



BIROn - Birkbeck Institutional Research Online

Rocha, Sinead - Elouise and Mareschal, Denis (2016) Getting into the groove: the development of tempo-flexibility between 10 and 18 months of age. *Infancy* 22 (4), pp. 540-551. ISSN 1525-0008.

Downloaded from: <https://eprints.bbk.ac.uk/id/eprint/17565/>

Usage Guidelines:

Please refer to usage guidelines at <https://eprints.bbk.ac.uk/policies.html>
contact lib-eprints@bbk.ac.uk.

or alternatively

Getting into the Groove: the development of tempo- flexibility between 10 and 18 months

Sinead Rocha
Denis Mareschal

Centre for Brain and Cognitive Development
Department of Psychological Sciences
Birkbeck University of London

Abstract

Despite good early rhythm processing abilities, and clear enjoyment of music, infants appear not to be able to spontaneously synchronize their movement to the beat of a song (Zentner & Eerola, 2010). We present a new social bell-ringing task designed to facilitate synchronous movement to music in infants. Ten-month-olds, 18-month-olds, and adults were played musical tracks of various tempos and given handheld bells to ring, in the presence of either a live experimenter or an animated non-social stimulus. Surface electromyography (EMG) was used to measure the timing of arm movements during periods of bell ringing. Infants showed no evidence of synchronous bell ringing at any tempo. However, while the 10-month-olds did not modulate their ringing to the music tempo, the 18-month-olds showed tempo flexibility. Moreover, 18-month-olds displayed more associated behaviors such as bouncing and rocking in the absence (rather than presence) of a social partner, whereas the behavior of the 10-month-olds was not modulated by the presence or absence of a social partner. The results suggest a distinction between 'moving together' and 'moving to the beat', which may have separate underlying mechanisms and developmental trajectories.

Music is present in all human cultures, although it can be highly variable in rhythm, melody and performance styles (Ayres, 1973). Equally, movement to music is a universally present behavior, be it through dance, drumming or singing (Wallin, Merker & Brown, 2001), with a direct comparison of cross-cultural music capturing a network of related features centered on group performance and dance (Savage, Brown, Sakai & Currie, 2015). Tracking the development of movement to music in infancy provides a window into the perceptual and physical skills, experience and contexts necessary, for synchronizing movements to music. The current paper will discuss two types of behavior commonly seen in response to music: (1) moving isochronously, or moving at a steady rate, and (2) moving synchronously, or moderating rhythmic behavior so that it coincides with an external auditory rhythm.

From an early age, infants hold many of the prerequisites for movement to music. They are able to detect violations of rhythms from birth (Winkler et al., 2009), and by seven-months-of-age they can process complicated variations in rhythmic structure (Trehub & Thorpe, 1989). A relationship between movement and music also appears around this age. For example, movement to a beat biases the perception of an ambiguous rhythm from seven-months-of-age (Phillips-Silver & Trainor, 2005). Finally, cultural specificity in rhythm preference is accelerated if infants are subjected to movement training (Gerry, Faux & Trainor, 2010).

However, although the skills that underlie music (and especially rhythm) perception are in place very early on, infants do not seem to synchronize their movement to music spontaneously, despite spending up to 40% of their time performing repetitive movements (Thelen, 1979; 1981). The

closest evidence of infants moving to a beat comes from Zentner and Eerola (2010). Using motion capture technology these authors demonstrated that infants aged 5 to 24 months engage in more isochronous movement to music than to speech, and have a degree of tempo flexibility; i.e., infants spontaneously move faster to faster rhythms, and slower to slower rhythms. Zentner and Eerola's work hints at a developmental progression from moving isochronously in response to music, as seen in their data, to moving synchronously with music, as commonly seen in adults.

Infants appear not to progress into moving synchronously with exogenous rhythms until the early preschool years. By 2.5 years of age children will modify their behavior to entrain a drumming movement with a significantly slower than natural inter-stimuli-interval (ISI), though only in the presence of a social partner (Kirschner & Tomasello, 2009). This hints at how humans may transition from 'feeling' the beat of music, to moving to it: Moving to music might be inherently linked to moving together, or joint action, where individuals are motivated towards a higher-level process of reaching a common goal.

The facilitative effect of a social context seems intuitive. We move in synchrony with others unconsciously, even when it is not the most efficient action (Goodman et al., 2005). Adults (Chartrand & Bargh, 1999) and infants (Tuncgenc, Cohen & Fawcett, 2014) prefer those who mimic their movements. In the context of music, the desire to move together may go beyond physical mimicry, and may actually speak to the adaptive value of facilitating social cohesion; producing, hearing and performing to music may elicit a shared emotion in a group, which induces cooperation, a key skill for

increased chance of survival (Trainor, 2010). Moving together, even when not initiated by the infant themselves, has been shown to increase pro-social behavior in 14-month-olds: Infants bounced to music in time with an experimenter were more helpful to that experimenter than if bounced out of time (Cirelli, Einarson & Trainor, 2014; Cirelli, Wan & Trainor, 2014).

However, an alternative explanation for how infants transition to moving synchronously with music is that infants may 'feel' music in a qualitatively similar way to adults from very early on, but simply lack the motor skills to synchronize their movement (e.g. Zentner & Eerola, 2010). The finding that infant preference for rhythm is not culturally defined has led to the discussion of beat induction as a 'spontaneously developing' process, emphasizing a biological basis over a cultural, or learned basis (Honing, 2012). Furthermore, anthropometric features including height and leg length have been shown to correspond with preferred beat rate in adults, with longer limbs associated with a slower preferred beat (Todd, Cousins & Lee, 2007; Dahl, Huron & Brod, 2014). Children have a faster spontaneous motor tempo (SMT) than adults; under-three-year-olds spontaneously tap at an inter-stimuli-interval (ISI) of around 400ms, whereas adults typically tap at an ISI of around 600ms (Provasi & Bobin-Begue, 2003). If rhythm production is tied into physical characteristics of the body, it is plausible to predict that infants' natural rhythm is again faster than young children's, and that infants will find it easier to synchronize when presented with musical stimuli of a faster than 400ms ISI.

The current study aims to test these two contrasting accounts of the development of movement to music, through the adoption of a novel

experimental procedure. Rather than measuring spontaneous movement, which has been shown to be asynchronous in infancy (Zentner & Eerola, 2009; Fujii et al., 2014), in the current study, infants are given small hand-held bells to ring. This provides auditory feedback from their movements, something essential for an ape synchronizing to a beat (Hattori et al., 2013). It also allows us to evaluate infant abilities on a movement that does not require advanced motor skill (unlike in the measurement of drumming or finger tapping, that require a precise spatial location of the movement). Finally, it allows us to predict where on the body a movement will originate, enabling the accurate measurement of muscle activity in the arms using surface electromyography (EMG). By moving away from measurement of spontaneous movement to music, we are better able to see what infants are capable of doing when guided, in addition to the actions they spontaneously produce, when presented with music.

To evaluate the role a social partner in moving to the beat, infants take part in two conditions, a social condition in which they interact with a live social partner, and a non-social condition in which they are presented with a non-social visual animation. In accordance with Kirschner and Tomasello's (2009) finding with 2.5-year-olds, we hypothesize that infants' isochronous movements will be more accurate in the social condition than the non-social condition.

Method

Participants

Seventeen 10-month-olds (6 female; mean age= 302 days, range= 290 days to 317 days), and 27 18-month-olds (7 female; mean age= 555 days, range= 534 days to 615 days) took part in this study¹. All caregivers gave written, informed consent concerning the experimental procedure. Infants received a certificate and a t-shirt as a thank you for participation. Ten adults (8 female; mean age= 34 years, range= 22-60 years) also took part. Adults gave written, informed consent and received no recompense for participation.

Procedure

For infants, surface electromyography (EMG) was used to record the electrical activity of the right and left biceps brachii. Infants always experienced the familiarization trial first. The social and non-social conditions were then presented in a counter-balanced order.

Familiarization Trial. Infants were given two small hand-held sleigh bells and seated on a cushion on the floor adjacent to their caregiver. The experimenter sat opposite the infant, held a separate sleigh bell in each hand and demonstrated ringing the bells using a vertical up-and-down movement whilst singing. Infants were allowed to play freely with their bells for approximately 10 seconds. They were congratulated on playing, regardless of their behavior during the trial. To familiarize the infants with the testing

¹ Although we initially matched the infant groups by number of participants, 18-month-olds provided significantly less data than 10-month-olds. We therefore recruited further 18-month-olds to match the number of data points (or 'bouts' of ringing) across the groups. The results of our analyses are the same both with and without the additional 18-month-olds.

environment, a video screen approximately 100cm from the infants was then switched on. Infants saw two cartoon stills alternating every 5 seconds for 45 seconds. Two speakers either side of the screen played the sound of running water concordantly. The sounds were intended to keep the infants' attention directed towards the screen (and away from the caregiver) during the trial, without providing an alternative rhythm.

Social Condition. Infants took part in four trials of 45 seconds each. Each trial used an abridged version of one of four naturalistic musical tracks, each of a different beat ISI (**300ms**, Traffic Jam by Weird Al Yankovic; **350ms**, Good Golly Miss Molly by Little Richard; **450ms**, Let's Get Loud by Jennifer Lopez; and **600ms**, Rock Your Body by Justin Timberlake), with the trial order randomized between infants and between conditions. In each trial, the experimenter played her sleigh bells using the vertical motion, in time with the underlying beat of the track being played through the speakers (i.e., at the corresponding ISI). Infants were engaged in eye contact and smiles by the experimenter, regardless of their behavior, remaining unconstrained and allowed to move freely. Between each trial infants were given a short (approximately 10 second) break during which they were congratulated on taking part; if they dropped or rejected their bells during the trial these were returned before the beginning of the next trial. If infants stood up and/or moved around the room during the trial, they were returned to their seated position.

Non-social Condition. In the non-social condition infants heard the same four tracks across four trials, for 45 seconds per trial, in a randomized order. In this condition the experimenter moved out of sight, behind a curtain,

and the video screen was turned on. For each trial, the infants saw an animation on the screen of two sleigh bells moving in a vertical up-and-down motion against a plain black background, in time with the track being played. Again, between trials infants were congratulated on taking part.

The adult protocol was identical to the infant protocol, without the familiarization condition. Adults were instead given the following instructions: 'You're going to hear two sets of four songs, and I'd like you to play your bells with the music. For one set of four, you will also see and hear me playing my bells with the song. For the other set, you will see and hear an animation of bells on the screen ahead of you.'

Apparatus

EMG data were collected using four bipolar pediatric surface electrodes (3M monitoring electrodes with micropore tape and solid gel) and the Myon 320 wireless EMG system, at a sampling rate of 4000 Hz. Animations for the baseline and non-social conditions were presented on a video screen using Matlab R2009b (Mathworks Ltd.). Simultaneous video recording of the testing session was conducted using a Logitech HD 1080p webcam positioned on top of the screen. See Figure 1 for a visual representation of testing set up.

Data Processing

Video recordings of the testing session were coded for all incidences of infant motor activity (see Table 1 for a summary of behaviors included). To be categorized as potentially rhythmic, infants had to make two or more of each movement; i.e., we coded for repetitive movements. Incidences in which

infants made only a single bounce or kick did not meet the criterion. Although we identified bouts of potentially rhythmic activity, no judgments about the relative timing of the movements were made at this stage of the analysis. Behaviors were excluded if the infant was in physical contact with the mother and the mother was moving, or if the infant performed repetitive movements in order to locomote (i.e. incidences of crawling and walking). An independent researcher double coded the video data for ten infants. The single measure ICC for duration of ringing behavior was .854, with a 95% confidence interval from .770 to .908, ($F(2,63)=12.658$, $p<.001$). For duration of other repetitive movements the ICC was .966, with a 95% confidence interval from .945 to .979, ($F(2,63)=57.826$, $p<.001$).

The EMG data were analyzed using the stand-alone ProEMG software (ProPhysics). Data were rectified and high-pass filtered at 400 Hz, low-pass filtered at 10 Hz and notch filtered at 50Hz. Infant EMG data were then segmented into corresponding periods of 'shaking behavior' as defined by the video coding. A researcher blind to trial type and the ISI of the track, hand-coded the onset of each burst of activity from the corresponding EMG channel traces for right or left biceps during the 'ringing' period by taking the first peak of each burst with processed amplitude at or above 1 volt (see Figure 2). If data were so noisy that no burst was visible, they were discarded. Distances between burst onsets were then calculated in milliseconds to give an inter-ring-interval (IRI). Adult data were processed in the same way, except that as adults rang their bells continuously through each trial, three-second periods (roughly the mean length of an infant segment) of clean data were pseudo-randomly selected from within the trial for analysis. The difference between

the IRI for each bout of ringing and the target ISI of the track was calculated to give an accuracy score for each trial (often referred to as level of asynchrony in the literature). Accordingly, in the results described below, a lower score reflects less difference from the target ISI, and can be regarded as more accurate. A pseudo-randomly selected subset of 10 infants were double coded by an independent researcher. The single measure ICC was .899, with a 95% confidence interval from .793 to .953, ($F(2,26)=18.621$, $p<.001$).

Results

EMG Data

A univariate ANOVA with Accuracy as the dependent variable, and Age Group (10-months, 18-months, and adult), Social/Non-Social Condition and Target ISI (300, 350, 450 and 600ms) as fixed factors, revealed significant main effects of Age (10-months $M=.209$, $SE=.013$, 95% CI (.184, .234); 18-months $M=.187$, $SE=.013$, 95% CI (.161, .213); adult $M=.024$, $SE=.013$, 95% CI (-.002, .051); ($F(2,270)=58.4$, $p<.001$)) and Target ISI (300ms $M=.105$, $SE=.014$, 95% CI (.076, .133); 350ms $M=.103$, $SE=.015$, 95% CI (.075, .132); 450ms $M=.131$, $SE=.016$, 95% CI (.099, .163), 600ms $M=.221$, $SE=.015$, 95% CI (.191, .252); ($F(3,270)=13.4$, $p>.001$)), with a significant Age*Target ISI interaction ($F(6,270)=6.04$, $p<.001$). We found no main effect of Social/Non-Social Condition (Social $M=.129$, $SE=.01$, 95% CI (.110, .148); Non-Social $M=.151$, $SE=.012$, 95% CI (.128, .174); ($F(1,270)=2.08$, $p=.15$)), and no other interactions.

Planned comparisons revealed that the main effect of Age was driven by the adult group being more accurate than both infant groups (both $p<.001$),

with no difference between the 10- and 18-month-olds ($p=.230$). The main effect of Target ISI was driven by significantly lower accuracy in the 600ms condition than the three faster tracks (all $p<.001$), with no other differences between tracks (all $p>.200$).

The significant Age*Target ISI interaction was further explored using a one-way ANOVA with Accuracy as the dependent variable and Age group as a factor, at each of the four target beat frequencies. All four ANOVAs confirmed the significant effect of Age (300ms, $F(2,73)=7.802$, $p<.001$; 350ms, $F(2,73)=7.143$, $p=.002$; 450ms $F(2,60)=13.355$, $p<.001$; 600ms $F(2,63)=67.969$, $p<.001$; see Table 2 for full descriptive statistics). Planned pairwise comparisons revealed that adults were significantly better than the two infant groups at all target frequencies (all $p<.001$), but that the 10- and 18-month-olds did not differ from each other in the three fastest conditions (300ms, $p=.917$; 350ms, $p=.147$; 450ms, $p=.158$). However, in the slowest 600ms condition, the comparisons confirmed a developmental progression whereby the 18-month-olds were significantly more accurate than the 10-month-olds, ($p=.001$), and adults were significantly better than both infant groups (all $p<.001$).

Despite the initial ANOVA showing no overall difference in accuracy between the two infant groups, we were interested in whether the developmental shift in the slow 600ms condition reflects an overall ability to modulate movement to music in the 18-month-olds (and lack thereof in the 10-month-olds). We reasoned that if participants were modulating their movement, they should be equally accurate across the different beat frequencies. We conducted a univariate ANOVA at each age group, with

Accuracy as the dependent variable and Target ISI as a fixed factor. We did not find a main effect of ISI for the adults ($F(3,80)=.990, p=.402$), who performed highly accurately across tracks, or the 18-month-olds ($F(3,86)=1.758, p=.162$), who performed to the same degree of accuracy across tracks. However, in the 10-month-old age group, we found a significant main effect of Target ISI ($F(3,104)=32.722, p<.001$). As shown in Table 2, the youngest infants were more accurate in the faster tracks, which are closer to hypothesized infant SMT, and less accurate in the slower tracks.

The results suggest that the 10-month-olds did not modulate their rate of bell ringing to the music. They were less accurate when the music was slower than their hypothesized SMT. There was no impact of a social partner on their accuracy. The 18-month-olds did show some tempo-flexibility: they were equally proficient in all four ISI conditions. A developmental progression from 10- to 18-months of age is evidenced in the increased accuracy of the 18-month-olds in the slow 600ms ISI condition, compared to the 10-month-olds. However, even these older infants were not synchronizing at an adult-like level. As with the younger age group, there was no impact of a social partner on the accuracy of the 18-month-olds.

Behavioral Data

Although we were only able to test the accuracy of one of our repetitive behaviors of interest (ringing), as piloting revealed infants would not reliably tolerate wearing more than two wireless EMG sensors, we also used the video data to calculate the amount of time infants spent in potentially rhythmic movement (see Table 1 for a full list).

At 10-months-of-age, a univariate ANOVA with time spent ringing bells as the dependent variable and Social/Non-social Condition and Target ISI as fixed factors revealed no difference in time spent ringing between the social condition ($M=7.729$, $SE=1.187$, 95% CI (5.360 10.097)) and the non-social condition ($M=9.886$, $SE=1.385$, 95% CI (7.123 12.648)); $F(1,76)=1.399$, $p=.241$), and no effect of target ISI (300ms $M=10.446$, $SE=1.766$, 95% CI (6.922 13.969); 350ms $M=10.972$, $SE=1.900$, 95% CI (7.182 14.762); 450ms $M=7.585$, $SE=1.869$, 95% CI (3.857 11.313); 600ms $M=6.226$, $SE=1.757$, 95% CI (2.721 9.732); $F(3,76)=1.580$, $p=.202$). Similarly, a univariate ANOVA with time spent in non-ringing repetitive behaviors as the dependent variable also showed no difference between the social and non-social conditions (social $M=9.086$, $SE=2.871$, 95% CI (3.251 14.920), non-social $M=13.394$, $SE=2.816$, 95% CI (7.670 19.117); $F(1,41)=1.147$, $p=.292$) or between target ISIs (300ms $M=8.605$, $SE=3.721$, 95% CI (1.044 16.166); 350ms $M=11.811$, $SE=4.102$, 95% CI (3.475 20.146); 450ms $M=12.190$, $SE=3.983$, 95% CI (4.096 20.284); 600ms $M=12.353$, $SE=3.983$, 95% CI (3.691 21.015); $F(3,41)=.241$, $p=.886$)

At 18-months-of-age we see a different pattern of behavior. Though a univariate ANOVA with time spent ringing as the dependent variable and Condition and Target ISI as fixed factors also showed no difference between conditions (social $M=5.600$, $SE=.986$, 95% CI (3.640 7.559); non-social $M=5.179$, $SE=1.029$, 95% CI (3.136 7.222); $F(1,99)=.087$, $p=.786$) or target ISI (300ms $M=6.018$, $SE=1.424$, 95% CI (3.190 8.845); 350ms $M=6.021$, $SE=1.424$, 95% CI (3.193 8.849); 450ms $M=5.047$, $SE=1.395$, 95% CI (2.276 7.817); 600ms $M=4.472$, $SE=1.457$, 95% CI (1.578 7.366); $F(3,99)=.283$,

$p=.838$), a univariate ANOVA with time spent in other repetitive behaviors revealed that at 18-months-of-age, infants engaged in non-ringing repetitive actions for significantly longer in the absence (non-social $M=3.880$, $SE=.828$, 95% CI (2.228 5.531)) than the presence (social $M=.916$, $SE=.896$, 95% CI (-.871 2.703)) of a social partner ($F(1,79)=5.896$, $p=.018$). Again, there was no effect of track (300ms $M=2.340$, $SE=1.217$, 95% CI (-.087 4.767); 350ms $M=2.287$, $SE=1.183$, 95% CI (-.073 4.646); 450ms $M=3.179$, $SE=1.236$, 95% CI (.714 5.643); 600ms $M=1.785$, $SE=1.244$, 95% CI (-.695 4.266); $F(3,79)=.217$, $p=.884$)).

Discussion

Our results revealed a developmental progression in the ability to move in time with music. Whilst 10-month-olds did display ringing behavior, they were not able to adapt this movement to the beat. At 18 months, infants demonstrated a degree of tempo-flexibility, modulating their movement: In contrast to the 10-month-olds, they were equally accurate across all four tracks. Though the 18-month-olds were not more accurate than the 10-month-olds overall, they performed significantly better in the slowest 600ms condition, the condition furthest from infants hypothesized SMT. This suggests that the 18-month-olds, but not the 10-month-olds, were able to move away from their natural rate of movement. However, this ability clearly continues to develop past 18 months, as even when showing tempo-flexibility, infants were not synchronizing their movement at an adult level. We should note that this progression is in contrast to Zentner & Eerola's (2010) finding, of no effect of age on tempo-flexibility in 5-24 month-olds. There are several

possible explanations for this. For one, Zentner and Eerola measured infants' spontaneous movement. The current study effectively engaged infants in a task of bell ringing. It may be that the presence of a partner (social or not) impacted younger infants' timing abilities, perhaps acting as a distracter from the music played. However, Zentner and Eerola also studied isochronous movement across the whole body and across almost the entire period of infancy. It may therefore be possible that the enormous advance in motor control seen between five and 24 months of age led to high heterogeneous variability in their data set, which may have masked age interactions. In the current study, we investigated infant abilities in a bell-ringing task, requiring a shaking motion that is well within the motoric competencies of both infant age groups. Perhaps we were better able to detect developmental change because our task was more constrained.

Our choice of design was motivated by a desire to facilitate infant synchrony, through the provision of visual, auditory and social cues; in particular we anticipated that the presence of a social partner would be advantageous for synchrony, in light of Kirschner and Tomasello's (2009) findings with young children. However, contrary to our hypothesis, we found no difference in accuracy in any age group between the social and non-social conditions. Kirschner and Tomasello referred to this advantage in their work as the product of joint action; they argue that when drumming with a human partner, young children are motivated by the relatively higher-level process of reaching a common goal. It may be that the infants in our experiment were too young to understand or act upon these motivations. However, studies show many of the prerequisites for joint action are apparent early in the first year of

life (for a review see Carpenter, 2009), with active engagement in joint tasks appearing between 12 to 18 months (see Sebanz, Bekkering & Knoblich, 2006). If understanding of joint action were crucial for synchronous movement to music, we would therefore expect some difference between the 10-month-olds and 18-month-olds in the current study.

Although we are only able to test accuracy of one action, bell ringing to music, we also recorded the duration of other repetitive motor actions during the testing session. Both infant groups displayed spontaneous repetitive behaviors. Whilst 10-month-olds showed no differences in amount of non-ringing repetitive behavior dependent on social/non-social condition, the 18-month-olds displayed significantly more spontaneous repetitive movement in the non-social condition. One possible explanation is that the 18-month-olds were more aware of a joint goal of ringing together, and inhibited other, perhaps more ecological movements, such as bouncing or nodding the head, when attempting to participate in joint ringing. According to this interpretation, the 18-month-olds understood the joint goal of ringing together, but this did not translate to better accuracy of movement to music. Further, we cannot ignore the fact that infant accuracy did indeed improve from 10 months to 18 months, at least in the difficult 600ms condition. That this improvement seems independent of the presence or absence of a social partner suggests a distinction between '*moving together*' and '*moving to the beat*', which may have separate underlying trajectories. Though they seem concurrent skills in the history of dance (Trainor, 2010) they may actually reflect separate developmental processes, with different historical adaptive advantages.

If we are thus wary of explaining the improvement in infant accuracy of movement to music as a product of better interpersonal coordination, it is interesting to consider what may explain the change between 10- and 18-months-of-age. The lowest level explanation is that infants' motor skills will have seen a dramatic improvement over these eight months. Perhaps, the 18-month-olds are better able to modulate their movement to music simply because they have better control over their movement in general. However, the current data also fit with a more complex picture of movement to music interacting with physical attributes of the human body.

Humans' optimal tempo to perceive is between 300-900ms, which is similar to the tempo of human gait (Trainor, 2007). Most music also falls within this category. When we consider individual differences, we see that limb length corresponds with preferred beat rate, both when perceiving a rhythm (Todd, Cousins & Lee, 2007) and when moving rhythmically (Dahl, Huron & Brod, 2014). Further, Trevarthen (1999) proposes that humans' ability to move in time to music is based in bipedal locomotion, in that our upright stance with flexibility of complex movements across the body provides our multi-jointed highly stacked bodies with the need to coordinate a multiplicity of rhythmic acts at any one time in order to locomote whilst also twisting, turning or isolating our free limbs. Anthropological data show that societies where infants are frequently held produce more music with a regular rhythm than those where infants are predominantly kept in baskets or cradles (Ayres, 1973). Most Western infants do not walk independently until after their first birthday (Storvold, Aarethun & Grete, 2013). It may be that the developmental progression seen in the current study reflects the infants' experience of self-

locomoting. Future studies should test the function of experience of bipedal locomotion directly.

In summary, we show a developmental progression in infants' ability to entrain with music when given a simple bell ringing to music task. Ten-month-olds are capable of ringing bells when presented with music, but are unable to modulate this movement to match the beat of the music played. Eighteen-month-olds are able to modulate their rhythmic movement, but not to an adult level of synchronisation. Further, we find that a social partner does not improve accuracy of movement to music, although in older infants it may impact the extent to which they deviate from the task.

References

- Ayres, B. (1973). Effects of infant carrying practices on rhythm in music. *Ethos*, 1(4), 387-404.
- Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of personality and social psychology*, 76(6), 893.
- Cirelli, L. K., Einarson, K. M., & Trainor, L. J. (2014). Interpersonal synchrony increases prosocial behavior in infants. *Developmental Science*.
- Cirelli, L. K., Wan, S. J., & Trainor, L. J. (2014). Fourteen-month-old infants use interpersonal synchrony as a cue to direct helpfulness. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 369(1658), 20130400.
- Dahl, S., Huron, D., Brod, G., & Altenmüller, E. (2014). Preferred Dance Tempo: Does Sex or Body Morphology Influence How We Groove?. *Journal of New Music Research*, 43(2), 214-223.
- Fujii, S., Watanabe, H., Oohashi, H., Hirashima, M., Nozaki, D., & Taga, G. (2014). Precursors of Dancing and Singing to Music in Three-to Four-Months-Old Infants. *PLoS one*, 9(5), e97680.
- Gerry, D. W., Faux, A. L., & Trainor, L. J. (2010). Effects of Kindermusik training on infants' rhythmic enculturation. *Developmental science*, 13(3), 545-551.

Goodman, J.R.L. et al. (2005) The interpersonal phase entrainment of rocking chair movements. In *Studies in Perception and Action VIII: Thirteenth International Conference on Perception and Action* (Heft, H. and Marsh, K.L., eds), pp. 49–53, Erlbaum 68.

Hattori, Y., Tomonaga, M., & Matsuzawa, T. (2013). Spontaneous synchronized tapping to an auditory rhythm in a chimpanzee. *Scientific reports*, 3, 1566.

Honing, H. (2012). Without it no music: beat induction as a fundamental musical trait. *Annals of the New York Academy of Sciences*, 1252(1), 85-91.

Kirschner, S., & Tomasello, M. (2009). Joint drumming: Social context facilitates synchronization in preschool children. *Journal of experimental child psychology*, 102(3), 299-314.

Phillips-Silver, J., Trainor, L.J., (2005). Feeling the beat: movement influences infants' rhythm perception. *Science*, 308, 1430.

Provasi, J., & Bobin-Bègue, A. (2003). Spontaneous motor tempo and rhythmical synchronisation in 2½- and 4-year-old children. *International Journal of Behavioral Development*, 27(3), 220-231.

Savage, P. E., Brown, S., Sakai, E., & Currie, T. E. (2015). Statistical universals reveal the structures and functions of human music. *Proceedings of the National Academy of Sciences*, 112(29), 8987-8992.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in cognitive sciences*, 10(2), 70-76.

Størvold, G. V., Aarethun, K., & Bratberg, G. H. (2013). Age for onset of walking and prewalking strategies. *Early human development*, 89(9), 655-659.

Thelen, E. (1979). Rhythmical stereotypies in normal human infants. *Animal behaviour*, 27, 699-715.

Thelen, E. (1981). Rhythmical behavior in infancy: An ethological perspective. *Developmental Psychology*, 17(3), 237-258.

Todd, N. P. M., Cousins, R., & Lee, C. S. (2007). The contribution of anthropometric factors to individual differences in the perception of rhythm. *Empirical Musicology Review*, 2, 1–13.

Trainor, L. J. (2007). Do Preferred Beat Rate and Entrainment to the Beat Have a Common Origin in Movement? *Empirical Musicology Review*, 2, 17-20.

Trainor, L. (2010). The emotional origins of music. *Physics of life reviews*, 7(1), 44-45.

Trehub, S. E., & Thorpe, L. A. (1989). Infants' perception of rhythm: Categorization of auditory sequences by temporal structure. *Canadian Journal of Psychology/Revue canadienne de psychologie*, 43(2), 217-229.

Trevarthen, C. (2000). Musicality and the intrinsic motive pulse: evidence from human psychobiology and infant communication. *Musicae Scientiae*, 3(1 suppl), 155-215.

Tunçgenç, B., Cohen, E., & Fawcett, C. (2015). Rock With Me: The Role of Movement Synchrony in Infants' Social and Nonsocial Choices. *Child development*, 86(3), 976-984.

Wallin, N. L., Merker, B., & Brown, S. (Eds.). (2001). *The origins of music*. MIT press.

Winkler, I., Háden, G. P., Ladinig, O., Sziller, I., & Honing, H. (2009). Newborn infants detect the beat in music. *Proceedings of the National Academy of Sciences*, 106(7), 2468-2471.

Zentner, M., & Eerola, T. (2010). Rhythmic engagement with music in infancy. *Proceedings of the National Academy of Sciences*, 107(13), 5768-5773.