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# Development of Interpersonal Coordination Between Peers During a Drumming Task

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During social interaction, the behavior of interacting partners becomes coordinated. Although interpersonal coordination is well-studied in adults, relatively little is known about its development. In this project we explored how 2-, 3-, and 4-year-old children spontaneously coordinated their drumming with a peer. Results showed that all children adapted their drumming to their partner's drumming by starting and stopping their drumming in a coordinated fashion, but only 4-year-olds adapted the rhythmic structure of their drumming to their partner's drumming. In all age groups, children showed similarly stable drumming. Typically, it was 1 of the 2 children who initiated drumming throughout the session. The results of this study offer new insights into the development of interpersonal coordination abilities in early childhood.

*Keywords:* interpersonal coordination, synchronization, drumming, early childhood



Social interaction often requires that we coordinate our actions with those of others. Interpersonal coordination has been found when two people carry out motor acts during social interaction. This can be all kinds of behaviors such as walking (van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008), finger movements (Oullier, de Guzman, Jantzen, Lagarde, & Scott Kelso, 2008), and chair rocking (Demos, Chaffin, Begosh, Daniels, & Marsh, 2012; Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007). Although the literature on interpersonal coordination in adults is extensive, much less is known about the development of interpersonal coordination in early childhood. Most studies that explore the development of coordination have focused on how children coordinate with nonhuman external stimuli (cf. Kirschner & Tomasello, 2010; McAuley, Jones, Holub, Johnston, & Miller, 2006; Provasi & Bobin-Bègue, 2003; Zentner & Eerola, 2010). In the instances that coordination during social interaction was studied in children, mainly interactions with adults were examined (cf. Kirschner & Tomasello, 2009; Meyer, Bekkering, Paulus, & Hunnius, 2010). Coordination with peers has received, by comparison, very little attention. Mapping the time course of interpersonal coordination between peers is important to our understanding of early social development, because interpersonal coordination is closely related to social aspects such as cooperation and helping in young children (Cirelli, Einarson, & Trainor, 2014; Kirschner & Tomasello, 2010; Kleinspehn, 2008). Moreover, this study is among the first to investigate interpersonal coordination in children younger than 4 years of age. We were especially interested in uninstructed coordination, as most interpersonal coordination in daily life is spontaneous. Therefore, the aim of this project was to explore 2-, 3-, and 4-year-olds' spontaneous coordination with a peer.

## Tempo Stability

Tempo stability is suggested to be a prerequisite for interpersonal coordination (Lakin, 2012), as performing a stable tempo (i.e., evenly spaced rhythm) at different tempos is needed for adapting your behavior to other people's behavior. There are notable differences in children's tempo when asked to perform a stable tempo compared with that exhibited by adults in similar tasks. Children's spontaneously produced tempo is faster than that of adults (Drake, Jones, & Baruch, 2000; McAuley et al., 2006), with intertap-intervals (ITIs) varying between 300 ms and 400 ms for 4-year-olds (Drake et al., 2000; Fitzpatrick, Schmidt, & Lockman, 1996; McAuley et al., 2006). The preferred tempo remains the same until the age of seven (Drake et al., 2000; Fitzpatrick et al., 1996; McAuley et al., 2006) and slows down to ITIs around

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600 ms in adulthood (Drake et al., 2000; McAuley et al., 2006). There is no information available about a preferred spontaneous tempo for children below the age of four, although there is some evidence that children as young as 2.5 years show a stable tempo over short periods of time (Provasi & Bobin-Bègue, 2003).

The range of stable tempos increases with age. When children are asked to tap as fast as possible or as slowly as possible, the range in tempo younger children produce is smaller (ITIs of 262–731 ms, 4–5 years of age) than the range older children (221–1,728 ms, 6–7 years of age) and adults (169–2,532 ms) show (Drake et al., 2000; McAuley et al., 2006). As they get older, children can produce a larger range of stable tempos because they can sustain different tempos without breaking performance. These findings suggest that stability develops in a way that makes it possible to generate and *maintain* stable tempo over time at different tempos, which is important for coordinating one's behavior with others.

## Synchronization

Synchronization is the coordination of simultaneous rhythmic activity in time (Bernieri & Rosenthal, 1991). We use the term synchronization to refer to coordination of rhythmic movement with an external event (cf. Repp & Su, 2013). The development of synchronization with external events has usually been studied using tapping or drumming with metronome sounds and less frequently using music. Typically, synchronization has been measured as the temporal distance between the hit produced and the external event (Repp, 2005; Repp & Su, 2013). To date, most synchronization studies included only children of 4 years and older (cf. Clizbe & Getchell, 2010; de Boer, 2012; Drake et al., 2000; Getchell, 2007). From these studies, it appears that older children are better at synchronizing (Clizbe & Getchell, 2010; de Boer, 2012; Drake et al., 2000; Provasi & Bobin-Bègue, 2003), that they are less variable in their synchronization than younger children (Getchell, 2007; Provasi & Bobin-Bègue, 2003; Volman & Geuze, 2000), and that the range of frequencies they can synchronize with increases with age (Drake et al., 2000; Fitzpatrick et al., 1996; McAuley et al., 2006). Only two studies examined synchronization in children younger than 4 years. These studies found that neither 2.5-year-old children (Provasi & Bobin-Bègue, 2003) nor 3-year-olds (Kirschner & Ilari, 2014) could synchronize their actions to an auditory event.

Instead of examining synchronization at the level of tap or drum hits, by studying the timing of each produced hit to the external event, young children's coordination can also be described in terms of tempo flexibility. For example, Kirschner and Tomasello (2009) measured the ability of 2.5-, 3.5-, and 4.5-year-old children to adjust their tempo to an external beat around (ITIs of 400 ms) and below (ITIs of 600 ms) their spontaneous tempo. All age groups were able to coordinate their behavior to the external beat close to their preferred motor tempo, but only the two older age groups were able to adjust their tempo to the slower beat (Kirschner & Tomasello, 2009). In younger children (5 to 24 months), Zentner and Eerola (2010) found indications of spontaneous tempo flexibility, as children moved their arms and legs faster when listening to fast music. These findings highlight that young children are able to adjust their tempo to external events, and that coordination becomes better and more stable as children's ability to perform a broader range of tempos increases.

## Interpersonal Coordination

Compared with coordination with external rhythmic events, coordination during social interaction can be easier for a child as they frequently practice this during daily social interactions. The study by Kirschner and Tomasello (2009) indeed showed that although 2.5-year-olds were not able to produce tempo adjustments to tempos below their spontaneous tempo with the drumming machine, they could do so when drumming together with an adult. However, recent work by Kirschner and Ilari (2014) showed that 3-year-old children were not able to coordinate their drumming actions after the adult changed the drumming tempo. These studies indicate that although young children show tempo adjustments to the adult tempo, they do not reach a level of coordination in which the timing of their hits is coordinated with the hits of the adult in the way that they hit the drum at the same time.

Moreover, Meyer et al. (2010) found that it is not until the age of three that children can acquire a comparable level of coordination interpersonally (i.e., when acting jointly with an adult) as intrapersonally (i.e., in the rhythmic structure of their own bimanual responses). In this study, 2.5- and 3-year-olds were instructed to play a sequential button-pressing game that could be played jointly or individually. Both age groups performed at the same level when acting individually. Of interest to the authors, while 3-year-old children timed their button presses equally well when they did the task alone or jointly with the adult, 2.5-year-olds were more variable in their timing in the joint condition as compared with the individual condition. Thus, although it seems easier for children to coordinate with an adult than with an external event, it is not until the age of three that they show comparable levels of intra- and interpersonal coordination and are able to adjust to different tempos with an adult.

While studies on child–adult coordination have provided intriguing findings on the development of coordination, critically, child–adult interactions are asymmetrical. This has at least two implications for how coordination unfolds: first, the adult's actions are more proficient and predictable than the child's and, second, adults have fully developed coordination abilities that allow them to accommodate for the instability in the child's actions which results in more coordination from adult to child. For instance, the 2.5-year-olds' difficulties with adapting their actions to those of a partner in Meyers et al.'s study (Meyer, 2010) might become even more salient if they had coordinated with a peer, as children are more variable and, therefore, more unpredictable than an adult partner. Indeed, when children in same- and mixed-aged dyads were instructed to coordinate their drumming, 5- and 12-year-olds were less accurate in coordinating their actions to peers than to an older person (Kleinspehn-Ammerlahn et al., 2011). This finding suggests that interpersonal coordination between peers is more difficult than coordination with an adult or external beat. However, because no studies have focused on peer coordination in young children, it is unclear to date how interpersonal coordination with peers develops and whether young children are indeed less predictable drumming partners as indicated by low tempo stability.

## Current Study

To investigate interpersonal coordination development in young children, we studied spontaneous drumming in 2-, 3-, and 4-year-olds with a same-gender peer. Our goal was to comprehensively describe how drumming together with a peer changes over age both in terms of the development of tempo stability and interpersonal coordination.

We studied drumming performance at the level of individual drum hits and at the level of drumming patterns. For the first, we used the methodology of previous studies on synchrony and interpersonal coordination (ITIs and cross-correlations; Repp, 2005) by measuring the elapsed time between the hits produced by each child during the entire session. We investigated children's tempo stability by measuring their variability in ITIs (*SD* ITIs) by measuring how stable each individual hit produced by the children related temporally to the preceding and subsequent hits in their own drumming. Additionally, we measured children's interpersonal coordination by measuring maximum cross-correlations. Maximum cross-correlations indicate how the hits produced by a child related temporally the best to their partner's drumming. In line with other studies on coordination with an external event or adult (e.g., Clizbe & Getchell, 2010; Meyer et al., 2010), we expected older children to be better at coordinating their drumming with a peer than younger children.

Second, we studied the drumming patterns children produced during the session and the association with their partner's drumming patterns. In our study it became evident that young children tended to produce frequent long pauses in their rhythmic behaviors, which resulted in a pattern of drumming short bouts of hits separated by long periods with no hits. Therefore, within drumming bouts, we again studied the stability of children's drumming tempos, which is not affected by long pauses.

A rhythmic performance that exhibits patterns with long pauses has important consequences for interpersonal coordination; if interpersonal coordination were to emerge between partners, it would likely occur in the overlap between the drumming bouts of the partners. Consequently, to study peer coordination we examined whether children converged more into overlapping drumming bouts as they got older. Moreover, we examined whether the overlapping drumming bouts were mutually coordinated by both children as is common in adults (Konvalinka, Vuust, Roepstorff, & Frith, 2010). Specifically, we were interested in whether both partners initiated overlapping drumming bouts or whether the drumming showed a leader–follower structure.

## Method

### Participants

The final sample consisted of 100 2-year-olds (50 dyads, $M$ = 28.0 months, $SD$ = .3), 60 3-year-olds (30 dyads, $M$ = 40.2 months, $SD$ = .3), and 66 4-year-olds (33 dyads, $M$ = 55.3 months, $SD$ = 4.1). Members of each dyad were of the same gender, and 55.3% of the dyads were male. There was no significant difference in the ratio of female and male dyads between age groups, $\chi^2(2, 113) = 1.53$, $p = .47$. The 2- and 3-year-old children were selected based on their age from a database of families who responded to an invitation letter sent to all families with infants in the Nijmegen area (a midsize city in the Netherlands with 165,000 inhabitants). All children were healthy and displayed no indications of atypical development. The 4-year-olds were recruited from a random selection of elementary schools in Nijmegen, of which two were willing to participate with their preschool classes. All parents were informed about the purpose of the study and signed a consent form before participation. The local ethical committee has approved this research.

The 2- and 3-year-old children were invited to the lab and randomly paired with an unfamiliar peer. The 4-year-olds were tested at their school and randomly paired with a peer from another classroom. Some children had seen their dyad partner before, but there were only two dyads that had actually played together previously. All participants spoke Dutch and came from mixed socioeconomic backgrounds. Three 2-year-olds and two 3-year-olds did not show up for their appointment, and therefore, their dyad was excluded from the study. Moreover, all dyads in which one child or both children did not engage in the task at all were excluded from the final sample. This resulted in the exclusion of 39 of the 89 2-year-old dyads that had originally been recruited. For the 3-year-olds, 43 dyads had been recruited of which 13 had to be excluded, and the same was the case for 2 of the 35 recruited 4-year-old dyads. This resulted in the final sample of 50, 30, and 33 dyads of 2-, 3-, and 4-year-olds, respectively.

### Materials

The equipment for the dyadic drumming task consisted of two 10-inch drums of a Hayman kid drum set (Hayman, 2010) and two plastic sticks (see Figure 1). The drums were placed on a stand, which could be adapted to the height of the children so that they could comfortably drum in standing position. The drums were connected via piezo contact microphones placed on the drumheads

*Figure 1.* A 3-year-old dyad performing the drumming task. The authors received signed consent for the children's picture to be published in this article.

to collect MIDI data via an Alesis D4 drum module (Alesis Innovations, 1991). Performances were recorded with Logic Express (Apple Inc., 2007).

## Procedure

The session started with 5 to 30 min of free play during which the children could familiarize with the two experimenters and each other. The duration of free play differed across age groups, as older children needed less time for this phase. This introductory phase was followed by a peer cooperation task based on the double tube task by Warneken, Chen, and Tomasello (2006) that took ~5 min. For a detailed description of the task as well as a report on children's performance on this task, please see Endedijk, Cillessen, Cox, Bekkering, and Hunnius (in press). Following the cooperation task, the dyadic drumming task was presented. Children did not receive any instructions pertaining to drumming together or coordinating their drumming with their dyad partner. Parents, who were present during the sessions of 2- and 3-year-olds, were instructed to minimize their interactions with the child and, if the child was clinging to the parent, to respond in ways to stimulate play without helping with the task. If a child did not start drumming, one of the experimenters started drumming on a third drum to encourage him or her, but stopped the drumming as soon as the child started to drum. When a child stopped drumming, he or she was encouraged to continue drumming. The drumming sessions lasted for a maximum of 5 min end ended when both children spontaneously stopped drumming. During the sessions with 4-year-olds, parents were not present and there was only one experimenter, as they took place at school. At the end of the session, the 2- and 3-year-old children received a book or 10 Euros "for their piggy bank" as a thank you for participation. Teachers of the 4-year-olds were offered a picture book for the participation of their class. The entire testing session was videotaped from two visual angles using two video cameras.

## Data Reduction and Analysis

The raw data from the drumming recordings were compared with the actual behavior of the children on the video recordings to establish start and end of each drumming session, to exclude sections during which the experimenter encouraged drumming by using the third drum, and to remove extra drum hits that occurred when a microphone accidentally registered an extremely loud hit as two hits or captured hits produced by the other child. All hits of the children that remained after the data cleaning were used in the first set of analysis (see Drum Hits in the Results section). To investigate changes in tempo stability between age groups, we calculated the variability in intertap-intervals (*SD* ITIs) by calculating the *SD* of the time elapsed between hits. Interpersonal coordination was measured in terms of the temporal similarities between the time series of ITIs (consecutive ITIs) obtained for each child, using maximum cross-correlation functions. To do so, the time series of ITIs of two partners were correlated across time to identify the highest association between the time series.

For the second set of analyses (see Drumming Bouts in the Results section), drumming bouts (i.e., a sequence of hits) were extracted from the cleaned drumming data using three rules. First, the first and last hit of a bout was defined as any hit for which the ITI between the hit and the previous hit, or next hit in case of the last hit of a bout, was bigger than 2.5 times the previous (or next) ITI. As a result, a bout was separated from another bout when there was a pause in the child's drumming or when a strong shift in drumming tempo occurred. Second, bouts had to contain at least three hits to prevent single hits from being selected as a bout. Third, a ratio was calculated between the number of hits within a bout and the total duration of the bout. Bouts with a ratio value smaller than 2.5 *SD*s below the mean ratio for all bouts in all children were removed. This was done to exclude bouts that did not consist of hits closely related in time to each other, but rather of single hits with comparably large ITIs. For the set of analyses at the level of bouts, again differences in tempo stability and interpersonal coordination were calculated between age groups. Tempo stability was calculated as the average *SD* of temporal distance between hits (*SD* ITIs) during bouts. Interpersonal coordination between bouts was studied by measuring the degree of overlap between bouts of two partners. To establish whether both partners coordinated mutually or showed a leader–follower structure in producing overlapping bouts, the initiation of these overlapping bouts by each partner was determined.

Age differences were tested using a one-way analysis of variance (ANOVA) with age as between-subjects factor and Bonferonni corrected post hoc tests. To test whether coordination was better than expected by chance, the observed time series of the ITIs of each child were randomly scrambled resulting in two new time series for each dyad (cf. Shockley, Santana, & Fowler, 2003). Interpersonal coordination was tested by ANOVA with age as a between-subjects factor and time series (observed vs. randomized) as a within-subjects factor.

# Results

## Drum Hits

**Tempo stability.** Based on all ITIs during the entire drumming session including pauses, children of 2, 3, and 4 years showed differences in drumming tempo. ITIs decreased significantly with age, $F(2, 223) = 5.07$, $p = .007$, $\eta^2 = .04$, with Levene's test indicating unequal variances, $F(2, 223) = 9.41$, $p < .001$. Post hoc analyses showed slower tempos and larger variances for 2-year-olds ($M = 3.00$ s, $SD = 7.09$) than for 4-year-olds ($M = .51$, $SD = .15$) and no differences between these age groups and the 3-year-olds ($M = 1.78$, $SD = 2.88$). Post hoc age comparisons also yielded a significant difference of age 2 ($M = 5.03$, $SD = 7.15$) and age 3 (M = 4.02, $SD = 6.36$) versus age 4 on the variability in ITIs (*SD* ITIs: $M = .77$, $SD = .59$), with older children drumming in a more stable manner than younger children, $F(2, 223) = 11.08$, $p < .001$, $\eta^2 = .09$. Again Levene's test indicated unequal variances, $F(2, 223) = 19.21$, $p < .001$. These results suggest that as children grow older drumming becomes faster and more stable. The average ITIs and variability in ITIs are large in comparison with the tempos found in earlier studies for children (300 to 400 ms for 4-year-olds). These large ITIs and their high *SD*s for mainly the younger age groups, in combination with unequal variances suggest that younger children tend to drum in bouts with pauses in between. The average ITIs and *SDs* of ITIs are, therefore, no valid measure of young children's actual tempo and tempo stability.

**Interpersonal coordination.** Maximum cross-correlation coefficients obtained for the time series of ITIs of the partners in each dyad were tested for age differences and compared with the maximum cross-correlation coefficients for the randomized time series. An ANOVA with age as a between-subjects factor and the time series (observed vs. randomized) as a within-subjects factor yielded a main effect of age, $F(2, 110) = 6.68$, $p = .002$, $\eta^2 = .11$. Post hoc tests indicated significant differences between the 2- and 4-year-old dyads, with 4-year-old dyads showing larger maximum cross-correlations ($M = .71$, $SD = .16$) than 2-year-old dyads ($M = .58$, $SD = .14$). The 3-year-old dyads ($M = .64$, $SD = .14$) were not significantly different from the other two age groups. There was a main effect of observed versus randomized time series, $F(1, 110) = 6.63$, $p = .01$, $\eta^2 = .06$, but no significant interaction effect with age, $F(2, 110) = 2.26$, $p = .11$, $\eta^2 = .04$ (see Figure 2). Although the interaction was not significant, the results in Figure 2 suggest that the difference between the time series was larger for 4-year-old dyads than for the two younger age groups. Therefore, we conducted paired sample $t$ tests for each age group separately comparing observed versus randomized time series. The $t$ tests yielded no significant effects of time series for the two younger age groups, $t(49) = .59$, $p = .56$, $\eta^2 = .01$ and $t(29) = .75$, $p = .46$, $\eta^2 = .02$, respectively, but a significant effect for the 4-year-old dyads, $t(32) = 2.69$, $p = .01$, $\eta^2 = .18$. These findings suggest that 4-year-olds coordinated their hits with each other.

## Drumming Bouts

Tempo stability and interpersonal coordination were further examined based on the drumming bouts produced by each child. Figure 3 demonstrates an example drumming recording of a dyad per age group thereby illustrating that the children drummed in bouts With respect to tempo stability, the tempo variability ($SD$ ITIs) within bouts instead of within the entire time series (including pauses), may clarify whether age differences in interpersonal coordination could be because of age-related changes in drumming stability. Children who did not produce at least one bout were removed from this analysis (viz., seven 2-year-old and two 3-year-old children).

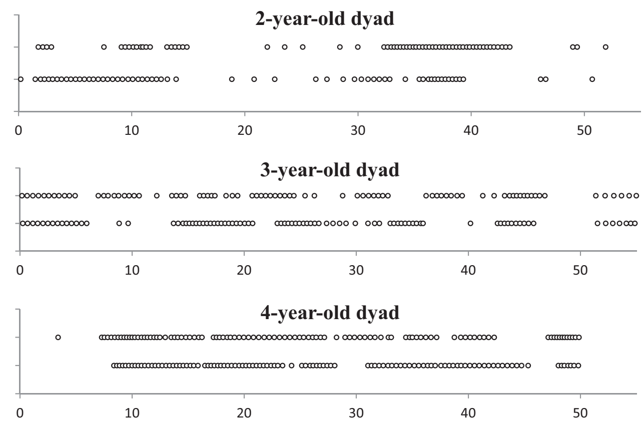


*Figure 3.* Example of the drumming recording of a dyad of 2-, 3-, and 4-year-old children that illustrates that they drum in bouts and produce longer sustained drumming over age.

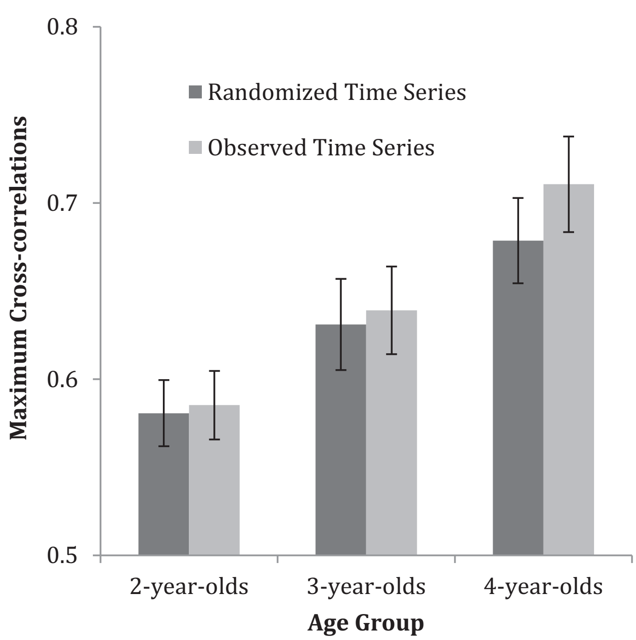


*Figure 2.* Maximum cross-correlations with $SE$s of randomized and observed time series for 2-, 3-, and 4-year-olds.

One-way ANOVAs with age as a between-subjects factor showed that older children produced bouts with a longer average duration, $F(2, 214) = 10.52$, $p < .001$, $\eta^2 = .09$, and more hits per bout, $F(2, 214) = 15.38$, $p < .001$, $\eta^2 = .13$ (see Table 1 for descriptive statistics). Post hoc analyses indicated that 4-year-olds differed significantly on these measures from 2- and 3-year-olds, who did not differ from each other. Comparison of the percentage of time children produced bouts relative to their total drumming time (time elapsed between their first and last drumming hit) over age groups showed that older children spent more time drumming in bouts, $F(2, 214) = 37.76$, $p < .001$, $\eta^2 = .26$. Post hoc analyses revealed that all age groups differed significantly from each other. This indicated that the drumming patterns of younger children were characterized by shorter periods of drumming with more or longer pauses compared with older children.

Table 1
*Bouts: Duration of Bouts, Number of Hits per Bout and Percentage of Time Spent Producing Bouts Relative to Total Drumming Time for 2-, 3-, and 4-Year-Old Children*

| | Age group | | | | | |
|---|---|---|---|---|---|---|
| | Age 2 | | Age 3 | | Age 4 | |
| | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Duration (s) | 6.32 | 5.46 | 7.07 | 4.25 | 11.72 | 11.55 |
| Hits (#) | 15.48 | 12.11 | 17.76 | 9.94 | 33.14 | 33.32 |
| Time spent producing bouts relative to total drumming time (%) | 37.76 | 22.65 | 49.42 | 28.30 | 70.13 | 18.46 |

**Tempo stability.** Average ITIs within bouts decreased significantly with age, $F(2, 214) = 3.97$, $p = .02$, $\eta^2 = .04$. Post hoc analyses showed significantly faster tempos for 4-year-olds ($M = .41$, $SD = .12$) than for 2-year-olds ($M = .48$, $SD = .21$), whereas 3-year-olds ($M = .44$, $SD = .09$) did not differ from the other age groups. In contrast to tempo stability as calculated for the entire time series (including pauses), children did not differ in their tempo stability during bouts (*SD* ITIs averaged across bouts), $F(2, 214) = .30$, $p = .74$, $\eta^2 < .01$, with an average *SD* ITIs of .12 seconds ($SD = .08$). Thus, there was no indication of significant differences between age groups in tempo stability when drumming was considered in bouts.

**Interpersonal coordination.** To investigate how dyads coordinated their drumming at the level of the bouts we studied the overlap between their drumming bouts. Coordination can exist of the same behavior of both partners at the same time (i.e., both children produce a bout at the same time) or by a turn-taking structure in which the partners produce bouts after each other. Most bouts children produced overlapped with a bout by their partner (see Table 2 for descriptive statistics), $t(214) = 10.06$, $p < .001$, $\eta^2 = .32$, and the percentage of overlapping bouts increased with age, $F(2, 214) = 22.88$, $p < .001$, $\eta^2 = .18$. Post hoc tests revealed significantly higher overlap for 4-year-olds than for 2- and 3-year-olds. These results indicate that all age groups showed a coordinative pattern of drumming at the same time (at least partly overlapping in time) more often than turn-taking patterns. Moreover, 4-year-olds showed overlap more frequently than the two younger age groups.

After removing dyads without any overlapping bout (11 2-year-old and two 3-year-old dyads), one-way ANOVAs revealed that overlapping bouts lasted longer in older dyads, $F(2, 97) = 3.53$, $p = .03$, $\eta^2 = .07$, and that older children produced more hits per overlapping bout, $F(2, 197) = 9.70$, $p < .001$, $\eta^2 = .09$ (see Table 2). Post hoc tests indicated a significant difference between the 4-year-olds compared with 2- and 3-year-olds for the number of hits, and a difference between 2- and 4-year-olds but not compared with 3-year-olds for the duration of overlapping bouts. To test whether older children spent more time producing overlapping bouts, independently of the overall amount of drumming activity, time spent drumming in overlapping bouts was divided by the duration of bouts produced by each child. These proportions of time spent producing overlapping bouts were tested for age differences and compared with the same measures as calculated based on the randomized time series. An ANOVA with age as between-subjects factor and time series (observed vs. randomized) as within-subjects factor yielded a main effect of time series, $F(1, 183) = 210.58$, $p < .001$, $\eta^2 = .54$. Children showed significantly better coordination as measured by the time spent drumming in overlapping bouts than based on chance. There was also a main effect of age, $F(2, 183) = 19.54$, $p < .001$, $\eta^2 = .18$, but no interaction-effect between age and time-series, $F(2, 183) = 1.06$, $p = .35$, $\eta^2 = .01$. Post hoc tests indicated significantly more overlapping drumming for 4-year-olds as compared with 2-, and 3-year-olds. In summary, children showed coordination at the level of the bouts, and older children showed more coordination, as they showed a higher degree of overlap in their drumming.

Interpersonal coordination between bouts can originate from peers mutually adapting to each other's drumming or from a leader-follower relationship. We examined these options by determining who initiated the overlapping drumming (i.e., the proportion of overlapping bouts started by each child). On average, 71% of the overlapping bouts were started by the same child (the leader) while the other child followed, with no difference between dyads of different age groups, $F(2, 97) = .11$, $p = .90$, $\eta^2 < .01$. This percentage of overlapping bouts initiated by the same child was significantly different from what would indicate mutual adaptation (i.e., 50% of the overlapping bouts initiated by each child), $t(99) = 15.76$, $p < .001$. This indicates that all age groups displayed drumming patterns with considerably stable leader and follower roles, with no indication of age differences in these leader–follower roles.

## Discussion

In this study, we investigated spontaneous coordination of 2-, 3-, and 4-year-old children with a peer in a drumming task. We examined both tempo stability and interpersonal coordination at the level of hits and bouts. It is common in research on coordination to examine how the timing of each produced hit during the entire time series is related to the hit of another person or external device (see Repp & Su, 2013). Our results suggest that when the drumming behavior exhibited by children is not continuous but characterized by periods of closely related hits (i.e., bouts) and pauses, analyzing the entire time series is not as informative and

Table 2
*Overlapping Bouts: Percentage of Overlapping Bouts, Duration of Overlapping Bouts, Number of Hits per Overlapping Bout, Percentage Leader, Percentage of Time Spent Producing Overlapping Bouts Relative to Time Spent Producing Bouts for 2-, 3-, and 4-Year-Old Children*

| | Age group | | | | | |
|---|---|---|---|---|---|---|
| | Age 2 | | Age 3 | | Age 4 | |
| | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| Percentage | 59.66 | 36.04 | 70.06 | 31.86 | 91.80 | 12.94 |
| Duration (s) | 4.03 | 3.50 | 4.80 | 2.99 | 7.70 | 9.42 |
| Hits (#) | 10.10 | 8.20 | 11.93 | 7.14 | 21.91 | 27.14 |
| Leader (%) | 72.85 | 17.58 | 71.40 | 18.48 | 70.96 | 18.21 |
| Time spent producing overlapping bouts relative to time spent producing bouts (%) | 53.64 | 26.78 | 64.63 | 28.01 | 82.28 | 16.34 |

could be potentially misleading. For instance, analyses over the entire time series showed that the older children's drumming was more stable than that of the younger children. However, when considering drumming in bouts, the age difference in tempo stability disappeared. Likely because they could maintain a stable drumming tempo for longer periods, 4-year-olds coordinated their hits. This was not the case for the younger children; 2- and 3-year-olds were not able to coordinate their hits better than chance. However, children spontaneously coordinated their drumming in bouts, as most of the time they produced a bout when their partner was doing the same. Moreover, the drumming of older children spontaneously overlapped to a higher degree than that of younger children. Drumming patterns were not mutually coordinated, but periods of overlapping drumming tended to be initiated by one of the children in the dyad, while the other child followed.

As hypothesized, older children were better at coordinating their behaviors with a peer than younger children at the level of the drum hits. Moreover, the maximum cross correlations only revealed evidence for coordination of the timing of hits for 4-year-old dyads. Younger children could maintain a stable drumming tempo for only a short time, which likely limited the possibilities to coordinate their hits. It is likely that, similar to adults (Roerdink, Bank, Peper, & Beek, 2011; Semjen, Vorberg, & Schulze, 1998), children require some time to coordinate interpersonally, in which case a longer sustained rhythm might help them to adapt their behavior to the drumming of the partner.

While 4-year-olds coordinated the timing of drum hits, children between 2- and 4 years of age showed indications of interpersonal coordination as indicated by the beginnings and endings of drumming bouts. Children showed more overlap in their bouts than would be expected by chance, and older children showed a higher degree of overlap than younger children even when controlled for the amount of drumming activity. This extends earlier findings that children become more successful at coordinating their behavior with external rhythms (cf. Clizbe & Getchell, 2010; de Boer, 2012; Drake et al., 2000; Provasi & Bobin-Bègue, 2003) and adults (Kirschner & Tomasello, 2009; Kleinspehn-Ammerlahn et al., 2011) as they get older. The present results suggest that young children also progressively become more proficient at coordinating their rhythmic behaviors to peers.

The improvement in interpersonal coordination with age cannot be explained by changes in the partners' tempo stability, as all age groups showed comparable stability in their drumming when the pauses between drumming bouts were not taken into account. In other words, it is not the case that 2-year-olds simply have a harder time coordinating with their peer because task demands change depending on the demands imposed by a more or less stable and predictable partner. This is in line with previous results by Getchell (2006) and Fitzpatrick et al. (1996), who found no differences in the stability of clapping and walking between 3 and 8 years. Our results suggest that changes in tempo stability might not significantly influence interpersonal coordination in early childhood. It is an open question whether such influences might arise in middle childhood, when significant gains in tempo stability have been documented (Fitzpatrick et al., 1996).

Our finding that all age groups showed comparable tempo stability but differences in their interpersonal coordination is, nevertheless, surprising, as producing stable tempos is assumed to be a prerequisite for coordination with a partner (Lakin, 2012). It also complements our understanding of social coordination processes in adults. In coordination tasks, people sometimes adjust the stability of their behavior to their partner. For example, they modify their speaking patterns or musical performance as to make themselves maximally predictable for a partner (Repp & Su, 2013; Vesper, van der Wel, Knoblich, & Sebanz, 2011). On the one hand, sustained drumming for longer periods of time (as we found in older age groups) might have served a similar purpose. On the other hand, improved attunement has been demonstrated between children and parents by more variability and flexibility in language acquisition during the age of 1.5 and 2.5 years (Cox & van Dijk, 2013). This suggests that interpersonal coordination entails a delicate balance between the stability and the flexibility of behavior.

We also found that children's dyadic drumming showed a leader–follower pattern, in which one child initiated the overlapping drumming periods and the other child joined the initiator. Konvalinka et al. (2010) found that when adults were instructed to synchronize, they mutually adapted to each other. Although this seems at odds with our findings of leader-follower roles, directionality in initiations of overlapping drumming could be unrelated to mutual adaptation during periods of overlap. It is possible that in our sample, despite directionality in the initiation of drumming bouts, both children still mutually adapted their hits within these overlapping bouts to each other. The children in our study received no instruction that might have led to less focus on the partner's drumming and more on social and communicative aspects of the task. Such a relationship between interpersonal coordination and social factors in children is supported by earlier studies (Cirelli et al., 2014; Kirschner & Tomasello, 2010; Kleinspehn, 2008). In this respect, the combination of personality traits might be at the heart of why one child initiated and the other child followed in drumming. From the perspective of social development, this possible association certainly deserves more in-depth investigation in future studies.

In summary, the current study confirms previous findings on the development of interpersonal coordination in young children and extends them to encompass age-related changes in spontaneous coordination abilities with peers. We found that young children coordinated their drumming bouts. By age four, children not only spontaneously coordinated when they drummed, but also how they drummed, by coordinating when they hit the drum to changes in their partners' drumming. These results are illustrative of how young children adapt their behavior in daily situations in which spontaneous coordination is often required, although the results cannot be generalized to situations in which they are instructed to coordinate. The findings of this study emphasize the importance of studying coordination at different time-scales by focusing not only on drum hits but also on drumming bouts. This provides a more comprehensive understanding of coordination especially in young children that have more difficulty with sustaining a rhythmic behavior. Moreover, our study contributes to a growing understanding of interpersonal coordination in early childhood (see Repp & Su, 2013) and it presents a new method for exploring the genesis of accommodation in social interactions. A longitudinal study in which children are followed in their interpersonal peer coordination could further clarify this time course, the individual developmental trajectories of interpersonal coordination, and the association with children's early social interactions with peers.

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