using a paradigm in which partner engagement is more explicit.

Limitations and future directions

Our findings were based upon highly rhythmical auditory interactions. Some of children's everyday social interactions are characterized 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 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 which may be influenced by extraneous 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 we were not able 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. 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 IS 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 IS. However, there is limited existing research on the affiliative effects of IS in people with neurodevelopmental conditions, which may be relevant in understanding differences in social functioning in neurodivergent populations.

Additionally, our findings 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, 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 IS did not influence affiliation in the socially lean paradigm employed in our 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 neurodevelopmental conditions (Jiménez-Muñoz et al., 2021; Stone et al., 2019). Our 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).

Conclusion

This is the first study to establish that the simultaneity and the regularity of partners' actions both influence children's affiliation judgements when they witness IS. Our findings indicate that 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 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 both typical and neurodivergent development.

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