Joint rhythmic tapping elicits distinct emotions depending on tap timing and prior musical training

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Abstract

Music plays a significant role in human life. It is a form of art and entertainment, and a powerful medium for interpersonal interaction. The experience of listening to music is often emotional. Previous research has elucidated many of the mechanisms that effect an emotional response in the listener. In contrast, much less is known about how joint musical engagement impacts emotions. Here we focus on synchronized rhythmic interaction, a fundamental feature of musical engagement. There are theoretical reasons for hypothesizing that synchronized interaction should elicit positive affect among interacting individuals, although empirical studies performed with adults have found little consistent evidence for such an effect. We revisited this question, studying children instead of adults, and used an implicit measure of experienced affect to compare children's responses to synchronized versus asynchronized joint tapping. Unlike previous studies, we distinguished between musically trained and untrained participants, since a background of musical training may be associated with altered emotional sensitivities to rhythmic interaction. We found a striking difference in emotional responses to synchronized versus asynchronized tapping, which strongly depended on musical training background. The untrained children responded to synchrony with more positive affect and less negative affect when compared to asynchrony, in line with theoretical predictions. In contrast, the musically trained children showed low positive affect following both synchrony and asynchrony and more negative affect in response to synchrony rather than asynchrony. These results suggest a possible emotional dissociation between synchronized and asynchronized interpersonal rhythmic interaction that may be influenced by musical training background.

Keywords: synchrony; emotion; musical training; children; social interaction

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It has long been appreciated that music is strongly associated with human emotionality (for recent discussions see for example, Hunter, Schellenberg, & Schimmack, 2010; Juslin, & Sloboda, 2011). Music is readily attributed with human emotions, such as cheerfulness, anger or calmness. At the same time, music also has the capacity to elicit emotions, and seems to make us feel, for instance, radiant, nostalgic or dreamy. Research has sought to classify and delineate the particular emotions associated with different types of music (e.g. Kallinen, 2005; Zentner, Grandjean, & Scherer, 2008) and has found that the emotions ascribed to music (perceived emotions) do not necessarily correspond to those induced by the music (felt emotions) (Zentner et al., 2008). Thus, for example, certain music could be perceived as having negative affect, but at the same time evoke a positive emotion (Kallinen & Ravaja, 2006).

Music is often considered to be a physical phenomenon, an artefact comprised of sounds arranged in time. Just like any other artefact, it may realize functional ends or afford aesthetic value. It is not exempt from the general human cognitive bias to anthropomorphize inanimate phenomena and artefacts, ascribing to them intentions and emotions (Epley, Waytz, Akalis, & Cacioppo, 2008). What is it about musical artefacts that renders them so universally amenable to emotional anthropomorphism? It has been suggested that the link between music and emotions lies in the morphological resemblance between the two (e.g. Cross, 2008; Kivy, 1981; Langer, 1953). Several studies have examined empirically the impact of specific features of musical structure on the intensity of associated emotions. These studies demonstrated an influence of features such as pitch, harmony, melody, tempo and rhythm on emotional response (e.g. Gomez & Danuser, 2007; Schellenberg, Krysciak, &

Campbell, 2000; Webster & Weir, 2005). These specific features could afford the basis for some degree of ascription of agency and hence underpin the attribution of affect.

An alternative framework for exploring the relationship between music and emotion is to regard music not as a sonic artefact but rather as an activity. Whether it is playing music together, listening to a live performance or just whistling in the street, music is essentially a human behavior, and it is most commonly a *social* behavior (Merriam, 1964). Individuals engaging in music, listening, composing or playing, participate together in this joint behavior; it should be noted that this participatory manifestation of music is at least as, if not more, prevalent globally than music in its presentational manifestations (Turino, 2008). Thus, rather than examining the limited interaction between listener and a musical artefact (e.g. Kallinen & Ravaja, 2006) as a locus for the elicitation of emotion, one can shift the focus to the interaction between two, three or more individuals as they engage together in musical behavior. An essential component of almost any human behavior is emotion, and this of course applies also to musical behavior. However, musical behavior stands out in the breadth of its emotional content and in the depth of its penetration in comparison to many other behaviors. For example, it has been shown that performers are capable of intentionally eliciting specific predefined emotions in listeners (Gabrielsson & Juslin, 1996). Thus, musical behavior can effectively and reliably convey specific emotions. What is it about musical behavior that makes it particularly conductive to association with emotions? What are the specific features of musical social behavior that resonate with emotionality?

Synchronous Rhythmic Interactions and Emotions

One prominent and well-studied feature of musical behavior is coordinated or synchronous rhythmic interaction (Merker, 1999). Since music progresses in time and its structure is generally based on a recurring beat, individuals who interact musically must ensure that their rhythmic behaviors and perceptions of own and others' behaviors are consistent and synchronized in order to remain coordinated (Clayton, Sager, & Will, 2004; Keller, 2014). This means that they need to constantly adjust their actions to each others' in order to co-adapt the timing of their behaviors so as to maintain joint adherence to a regular beat. It has been suggested that such shared motor experience should elicit positive affect (Bharucha & Curtis, 2008; Bharucha, Curtis, & Paroo, 2006; Overy & Molnar-Szakacs, 2009), and that, in particular, inter-personal synchrony should be associated with positive emotional valence (Ehrenreich, 2006; Haidt, Seder, & Kesebir, 2008; McNeill, 1995).

The single prior study (Labbé & Grandjean, 2014) that has explicitly explored the relationship between entrainment and emotion in musical contexts focuses on the musical artefact—music as *heard*—and relies on subjective self-report to indicate a link between a sense of entrainment and affective experience. In that study, entrainment was conceived of as concerning "ideas of predictability, expectations, and motion" (p. 171), with experienced affect arising as a consequence of any, some, or all of these factors. In a more recent review, Trost, Labbé and Grandjean (2017) distinguish between four levels of rhythmic entrainment: perceptual (representation of a beat or pulse); autonomic physiological (involving adaptation of physiological rhythms to the tempo of music); motor (sensorimotor synchronization with periodic features of the music); and social (involving synchronization of overt behaviour). It is notable that the authors follow the majority view that rhythmic entrainment is more likely than not to induce *positive* feelings (e.g., "Assuming that rhythmic entrainment procures and fosters also positive feelings and pleasant emotional states…", p. 106).

Surprisingly, empirical studies that have examined the influence of synchronous behavior on positive affect have produced almost no evidence for such an effect. For example, no difference in reported positive affect was found between participants who tapped together with an experimenter either synchronously or asynchronously or just tapped alone, even though synchronous tapping led to stronger affiliation with the experimenter compared to the other conditions (Hove & Risen, 2009). Similarly, participants who were instructed to walk synchronously as a group (aligning their steps and pace), subsequently exhibited more cooperation within the group and reported feeling closer and more trusting towards group members than a second group of participants who just walked normally. However, no differences were found between the groups in reported happiness (Wiltermuth & Heath, 2009).

What could be the reason for this discrepancy between the expected association between synchrony and positive affect, and the lack of such association in these experiments? First, changes in positive affect may have been too subtle to be detected. It has been shown that positive emotions or events are less effective in eliciting physiological, affective, cognitive and behavioral activity than negative emotions (e.g. Carretie, Mercado, Tapia, & Hinojosa, 2001; Inaba, Nomura, & Ohira, 2005; Taylor, 1991) and, in general, negative emotions are typically experienced as more emotionally intense (Cunningham, Raye, & Johnson, 2004; Ito, Cacioppo, & Lang, 1998). Thus, it might be easier to detect a decrease in negative affect than an increase in positive affect in response to synchrony. Indeed, a recent study, which found no difference in reported positive affect between participants who were either given or not given instructions to synchronize their marching, reported a reduced feeling of negative emotions among synchronized group members (Fessler & Holbrook, 2014). It is noteworthy, however, that the overall context of that study was negative, as it focused on estimating the perceived strength of a threat, and might thus confound the results. In contrast, another study that compared synchronous and asynchronous interactions, found no difference in self-ratings of either happiness or sadness between the two coordination conditions (Lumsden, Miles & Macrae, 2014). Indeed, of all the papers adduced in the review article by Mogan, Fischer & Bulbulia (2017) as indicating an effect of synchrony on affect, only that by Fessler & Holbrook (2014) reports finding any such relationship.

A second possible hurdle for detecting change in positive affect following synchrony might stem from the use of self-report to evaluate positive affect. Such explicit report has been broadly applied in the study of emotions, but may entail certain cognitive processes that could mask or interfere with measurement of a genuine affective response, due to the task's introspective and highly verbal nature. Third, participants' musical background is a potentially significant factor that has not been addressed. Numerous studies have shown that musical training is associated with multiple changes in cognitive (e.g. Costa-Giomi, 1999; Schellenberg, 2005; Slevc, Davey, Buschkuehl, & Jaeggi, 2016) and emotional (Clarke, DeNora, & Vuoskoski, 2015; Rabinowitch, Cross, & Burnard, 2013) skills, impacts brain development and induces plasticity (Hyde et al., 2009A, 2009B). These modulations associated with musical training have been claimed to be due to the training process itself (Habibi et al., 2014). However, certain prior genetic, cognitive, personality and demographic factors underlying the choice to engage in and persist with training (e.g., Butkovic, Ullén, & Mosing, 2015; Corrigall, Misura, & Schellenberg, 2013; Corrigall & Schellenberg, 2015; Mosing, Madison, Pedersen, & Ullén, 2016; Swaminathan, Schellenberg, & Khalil, 2017; Theorell, Lennartsson, Madison, Mosing, & Ullén, 2015) may also play a role. It is possible, that the emotional response to synchronous experience differs between individuals with and without musical training background, and when these two populations are blended together the effects cancel out. We thus sought to re-examine the fundamental question of whether synchrony has a distinct positive emotional impact.

Rationale for the Current Study

We designed an experiment wherein participants were asked to repeatedly tap a simple rhythmic pattern while an experimenter either tapped in synchrony with the participant, or tapped a complex rhythmic pattern that was entirely incompatible with the participant's pattern, producing an asynchronous rhythmic interaction. Following the tapping task we evaluated participants' felt emotion. This procedure, of measuring felt emotion as an indication of an emotional state following a task has been used in previous studies (e.g. Forgas & East, 2008; Khalfa, Peretz, Blondin, & Manon, 2002).

To address the possible factors that may have previously concealed a positive emotional response to synchrony, we designed the study in the following way.

First, we tested both positive and negative affect. We hypothesized that synchronous experience will increase felt positive affect and reduce felt negative affect. We ensured independence of these two tests by splitting the participants into those tested exclusively for positive affect and those tested exclusively for negative affect.

Second, we used an implicit measure of felt emotion instead of self-report. To this end we adopted an approach employed in previous studies on emotion, based on the congruence between emotional state and the perceived emotional expression of another's face. This technique has been thoroughly established both in adults (Harmer, Shelley, Cowen, & Goodwin, 2004; Niedenthal, Halberstadt, Margolin, & Innes-ker, 2000; Schiffenbauer, 1974) and in children (Stegge, Terwogt, & Koops, 1994; Terwogt, Kremer, & Stegge, 1991). In these studies an experimenter first induced a particular emotion in participants, and then participants were implicitly (except for Schiffenbauer, 1974) requested to judge the emotional valence of emotionally ambiguous facial expressions. In all studies participants exhibited a clear bias in the assignment of emotional valence towards the emotion they were experiencing, so that, for example, a happy participant tended to judge a certain ambiguous facial expression as being happy, while a sad participant was more likely to judge the same facial expression as being sad or at least not happy. Therefore, one's judgment of the emotional valence of an ambiguous facial expression seems to be a good indicator of one's emotional state following the induction of that emotion. We reasoned that if synchronous or asynchronous tapping were inducing particular emotions in participants, then these felt emotions could be revealed, similarly to previous studies, by emotional judgment of ambiguous facial expressions.

Third, to study possible influences of musical training background to the nature of the emotional response to synchrony we distinguished between musically trained and untrained participants and compared performance of these two separate groups. This key feature of our study led us to focus on participants between 9-15 years of age. This choice of age served to balance our desire to include participants with sufficient musical training versus participants who were as naïve as possible with regards to musical experience (i.e. as young as possible). Most children do not start formal training to play an instrument before they are 8 (Harrison & O'Neill, 2000); 9-15 years of age should thus provide a set of participants who are as young as possible and yet exhibit a wide range of experience of musical training. In addition, although participants were not required actively to synchronize, but rather to produce a steady rhythm (it was the experimenter's tapping pattern that determined whether the interaction was synchronous or not; see Methods), we still took into consideration in our age choice the fact that the ability to synchronize consistently and accurately with a rhythmic sequence appears only around the age of 10 (Drake, Jones, & Baruch, 2000).

To our knowledge, this is the first study addressing experimentally both positive and negative emotional responses to rhythmic synchrony as a function of musical training background.

Method

This study was carried out in accordance with the University of Cambridge's guidance on Research Integrity and was approved by the University of Cambridge's Psychology Research Ethics Committee. All parents of children gave written informed consent for their children to participate in this study and all children gave oral informed assent in accordance with the Declaration of Helsinki.

Participants

A total of 226 school children (121 girls, 105 boys, M_{age} = 12.4 years, age range: 9-15 years, *SD* = 1.7 years) invited by their teachers to participate in the study were included in the final analysis. Data from two additional children who did not understand or could not perform the experimental tasks were omitted. 106 children (62 girls) were musically trained and 120 (59 girls) were not musically trained. Musical training was defined as participation for at least 6 consecutive months in instrumental or vocal formal music lessons on a routine basis prior to the study (M_{training} = 3.7 years, training range: 0.5-11 years, *SD* = 2.2 years). 67% of the musically trained children played one instrument (singing included), and 33% played two or three instruments; 71% of the musically trained children also participated in group musical activities such as orchestras, bands, ensembles, or choirs. This information was collected through self-report, which was followed up and supported by parent reports in cases where the children were not certain. We calculated the extent of musical training as the total time spent training, even when this was split between different instruments. For example, a child who has been playing both the piano and violin for 2 years would have a total training time of 2 years. The mean age of the children in the trained and untrained groups were M_{age} = 12.3 (range: 9-14.7, *SD* = 1.5) and M_{age} = 12.4 (range: 9.1-15.7, *SD* = 1.9), respectively. Children were recruited from two UK schools with similar socioeconomic ratings according to their Ofsted reports (Ofsted, 2006, 2009). A total of 113 children (52 musically trained and 61 musically untrained) underwent the synchrony interaction experience, and 113 (54 musically trained and 59 musically untrained) children underwent the asynchronous interaction experience.

Design

The experiment consisted of first a tapping task in which a child participant and an experimenter tapped together, and then a facial emotion recognition task, for assessing the participant's post-task emotional state. The experiment had a 2 (rhythmic interaction: synchronous vs. asynchronous) x 2 (musical training: trained vs. untrained) between-subjects design. The dependent variable was the degree of either happy or sad emotional response. To avoid order effects each child participated in only one rhythmic interaction and was asked to judge only one type of emotion: happy or sad. Analysis of variance (ANOVA) tests were performed accordingly. In addition we performed ANOVA tests for the interactions of age or gender X tapping mode (synchronous vs. asynchronous). All t-tests are 2-tailed. Results are presented as mean ± standard error of the mean.

The Tapping Task and Synchrony Evaluation

Tapping Task. The tapping task consisted of the child tapping together with an experimenter for a duration of 2 minutes. Two types of rhythmic interactions were used: synchrony and asynchrony. Each child was randomly assigned to one of these two conditions. The tapping was performed on an electrical tapper, a hand-played electronic percussion controller with 6 individual pads (Roland, SPD-6). In both types of interaction the child played the same simple rhythmic pattern, while the experimenter joined and played along, either in synchrony or in asynchrony. The children were told that their task was to play a rhythmic pattern consisting of 4 beats (repeated one quarter and two eighth notes; Figure 1A), which they performed easily after a short self-practice. The experimenter further instructed the child: "you will start playing and I will join you and we'll play together for two minutes". After the child's first four taps the experimenter joined in on a separate tapper, continuing together for two minutes. In the synchrony condition the experimenter alternated between tapping the same pattern as the child (Figure 1A), a complementary pattern to that of the child or just the beats, synchronizing with the child's speed. This alternation was done in order to emphasize synchronization rather than imitation. In the asynchrony condition the experimenter tapped a prearranged rhythmic line that could not possibly synchronize with the child's line (Figure 1B). Prior to the experiment, the experimenter practiced the tapping with children of the same age. The rhythmic interaction was recorded on a Macbook Pro laptop using LogicPro.

Synchrony evaluation. The ability to synchronize rhythmically with another person is a universal human capacity (Wallin, Merker, & Brown, 2000), which does not seem to require any special training. However, since musically trained children naturally gain more actual experience in rhythmic entrainment, we sought to verify that there were no substantial differences in the experienced tapping interaction between them and the musically untrained children (although the experimenter was responsible for the synchronization, the child nevertheless needed to maintain a reasonably stable beat). We also wished to ensure that the children were indeed experiencing two distinct types of interaction, synchronous and asynchronous and that they performed correctly their task of tapping according to a specific pattern.

In order to evaluate the degree of synchrony and asynchrony between each experimenter and participant we computed the cross-correlations between their tapping sequences. The cross-correlation provides a measure of similarity between the two tapping sequences as a function of the temporal time lag between them. During synchronous tapping, even if a short time lag exists between experimenter and participant, a peak in similarity should appear around 0 time lag, followed by recurring peaks that reflect the periodicity of the tapping. In contrast, during asynchronous tapping, no structure should appear in the cross-correlation. We first binned the tapping events into 25ms bins and then calculated the correlations between the two sequences at various time lags, ranging between -0.5sec and +0.5sec in 25ms intervals (Supplemental Figure S1A). These analyses were performed using custom script written in Matlab R2106b (Mathworks), using the function xcorr. For comparison, we also randomly permutated participant and experimenter tapping events and computed the cross-correlations between each such pair of shuffled tapping sequences (Supplemental Figure S1B). As an index for synchrony, we derived for each participant-experimenter interaction the percent difference between the original and shuffled peak cross-correlation [(peak unshuffled – peak shuffled) / peak shuffled x 100; Figure 3]. An index value of zero indicates complete asynchrony, since the tapping sequence is indistinguishable from a random sequence. A more positive index indicates more synchronous tapping. Data from fifteen children were not available due to recording errors.

Emotional Responses Measure and Scoring

Facial Emotion Recognition Task. Immediately after the rhythmic interaction each child performed a facial emotion recognition task similar to Niedenthal et al. (2000) and Harmer et al. (2004). Each child was sequentially presented with 12 randomized morphed slides on a computer screen of the same male or female actor ranging from a full 'sad' or 'happy' expression via 12 steps to a 'neutral' one morphed using FantaMorph. Pictures were taken, with permission, from the NimStim set (Tottenham et al., 2009). Each child was tested for either a 'happy' (104 children, 46 (27 girls) musically trained and 58 (29 girls) not musically trained) or 'sad' (122 children, 60 (35 girls) musically trained and 62 (30 girls) not musically trained) emotion. The type of emotion and the gender of the presented face were randomly assigned for each child. To avoid an emotional 'spill over' between the two emotional conditions, each child was tested only for one type of emotion. On the left side of the screen was the question, 'SAD?' or 'HAPPY?'. As each slide was presented, the child had to click one of two buttons at the bottom of the screen, 'YES' or 'NO' (Figure 2) according to whether they thought the person in the picture was sad/happy or not. The emotion recognition score was computed as the weighted sum of the number of 'YES' slide selections. Slides were weighted according to their rank along the range between full 'sad' or full 'happy' (rank 1) and 'neutral' (rank 12) divided by 78 (the maximum possible score, if

'YES' is selected for all slides; see examples in Figure 2). The experiment was run using a custom written Matlab (Mathworks, Natick, Mass; student version) program.

Procedure

In a quiet room in school, a child and an experimenter sat next to each other, near a table, at a ~45º angle one to the other, so that they could see each other while interacting. After explaining the experiment to the child and after a short practice, the tapping task was performed, immediately followed by the facial emotion recognition task. As we wished to gauge the emotional effects of the interaction, we chose to avoid pre-task testing which could have, in itself, induced a certain affective state in the children prior to the interaction. Musical and other background information was collected at the end of the session. The duration of the whole process was approximately 10 minutes.

Results

Synchrony Versus Asynchrony Evaluation

We first wished to assess the degree of synchronization between experimenter and participant, and confirm that it was similar between the musically trained and musically untrained children. We thus computed participant-experimenter cross-correlations (Supplemental Figure S1A; see Method) and compared the peak cross-correlation of the original tapping sequences with that of a randomly shuffled version of the same sequences (Supplemental Figure S1B). An ANOVA showed a statistically significant main effect of rhythmic interaction ($F(1,207) = 1044.94$, $p < .0001$, $\eta_p^2 = .84$), but no main effect of musical training ($F(1,207) = .26$, $p = .61$, $\eta_p^2 = .001$), and no interaction between the two factors ($F(1,207) = .14$, $p = .71$, $\eta_p^2 = .001$), confirming that the musically trained and untrained participants underwent similar experience, and that these experiences were clearly distinct between synchronous and asynchronous conditions (Figure 3). In particular, these results show that during the asynchrony condition, the experimenter and participant tapping sequences were completely uncorrelated (flat cross-correlation similar to that of the randomly shuffled tapping sequences; Supplemental Figure S1), indicating that the experimenter and child did not synchronize with each other. Had they inadvertently synchronized then this would have appeared as a peak in the cross-correlation, as in the synchrony condition (Supplemental Figure S1A). Thus, our data suggest that in this condition the children and the experimenter successfully performed their tasks of tapping their own prescribed sequence of beats, producing together the intended form of either synchronous or asynchronous interaction.

Facial Emotion Recognition Task

We computed for each participant the emotion recognition score (see Method) and statistically analyzed the results for positive affect (happiness) and negative affect (sadness) separately, since each may represent an independent emotional dimension of the affective system (Cacioppo & Gardner, 1999).

Positive affect. We first compared the level of positive (happy) affect following synchrony and asynchrony in the musically trained and untrained children (Figure 4). An ANOVA showed a significant interaction of rhythmic interaction X musical training ($F(1,100) = 6.36$, $p = .013$, $\eta_p^2 = .06$), confirming our hypothesis that the emotional response to synchrony may vary between musically trained and untrained children. We also found a significant main effect of musical training ($F(1,100) = 4.41$, $p = .038$, $\eta_p^2 = .04$). Among the musically untrained children, synchrony led to higher positive affect scores compared to asynchrony (0.34 ± 0.02 vs. 0.25 ± 0.02, $t(56) = 2.39$, $p = .02$; Figure 4A). In contrast, no such effect was found among the musically trained children (0.22 ± 0.02 vs. 0.26 ± 0.03, $t(44) = 1.23$, $p = .23$). There were no significant main effects or interactions of age or gender X tapping mode ($F < 1.2$, $p > .05$; $F < 3.3$, $p > .05$, respectively). Interestingly, when we pooled the scores of the musically trained and untrained children the significant difference in positive affect between synchrony and asynchrony vanished (t(102) = 1.07, p = .29; Figure 4B), emphasizing the importance of distinguishing between musically trained and untrained participants.

Negative affect. We next compared the level of negative (sad) affect following synchrony and asynchrony (Figure 5). An ANOVA showed a significant interaction of rhythmic interaction X musical training ($F(1,118) = 9.09$, $p = .003$, $\eta_p^2 = .07$) and no main effects. We further explored this result by post hoc t-test comparisons (Figure 5A). The musically untrained children exhibited significantly lower negative affect scores after synchrony, when compared to asynchrony (0.37 ± 0.03 vs. 0.48 ± 0.04, t(52) = -2.06, p = .045). In contrast, the musically trained children produced significantly higher negative affect scores after synchrony, when compared to asynchrony (0.48 ± 0.04 vs. 0.36 ± 0.03, t(58) = 2.18, p = .033). There were no significant main effects or interactions of rhythmic interaction X age or gender ($F < 1.4$, $p > .05$; $F < 2.5$, $p > .05$, respectively). Similarly to the positive affect scores, when the negative affect scores of the musically trained and untrained children were pooled together, the difference between synchrony and asynchrony was no longer significant (t(120) = .53, p = .96; Figure 5B).

Discussion

We have found that children respond differentially to two types of interpersonal rhythmic interaction, synchrony and asynchrony, and that these response patterns depend on whether these children come from a background of formal musical training or no musical training. Participating children showed clear differences in their propensity to recognize happiness and sadness in ambiguous facial expressions, depending on the preceding rhythmic interaction and on their musical training background. Based on previous studies that have established facial emotion recognition as strongly influenced by emotional state (Harmer et al., 2004; Niedenthal et al., 2000; Schiffenbauer, 1974; Stegge et al., 1994; Terwogt et al.,

1991) we conjecture that distinct forms of rhythmic interaction—synchrony, and asynchrony—evoke different types of emotions in children. Furthermore, these emotional responses vary dramatically among participants with a background of formal musical training. Our study thus demonstrates that even in isolation from other features of musical behavior, rhythmic interaction is sufficient to evoke basic and distinct emotions in children, and that this newly discovered mapping between rhythmic interaction and emotion is associated with long-term musical training.

Several novel features of the present study have made it possible to reveal the emotional reactions to rhythmic interaction. First, implicit measures of emotional state, such as the one used in our study, is a reliable and sensitive indicator for experienced emotion, and might be a better choice than explicit verbal report in dynamic and interactive contexts. Second, distinguishing between participants with or without musical training background is important; otherwise the opposing effects in the two groups may cancel out, as occurred, for example, when we pooled the scores of the musically trained and untrained participants in the current study (Figure 4B, 5B). Third, evaluating negative affect in addition to positive affect was important for revealing the full effect of the rhythmic interaction. Here, the musically trained children showed a clear difference between synchrony and asynchrony in negative, but not in positive affect. Finally, studying children's emotional responses to rhythmic interaction complements previous adult studies, providing a relatively more naïve perspective on these processes.

What could be the reason for the increased positive affect and reduced negative affect in response to synchronized compared to asynchronized interaction among the musically untrained children? One explanation could be that all children were actively trying to synchronize with the experimenter, possibly due to a natural inclination to synchronize. This challenge may have been too frustrating for the untrained children, as opposed to the trained children, explaining the negative emotional response in the former as opposed to the latter. This possibility is not very likely, however, since the children were explicitly instructed to tap according to their assigned rhythmic pattern, which they practiced before beginning the joint tapping (Methods), and were conscious of the task demands and of keeping their pattern consistent even under the asynchrony condition. The analysis of recorded tapping patterns (Figure 3, Supplemental Figure S1) further demonstrates that children from both groups produced consistent and similar tapping patterns in both the synchrony and asynchrony conditions, and shows no evidence of any modification of these patterns in an attempt to synchronize with the experimenter.

It is important to note that the musically untrained children are not musically deprived. On the contrary, they often listen to music, sing and experience many types of rhythmic interactions. We speculate that precisely such repeated experiences of synchronous interaction coupled with social harmony may have left in them a strong association between synchrony and positive affect, and vice versa, between asynchrony and negative affect, in line with the general consensus in the literature on affect in entrained musical interaction.

Notably, even brief episodes of interpersonal synchronization have been shown to positively impact on children’s social attitudes and behavior. For example, rhythmic synchrony increased 8-year-old children’s sense of similarity and closeness towards one another (Rabinowitch & Knafo-Noam, 2015), strengthened social bonds across groups of 7-11 year-olds (Tunçgenç & Cohen, 2016), enhanced cooperation between 4-year-olds (Rabinowitch & Meltzoff, 2017) and increased the likelihood that 14-month-old infants would show helping behavior (Cirelli, Einarson & Trainor, 2014). Given this positive role for synchrony in human social interaction, we propose that humans might be generally predisposed to feeling happiness when experiencing interactive synchrony, and perhaps conversely, be saddened when sensing asynchrony. It remains to be resolved which of the two, synchrony or asynchrony, directly influences affect—or whether both are responsible. One way or the other, such emotional feedback may serve as a proximal drive, encouraging participation in synchronous interaction, ultimately leading to prosocial behavior. We further postulate that in the course of hominin social evolution a selection bias favoring synchronous rhythmic interaction over asynchronous interaction may have arisen, either music-specifically as part of cultural evolution, or as an exaptation of more general cognitive mechanisms.

Why do children with formal musical training background respond so differently from the musically untrained children? One possibility is that formal musical training often focuses on dexterity, precision, expertise etc. instead of, or in addition to the social interactive aspects of music. Thus, the musically trained children may have learned to overcome a possibly natural inclination to associate synchronous rhythmic interaction with positive emotions, and to prefer complicated rhythms and more complex forms of entrainment and virtuosity over a basic and well-coordinated rhythmic interaction. In fact, they may have found the rhythmic interaction in the experiment to be rather simple, perhaps even boring, which would in itself explain their overall low happiness scores (Figure 4A). In addition, a large body of literature has documented substantial differences in development and cognitive and brain function in musicians versus non-musicians. For example, expert jazz musicians appear to show increased sensitivity to subtle deviations in rhythm, compared to non-musicians, and exhibit altered brain responses that suggest the development of a significant role for rhythmic incongruences in musical communication (Vuust et al., 2005; Herdener et al., 2014). Therefore, for the musically trained children in our study, the synchronous tapping may have presented a rather sparse and unappealing form of communication, lacking any rhythmic cues or content and thus leading to lower positive and higher negative affect. This hypothesis will require separate future examination. It will also be important to consider the specific factors that distinguish between musically trained and untrained children, which lead to almost inverse emotional responses to synchrony versus asynchrony. It is possible that particular cognitive, personality and demographic factors, such as IQ, openness to experience and socio-economic status, formed by a gene-environment combination, is what drove children to engage in and persist with musical training in the first place (Butkovic et al., 2015; Corrigall et al., 2013; Corrigall & Schellenberg, 2015; Mosing et al., 2016; Swaminathan et al., 2017). These factors instead of, or in addition, to the training itself may have contributed to the differences in sensitivity towards the rhythmic stimulus we found in children with musical training background in comparison to the musically untrained children. The nature and impact of these underlying factors warrants further investigation.

Several interesting questions follow from this study: Would the musically trained children still prefer asynchrony even in a more sophisticated and complex rhythmic interaction? Could musical training in a more social context such as musical group interaction (Rabinowitch et al., 2013) 'reverse' the musically trained children's responses? Would similar effects be found in adults tested separately according to musical training? Our findings also prompt the investigation of further features of joint engagement in music and their effects on additional types of emotions in an effort to explore possible regularities in the links between the structure of musical interaction and emotions.

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References

Bharucha, J. J., & Curtis, M. (2008). Affective spectra, synchronization, and motion: Aspects of the emotional response to music. *Behavioral and Brain Sciences*, *31*, 579-579. https://doi.org/10.1017/S0140525X08005335

Bharucha, J. J., Curtis, M., & Paroo, K. (2006). Varieties of musical experience. *Cognition*, *100*, 131-172. https://doi.org/10.1016/j.cognition.2005.11.008

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: underlying environmental and genetic influences. *Personality and Individual Differences*, *74*, 133-138. https://doi.org/10.1016/j.paid.2014.10.006

Cacioppo, J. T. & Gardner, W. L. (1999). Emotion. *Annual Review of Psychology, 50*, 191-214. https://doi.org/10.1146/annurev.psych.50.1.191

Carretie, L., Mercado, F., Tapia, M., & Hinojosa, J. A. (2001). Emotion, attention, and the 'negativity bias', studied through event-related potentials. *International Journal of Psychophysiology, 41*, 75-85. https://doi.org/10.1016/S0167-8760(00)00195-1

Cirelli, L. K., Einarson, K. M., & Trainor, L. J. (2014). Interpersonal synchrony increases prosocial behavior in infants. *Developmental Science*, *17*, 1003-1011. https://doi.org/10.1111/desc.12193

Clarke, E., DeNora, T., & Vuoskoski, J. (2015). Music, empathy and cultural understanding. *Physics of Life Reviews*, *15*, 61-88. https://doi.org/10.1016/j.plrev.2015.09.001

Clayton, M., Sager, R., & Will, U. (2004). In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM CounterPoint, 1*, 1-82.

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology*, 6:282. https://doi.org/10.3389/fpsyg.2015.00282

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, 4:222. https://doi.org/10.3389/fpsyg.2013.00222

Costa-Giomi, E. (1999). The effects of three years of piano instruction on children's cognitive development. *Journal of Research in Music Education*, *47*, 198-212. https://doi.org/10.2307/3345779

Cross, I. (2008). Musicality and the human capacity for culture. *Musicae Scientiae*, *12*, 147-167. https://doi.org/10.1177/1029864908012001071

Cunningham, W. A., Raye, C. L., & Johnson, M. K. (2004). Implicit and explicit evaluation: fMRI correlates of valence, emotional intensity, and control in the processing of attitudes. *Journal of Cognitive Neuroscience, 16*, 1717-1729. https://doi.org/10.1162/0898929042947919

Drake, C., Jones, M. R., & Baruch, C. (2000). The development of rhythmic attending in auditory sequences: Attunement, referent period, focal attending. *Cognition, 77*, 251-288. https://doi.org/10.1016/S0010-0277(00)00106-2

Ehrenreich, B. (2006). *Dancing in the streets: a history of collective joy* (1st ed.). New York, NY: Metropolitan Books.

Epley, N., Waytz, A., Akalis, S., & Cacioppo, J. T. (2008). When we need a human: Motivational determinants of anthropomorphism. *Social Cognition*, *26*, 143-155. https://doi.org/10.1521/soco.2008.26.2.143

Fessler, D. M., & Holbrook, C. (2014). Marching into battle: Synchronized walking diminishes the conceptualized formidability of an antagonist in men. *Biology Letters*, *10*, 20140592. https://doi.org/10.1098/rsbl.2014.0592

Forgas, J. P., & East, R. (2008). How real is that smile? Mood effects on accepting or rejecting the veracity of emotional facial expressions. *Journal of Nonverbal Behavior*, *32*, 157-170. https://doi.org/10.1007/s10919-008-0050-1

Gabrielsson, A., & Juslin, P. N. (1996). Emotional expression in music performance: Between the performer's intention and the listener's experience. *Psychology of Music*, *24*, 68-91. https://doi.org/10.1177/0305735696241007

Gomez, P., & Danuser, B. (2007). Relationships between musical structure and psychophysiological measures of emotion. *Emotion*, *7*, 377-387. https://doi.org/10.1037/1528-3542.7.2.377

Habibi, A., Ilari. B., Crimi, K., Metke, M., Kaplan, J. T., Joshi, A. A., Leahy, R. M., ... & Damasio, H. (2014). An equal start: absence of group differences in cognitive, social, and neural measures prior to music or sports training in children. *Frontiers in Human Neuroscience*, 8:690. https://doi.org/10.3389%2Ffnhum.2014.00690

Haidt, J., Seder, J. P., & Kesebir, S. (2008). Hive psychology, happiness, and public policy. *Journal of Legal Studies, 37*, S133-S156. https://doi.org/10.1086/529447

Harmer, C. J., Shelley, N. C., Cowen, P. J., & Goodwin, G. M. (2004). Increased positive versus negative affective perception and memory in healthy volunteers following selective serotonin and norepinephrine reuptake inhibition. *American Journal of Psychiatry, 161*, 1256-1263. https://doi.org/10.1176/appi.ajp.161.7.1256

Harrison, A. C., & O'Neill, S. A. (2000). Children's gender-typed preferences for musical instruments: An intervention study. *Psychology of Music, 28*, 81-97. https://doi.org/10.1177/0305735600281006

Herdener, M., Humbel, T., Esposito, F., Habermeyer, B., Cattapan-Ludewig, K., & Seifritz, E. (2012). Jazz drummers recruit language-specific areas for the processing of rhythmic structure. *Cerebral Cortex*, *24*, 836-843. https://doi.org/10.1093/cercor/bhs367

Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition, 27*, 949-960. https://doi.org/10.1521/soco.2009.27.6.949

Hunter, P. G., Schellenberg, E. G., & Schimmack, U. (2010). Feelings and perceptions of happiness and sadness induced by music: Similarities, differences, and mixed emotions. *Psychology of Aesthetics, Creativity, and the Arts*, *4*, 47-56. http://dx.doi.org/10.1037/a0016873

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009A). Musical training shapes structural brain development. *Journal of Neuroscience*, *29*, 3019-3025. https://doi.org/10.1523/JNEUROSCI.5118-08.2009

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009B). The effects of musical training on structural brain development. *Annals of the New York Academy of Sciences*, *1169*, 182-186. https://doi.org/10.1111/j.1749-6632.2009.04852.x

Inaba, M., Nomura, M., & Ohira, H. (2005). Neural evidence of effects of emotional valence on word recognition. *International Journal of Psychophysiology, 57*, 165-173. https://doi.org/10.1016/j.ijpsycho.2005.01.002

Ito, T., Cacioppo, J. T., & Lang, P. J. (1998). Eliciting affect using the international affective picture system: Trajectories through evaluative space. *Personality and Social Psychology Bulletin, 24*, 855-879. https://doi.org/10.1177/0146167298248006

Juslin, P. N., & Sloboda, J. (Eds.). (2011). Handbook of music and emotion: Theory, research, applications. Oxford University Press.

Kallinen, K. (2005). Emotional ratings of music excerpts in the western art music repertoire and their self-organization in the Kohonen neural network. *Psychology of Music*, *33*, 373-393. https://doi.org/10.1177/0305735605056147

Kallinen, K., & Ravaja, N. (2006). Emotion perceived and emotion felt: Same and different. *Musicae Scientiae*, *10*, 191-213. https://doi.org/10.1177/102986490601000203

Keller, P. E. (2014). Ensemble performance: Interpersonal alignment of musical expression. In D. Fabian, R. Timmers & E. Schubert (Eds.), *Expressiveness in music performance: Empirical approaches across styles and cultures*, (pp. 260-282). Oxford, UK: Oxford University Press.

Kivy, P. (1981). *The corded shell: Reflections on musical expression*. Princeton University Press.

Khalfa, S., Peretz, I., Blondin, J-P., & Manon, R. (2002). Event-related skin conductance responses to musical emotions in humans. *Neuroscience Letters*, *328*, 145-149. https://doi.org/10.1016/S0304-3940(02)00462-7

Labbé, C., & Grandjean, D. (2014). Musical emotions predicted by feelings of entrainment. *Music Perception, 32*, 170-185. https://doi.org/10.1525/mp.2014.32.2.170

Langer, S. K. (1953). *Feeling and form* (pp. 28-47). New York: Scribner.

Lumsden, J., Miles, L. K., & Macrae, C. N. (2014). Sync or sink? Interpersonal synchrony impacts self-esteem. *Frontiers in Psychology*, 5:1064. https://doi.org/10.3389%2Ffpsyg.2014.01064

McNeill, W. (1995). *Keeping together in time: dance and drill in human history*. Cambridge, MA: Harvard University Press.

Merriam, A. P. (1964). *The anthropology of music*. Evanston, IL: Northwestern University Press.

Merker, B. H. (1999). Synchronous chorusing and the origins of music. *Musicae Scientiae, special issue on rhythm, musical narrative, and origins of human communication*, 59-73. https://doi.org/10.1177/10298649000030S105

Mogan, R., Fischer, R., & Bulbulia, J. A. (2017). To be in synchrony or not? A meta-analysis of synchrony's effects on behavior, perception, cognition and affect. *Journal of*

Experimental Social Psychology, *72*, 13-20. https://doi.org/10.1016/j.jesp.2017.03.009

Mosing, M. A., Madison, G., Pedersen, N. L., & Ullén, F. (2016). Investigating cognitive transfer within the framework of music practice: Genetic pleiotropy rather than causality. *Developmental Science*, *19*, 504-512. https://doi.org/10.1111/desc.12306

Niedenthal, P., M, Halberstadt, J., B, Margolin, J., & Innes-ker, A., H. (2000). Emotional state and the detection of change in facial expression of emotion. *European Journal of Social Psychology, 30*, 211-222. https://doi.org/10.1002/(SICI)1099-0992(200003/04)30:2<211::AID-EJSP988>3.0.CO;2-3

Ofsted. (2006, 2009). Primary schools inspection reports, *Office for Standards in Education, Children's Services and Skills*: London: Ofsted.

Overy, K., & Molnar-Szakacs, I. (2009). Being together in time: Musical experience and the mirror neuron system. *Music Perception: An Interdisciplinary Journal*, *26*, 489-504. 10.1525/mp.2009.26.5.489

Rabinowitch, T-C., Cross, I., & Burnard, P. (2013). Long-term musical group interaction has a positive influence on empathy in children. *Psychology of Music*, *41*, 484-498. https://doi.org/10.1177/0305735612440609

Rabinowitch, T-C., & Knafo-Noam, A. (2015). Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. *PloS One*, *10*, e0120878. https://doi.org/10.1371/journal.pone.0120878

Rabinowitch, T-C., & Meltzoff, A. N. (2017). Synchronized movement experience enhances peer cooperation in preschool children. *Journal of Experimental Child Psychology*, *160*, 21-32. https://doi.org/10.1016/j.jecp.2017.03.001

Schellenberg, E. G. (2005). Music and cognitive abilities. *Current Directions in Psychological Science*, *14*, 317-320. https://doi.org/10.1111/j.0963-7214.2005.00389.x

Schellenberg, E. G., Krysciak, A. M., & Campbell, R. J. (2000). Perceiving emotion in melody: Interactive effects of pitch and rhythm. *Music Perception: An Interdisciplinary Journal*, *18*, 155-171. https://doi.org/10.2307/40285907

Schiffenbauer, A. (1974). Effect of observer's emotional state on judgements of the emotional state of others. *Journal of Personality and Social Psychology 30*, 31-35. http://dx.doi.org/10.1037/h0036643

Slevc, L. R., Davey, N. S., Buschkuehl, M., & Jaeggi, S. M. (2016). Tuning the mind: Exploring the connections between musical ability and executive functions. *Cognition*, *152*, 199-211. https://doi.org/10.1016/j.cognition.2016.03.017

Stegge, H., Terwogt, M. M., & Koops, W. (1994). Positive and negative mood effects in children: The mediating influences of task characteristics. *The Journal of General Psychology 121*, 333-344. http://dx.doi.org/10.1080/00221309.1994.9921207

Swaminathan, S., Schellenberg, E. G., & Khalil, S. (2017). Revisiting the association between music lessons and intelligence: Training effects or music aptitude?. *Intelligence*, *62*, 119-124 https://doi.org/10.1016/j.intell.2017.03.005

Taylor, S. E. (1991). Asymmetrical effects of positive and negative events - the mobilization minimization hypothesis. *Psychological Bulletin, 110*, 67-85. http://dx.doi.org/10.1037/0033-2909.110.1.67

Terwogt, M. M., Kremer, H. H., & Stegge, H. (1991). Effects of children's emotional state on their reactions to emotional expressions: A search for congruency effects. *Cognition and Emotion*, *5*, 109-121. http://dx.doi.org/10.1080/02699939108411028

Theorell, T., Lennartsson, A. K., Madison, G., Mosing, M. A., & Ullén, F. (2015). Predictors of continued playing or singing–from childhood and adolescence to adult years. *Acta Paediatrica*, *104*, 274-284. https://doi.org/10.1111/apa.12870

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168*, 242-249. https://doi.org/10.1016/j.psychres.2008.05.006

Trost, W., Labbé, C., & Grandjean, D. (2017). Rhythmic entrainment as a musical affect induction mechanism. *Neuropsychologia*, 96, 96-110. https://doi.org/10.1016/j.neuropsychologia.2017.01.004

Tunçgenç, B., & Cohen, E. (2016). Movement synchrony forges social bonds across group divides. *Frontiers in Psychology*, 7:782. https://doi.org/10.3389/fpsyg.2016.00782

Turino, T. (2008). *Music as social life: The politics of participation*. Chicago, IL: University of Chicago Press.

Vuust, P., Pallesen, K. J., Bailey, C., van Zuijen, T. L., Gjedde, A., Roepstorff, A., & Østergaard, L. (2005). To musicians, the message is in the meter: pre-attentive neuronal responses to incongruent rhythm are left-lateralized in musicians. *Neuroimage*, *24*, 560-564. https://doi.org/10.1016/j.neuroimage.2004.08.039

Wallin, N. L., Merker, B., & Brown, S. (2000). An introduction to evolutionary musicology. In N. L. Wallin, B. Merker & S. Brown (Eds.), *The origins of music* (pp. 3-24). Cambridge, Mass. London: MIT Press.

Webster, G. D., & Weir, C. G. (2005). Emotional responses to music: Interactive effects of mode, texture, and tempo. *Motivation and Emotion*, *29*, 19-39. https://doi.org/10.1007/s11031-005-4414-0

Wiltermuth, S. S., & Heath, C. (2009). Synchrony and cooperation. *Psychological Science, 20*, 1-5. https://doi.org/10.1111/j.1467-9280.2008.02253.x

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions evoked by the sound of music: characterization, classification, and measurement. *Emotion*, *8*, 494-521. http://dx.doi.org/10.1037/1528-3542.8.4.494

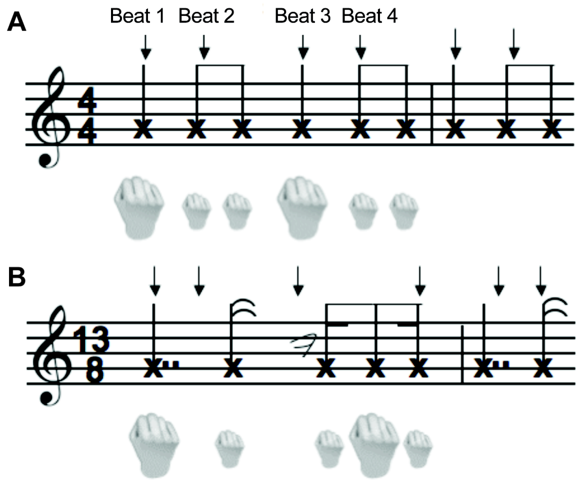


Figure 1. (A) Participant rhythmic line in the tapping task. The experimenter either tapped a line similar to that of the participant or a variation of it in the synchrony condition (A) or an entirely incompatible rhythmic line in the asynchrony condition **(B)**. Hand symbols represent tapping, arrows indicate beat times.

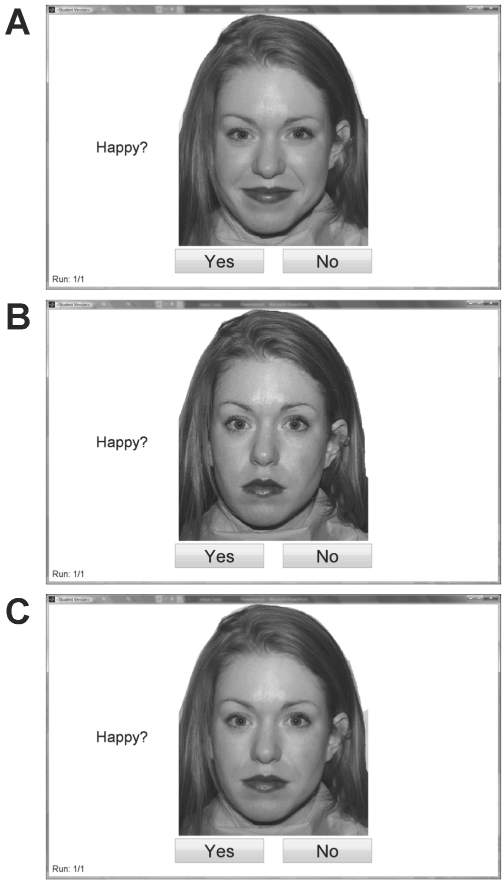


Figure 2. Screen shot examples of 'happy' morphed slides used in the implicit emotional valence task. **(A)** Full 'happy' emotional expression slide (rank 12, weight 1/78; see Method). **(B)** Neutral expression (rank 1, weight 12/78). **(C)** Intermediate morphed slide between 'happy' and 'neutral' (rank 5, weight 8/78). Pictures are used with permission from the NimStim set of facial expressions (Tottenham et al., 2009).

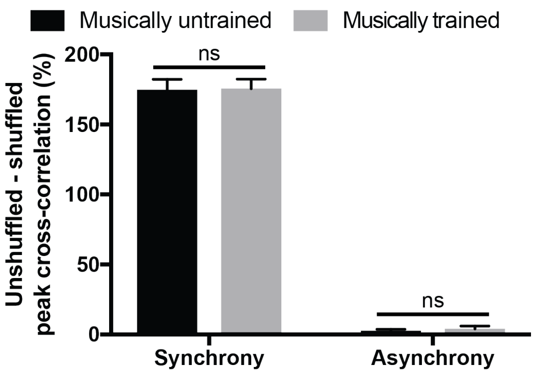


Figure 3. Percent difference between original and shuffled peak cross-correlation between participant and experimenter tapping sequences (see Materials and Methods). ns – not significant.

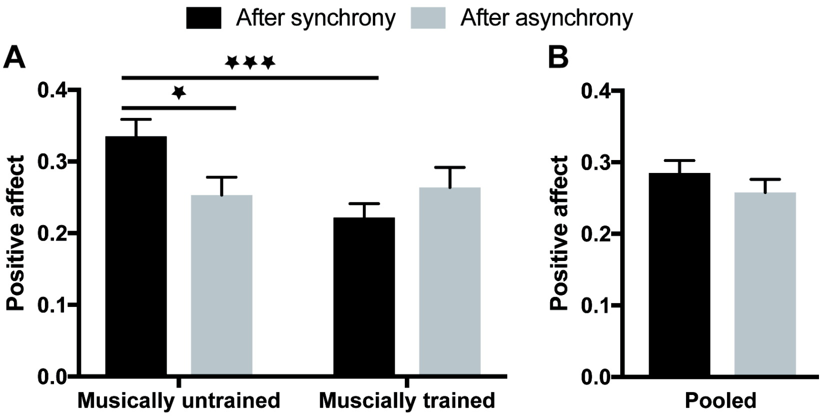


Figure 4. (A) Positive affect scores for musically untrained and musically trained children after synchronous and asynchronous musical interactions. **(B)** Pooled positive affect scores as a function of rhythmic interaction (error bars represent SEM). *p < .05.

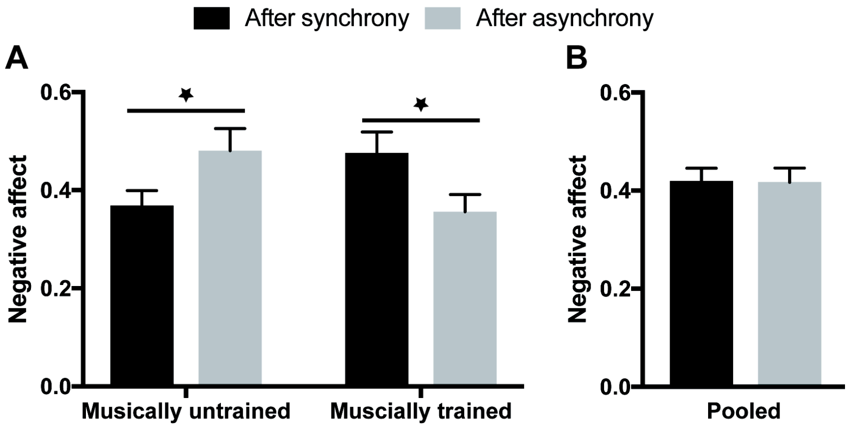
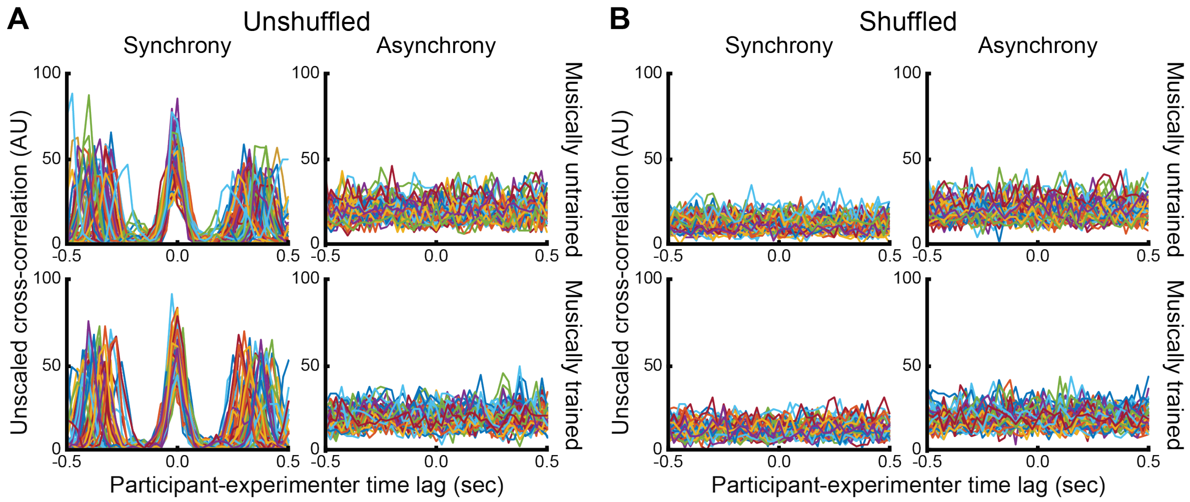


Figure 5. (A) Negative affect scores for musically untrained and musically trained children after synchronous and asynchronous musical interactions. **(B)** Pooled negative affect scores as a function of rhythmic interaction (error bars represent SEM). *p < .05.



Supplemental Figure S1. (A) Cross-correlations between participant and experimenter tapping sequences. Each colored line is from a different participant. (**B**) Same tapping sequences from (A) were first randomly shuffled and the cross-correlations were re-computed.