RUNNING HEAD: Tiny Dancers

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Tiny dancers: Effects of musical familiarity and tempo on children's free dancing

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Author Note: Video data collected from participants are available to authorized researchers via Databrary (volume 1141; Kragness et al., 2020). Data and analysis codes are available by emailing the corresponding author. This study's design and analysis were not pre-registered.

Abstract

Around the world, musical engagement frequently involves movement. Most adults easily clap or sway to a wide range of tempos, even without formal musical training. The link between movement and music emerges early –young infants move more rhythmically to music than speech, but do not reliably align their movements to the beat. Laboratory work encouraging specific motor patterns (e.g., drumming, tapping) demonstrates that toddlers and young children’s movements are affected by music in a rudimentary way, such that they move faster to faster rhythms (*tempo flexibility*). In the present study, we developed and implemented a novel home recording method to investigate how musical familiarity and tempo affect children’s naturalistic free-dance movements. Caregivers made home recordings of their children’s responses to an experimenter-created playlist ($N = 83$, age range = 1.25 to 3.91 years, M age = 2.39 years, $SD = 0.74$ years; 41 girls, 42 boys; 75% of household incomes > \$90 000 CAD). Children listened to 1-min excerpts of their favorite music and unfamiliar, genre-matched music, each played at 90, 120, and 150 bpm (pitch constant; order randomized). Children moved faster to faster music and demonstrated tempo flexibility for both favorite and unfamiliar music. Favorite music encouraged more smiling across tempo conditions than unfamiliar music, as well as more dancing in the slowest tempo condition. Results demonstrate that young children’s self-selected movements are affected by musical tempo and familiarity. We also demonstrate the usefulness of a naturalistic home recording method for assessing early auditory-motor integration.

Keywords: music, rhythm, movement, dance, development, children

Introduction

Movement is a widespread feature of musical engagement. This can be seen when we inadvertently tap along to a song on the radio, rock an infant while gently singing a lullaby, or perform choreographed dance routines. Neural and behavioral evidence underscore the involvement of motor processes in rhythm perception, even in the absence of overt movement (Cannon & Patel, 2021; de Kock et al., 2021; Grahn & Brett, 2007; Gordon et al., 2018; Manning & Schutz, 2013; Morillon & Baillet, 2017). Indeed, movement is considered an inseparable component of musical engagement in many cultures (Savage et al., 2015; Bohlman, 2002; Trehub et al., 2015).

Most adults easily move in synchrony with a musical beat (the underlying isochronous pulse in a piece of music). Though beat synchronization often feels effortless, it requires a complex interplay between auditory and motor systems (Patel & Iverson, 2014). Accordingly, rhythm perception and musical synchronization abilities develop slowly and may not reach adult levels until late childhood or adolescence (McAuley et al., 2006; Nave-Blodgett et al., 2020). However, the link between movement and music is observable in early infancy (Philips-Silver & Trainor, 2005; Zentner & Eerola, 2010). Some precocious infants display the urge to move to music just a few months after birth (Fujii et al., 2014), and most North American caregivers report that their infants move in response to music by 8 months of age (Kim & Schachner, 2021).

The ability to move faster to faster music and slower to slower music, *tempo flexibility*, is thought to be an important prerequisite for auditory-motor synchronization (e.g., Zentner & Eerola, 2010). In the lab, children exhibit tempo flexibility well before they are able to synchronize reliably to music. In one early laboratory study, 5- to 24-month-olds produced faster movements to faster music and rhythms (Zentner & Eerola, 2010). More recently, Rocha and Mareschal (2017) provided 10- and 18-month-old infants with handheld sleigh bells while they listened to a series of lively pop music (e.g., Jennifer Lopez' *Let's Get Loud*). Neither age group

showed strong evidence of synchronization, but the older infants displayed more tempo flexibility than the younger infants. Yu and Myowa (2021) asked 18-, 30-, and 42-month-olds to tap on a set of toy drums to *Twinkle, Twinkle, Little Star*. Children in all three age groups tapped faster when the music was faster, although the youngest children hit the drum less frequently, showed greater variability, and were further from the target tempo in the slow condition, especially compared to the older children. Other laboratory research has investigated children's ability to tap their finger on a touch-screen device or to strike a drum using a drumstick along to isochronous drumbeats without musical accompaniment. While 2.5-year-old children show some tempo flexibility, especially when synchronization is modelled by a social partner or reinforced by interesting visual displays, in general, substantial improvements are observed between 2.5 and 4 years (Provasi & Bobin-Bègue, 2003; Kirschner & Tomasello, 2009).

Familiarity is potentially an important factor in early musical movements. In laboratory studies, infants preferentially listen to and are soothed by familiar over unfamiliar songs (Cirelli & Trehub, 2020; Kragness, Johnson, & Cirelli, 2022). Previous studies of musical beat synchronization have largely used familiar music (but see Rocha & Mareschal, 2017), assuming that a boost in task enjoyment would facilitate optimal performance. Results from a recent case study comparing one child's responses to familiar and unfamiliar music stand in contrast to that view. Researchers implemented a home-based method for exploring early musical movements with 19-month-old "V" (Cirelli & Trehub, 2019). V was recorded at home while she listened to 1-min clips of two familiar pieces of music and two unfamiliar pieces of music over several weeks. Each piece of music was presented at its original tempo (close to 120 beats per minute, bpm) and at a faster (140 bpm) and slower (100 bpm) tempo without modulating pitch. V danced more to familiar music and smiled more frequently when she danced. Notably, V showed better tempo matching when listening to unfamiliar compared to familiar music. Familiar music, regardless of tempo, elicited fast dancing.

1 Much of what is known about early musical movements stems from laboratory research
2 investigating specific target movements, like clapping, tapping, or drumming. Henry and
3 colleagues (2021) recently argued that a comprehensive investigation of synchronization
4 abilities across the animal kingdom must consider the body parts and motivational goals that
5 apply to each species, which can be achieved by combining traditional lab work with
6 observational field studies. A similar approach will be crucial for understanding age-related
7 differences in movement to music. To our knowledge, only one previous study has used a free
8 dancing methodology to examine children's auditory-motor integration (Eerola et al., 2006).
9 Researchers used motion capture to measure the properties of 2- to 4-year-old children's free
10 dancing in a lab. Though children's movements were at times periodic, their movements were
11 unaffected by manipulations of the musical tempo. Moreover, many of the children (18 of the 46
12 tested) refused to dance at all. It is likely that children would be more motivated to engage in
13 musical behaviors in familiar settings, such as their own home. Indeed, North American
14 preschool children often spontaneously integrate musical movement in their play at home (Cirelli
15 et al., 2020). Home-based assessments of singing proficiency and pitch range in toddlers and
16 preschoolers reveal that laboratory measures may underestimate early musical abilities
17 (Gudmundsdottir & Trehub, 2018). Thanks to technological advancements, home-based
18 methods are gaining popularity in developmental research, providing windows into a variety of
19 behaviors such as play (Herzberg et al., 2021), language acquisition (Bergelson et al., 2018),
20 and visual attention (Slone et al., 2018).

21 The purpose of the present study was to examine the effects of tempo and musical
22 familiarity on 1- to 4-year-old children's free dancing using a novel home-recording method. By
23 asking children to dance freely at home, we hoped to provide a context conducive to children's
24 comfort and motivation. Caregivers were provided with a custom playlist including 1-min
25 excerpts of their child's favorite music and genre-matched unfamiliar music at three tempos (90,
26 120, and 150 bpm). Caregivers played the playlist for their child at home while recording videos

(see Supplemental Material for video examples). Videos were annotated to identify when children danced, movement tempos, and when they smiled. We predicted that (1) children would free dance faster to faster music, and (2) tempo flexibility would increase with age. We additionally explored whether musical familiarity modulated children's movement rate and tempo matching. If the rate of children's dancing was more congruent with the metrical hierarchy for favorite music, this would suggest that motivational features and/or familiarity with musical features might scaffold tempo matching. In contrast, excited responses to the favorite music could inhibit children's tempo flexibility by encouraging universally fast movements, as observed in the case study results with toddler V (Cirelli & Trehub, 2018). Finally, we predicted that children would dance and smile more to favorite than unfamiliar music.

Methods

Participants

Caregivers ($n = 210$) first participated in the Favorite Music Survey. Families with children 1.25 to 3.9 years old were recruited via social media, recruitment websites (Children Helping Science), and the UTSC iKids Centre family database. After filling out an online questionnaire, families were invited to participate in the Dance Phase portion of the study. Videos were received from 92 participants. This final N was determined by the number of children that could be recruited for this study in one year, and efforts were made to recruit evenly across the age range. One participants' video was lost due to technical difficulties, and three additional participants' data were omitted due to experimenter error in creating their stimuli. Two participants' caregivers indicated that this was the second recording of the dance session, thus familiarizing their children with the "unfamiliar" tunes, and trials in which caregivers danced in frame with their child were also omitted (8.2% of trials, three additional participants). After these exclusions, a total of 83 participants remained (age range = 1.25 to 3.91 years, M age = 2.39 years, $SD = 0.74$ years, 41 girls, 42 boys; 81 children from Canada, 1 from the USA,

1 from the UK). Household income varied, and most families were economically wealthier than the average family in Toronto, Canada (45% reporting > \$120,000 CAD/year, 40% reporting between \$60,000 and \$120,000/year, 13% reporting < \$60,000/year, 2 families did not respond). As a token of appreciation, families received a Junior Scientist certificate for each completed phase and were entered into a gift certificate draw (1 in 20 chance at a card valued at \$30 CAD). All procedures were approved by the University of Toronto Research Ethics Board (Protocol 36642, Adult, children and infant music perception and engagement).

9 Stimuli

10 In the initial survey, caregivers were asked to indicate up to five of their child's favorite
11 pieces of music, including the title and artist (if applicable), and a rating of how often their child
12 hears the music on a scale of 1-*rarely* to 5-*multiple times each day* (four caregivers provided
13 music, but did not provide frequency ratings on their surveys). From this list, an experimenter
14 selected one piece of music to designate as the "favorite" in this study, using their judgment to
15 select music that was both frequently heard and easily sourced for the experiment. For most of
16 the children (74 of the 79), the selected "favorite" was the music the child heard most frequently,
17 according to caregiver report. A specific favorite *version* (recording by a specific artist) could be
18 identified for 70 of the 83 participants. The remaining participants' favorite music were well-
19 known children's songs with no specified artist (e.g., "Wheels on the Bus", "Old McDonald had a
20 Farm"). For these 13 participants, the experimenter used a recorded child-directed version of
21 that song.

22 The "unfamiliar" music was a pre-selected genre-matched recorded piece of music (see
23 Supplemental Material). A research assistant used their best judgment to determine the tempo
24 of the original music by tapping along to the music using an online bpm tool
25 (www.beatsperminuteonline.com). The average tempo of favorite music was 115 bpm (SD = 25
26 bpm). Excerpts from both the "favorite" and "unfamiliar" music were edited in Audacity software

v2.3.0 (Audacity Team, 2018) to manipulate tempo while maintaining the pitch. The music was edited to three different tempos (90, 120, and 150 bpm). Unless the music had an original tempo of either 90, 120, or 150 bpm, all three versions were modified from the original. The music was then cropped to excerpts one minute of length starting either when lyrics began or, for music without lyrics, at the beginning of the recording. This was done to ensure recognition of the music with lyrics. Finally, the 1-min excerpts were compiled into a playlist with 5s of silence between each of the 6 excerpts, with a brief fade-in and fade-out for each excerpt. Playlists were pseudo-randomly ordered such that the favorite and unfamiliar music alternated, but tempo order was randomized. These custom playlists were uploaded to YouTube.com and shared with the caregiver.

Procedure

If caregivers indicated interest in the Dance Phase at the end of the Favorite Song Survey, the experimenter sent clips of the music to caregivers via email to listen to (without their child present) to confirm that the child knew the “favorite” music and that they did not know the genre-matched “unfamiliar” music. The experimenter then sent the custom playlist to the family. Caregivers were given the option to record video on their own ($N = 70$), or to schedule an appointment with an experimenter through video call so that video could be recorded via screen capture ($N = 13$). All caregivers were asked to prepare an open, safe area for their child to move around in before beginning the experiment, and to avoid dancing themselves or influencing their child’s behavior, especially while the music was playing. General words of encouragement were permitted (e.g., “Great job!”).

After the Dance Phase, caregivers completed a demographics questionnaire, which included questions about children’s history participating in dance/musical movement classes. Caregivers were also asked to complete the Music@Home Preschool questionnaire (Politimou et al., 2018), which captures information about children’s home musical environment including

parental beliefs about the importance of music in early childhood, children's engagement with music, parental initiation of musical behavior, and the breadth of musical exposure children experience at home. Neither experience with dance classes or scores on the Music@Home (or corresponding subscales) significantly correlated with any dependent measure (see Supplemental Materials).

Behavioral Annotation. A research assistant divided the video recording into six 1-min excerpts corresponding to times when the music was being presented to the participants and uploaded these trial-level videos to Databrary (volume 1141, Kragness et al., 2020). Trained annotators downloaded the videos from Databrary and annotated behaviors using ELAN Linguistic Annotator (<https://tla.mpi.nl/tools/tla-tools/elan>, Lausberg and Sloetjes, 2009).

Videos were played back silently to ensure that annotators were naïve to condition. For each video, annotators first notated (1) *bouts of dancing*. Dance bouts were defined as windows of time in which the child was subjectively judged to be moving because of the music, and not for another obvious reason. Within dance bouts, they next identified (2) *rhythmic bursts*, or bursts of movements that had an identifiable tempo (e.g., the same movement was repeated two or more times). Within these bursts, annotators indicated (3) *the onset of each movement* belonging to the same burst, defined as the most discrete component of the rhythmic movement (e.g., if a child clapped three times, the moments when their hands connected each time were identified; if they alternated between stepping on their left foot and then their right, the moments when their left foot connected with the ground were identified). For expressions of joy, annotators indicated windows of time when (1) *the child's facial expressions were visible* and (2) *expressions of positive affect were evident* (i.e., smiling, laughing). Two annotators identified facial visibility and positive affect, and two completed movement annotation. Interrater agreement for 18 videos (all six videos from three children, pseudo-randomly selected such that all three contained all behaviors of interest) was high for duration of face visibility (Pearson's r

=.98), duration of expressions of joy ($r = .87$), duration of dancing ($r = .98$), and average inter-onset interval between repeated movements in a trial ($r = .92$).

Secondary video coding was done with audio on. Research assistants indicated (1) how long children were completely out of the video frame, and (2) how often caregivers specifically asked children to dance. Results from a mixed effects model did not indicate any evidence that caregivers' requests to dance differed across tempo or familiarity conditions (p 's > .330), so trials containing such requests were retained in the full analysis. Independent coding of 16% of the trials yielded high interrater reliability for the 3 measures (time off frame, $r = 0.94$; caregiver verbal encouragement, 92.8% trial-level agreement; caregiver dance requests, 88.5% trial-level agreement).

Analyses. Linear mixed effects models (LMEM; glmmTMB package, Brooks et al., 2017) in R (version 3.6.3, R Core Team, 2020) were used to evaluate the effects of familiarity and tempo on children's behavior. The dependent measures were (1) median movement tempo (calculated from inter-movement intervals in rhythmic burst coding), (2) temporal correspondence (calculated from inter-movement intervals and described in more detail below), (3) proportion of time dancing (sum of dance bout times/time in frame), and (4) proportion of time smiling (total time smiling/time their face was visible). We contrast-coded the familiarity factor (favorite = 1, unfamiliar = -1). Tempo was treated as an ordinal variable, and we tested linear effects. For each model, we first tested whether including any interactions (age*familiarity*tempo, age*familiarity, age*tempo, or familiarity*tempo) significantly improved model fit, and removed it from the model when it did not (see Supplemental Material for model specifications and output). Random intercepts were included in the models for participant identity to account for repeated measures, but random slopes were not included due to failure to converge and/or failure to improve model fit. Finally, age was included as a continuous predictor. For proportion data (temporal correspondence, proportion of time dancing, expressions of joy) we used a beta distribution for the outcome variables, and included zero-

inflation when it significantly improved the model. For non-proportion data (median movement tempo), we used a Gaussian distribution for the outcome variable.

Transparency and openness. Video data are available to authorized researchers via Databrary (volume 1141, Kragness et al., 2020). Sample size determination, all exclusions and all manipulations are reported above. Data and analysis codes are available via the Open Science Framework (Kragness, Ullah, Chan, Moses, & Cirelli, 2022; <https://osf.io/q8zjy/>). Data were analyzed using R (version 3.6.3, R Core Team, 2020). This study's design and analysis were not pre-registered.

Results

Out of 83 children, 10 never danced (~12%), and 64% of trials overall contained dancing. When they danced, they often did so for a significant portion of the 1-min excerpt ($M = 43\%$, $SD = 30\%$).

Tempo Flexibility

Inter-movement-intervals were calculated as the time between maximal extensions belonging to the same rhythmic burst (in other words, *between-burst* inter-movement-intervals were omitted) and converted to a rate (beats per minute).

To obtain a movement tempo measurement for each trial, we used the *median* movement tempo. Identical statistical results were observed if we used the *mean* tempo instead of the median tempo. Children for whom no *rhythmic bursts* were identified were omitted from this analysis, leaving 73 children. Children demonstrated tempo flexibility: median movement tempo increased linearly with musical excerpt tempo, $B = 13.308$, $SE = 3.776$, $z = 3.525$, $p < .001$. Older children danced at a slower tempo than younger children, $B = -13.665$, $SE = 6.157$, $z = -2.219$, $p = .026$, and children danced faster in the favorite vs. unfamiliar condition, $B = 4.495$, $SE = 2.200$, $z = 2.044$, $p = .041$. On average, children's median dance tempo was 104 bpm in the context of favorite music, compared to 97 bpm in the context of unfamiliar music (Figure 1; see Supplemental Table 1).

To further explore whether age related to tempo flexibility, median movement bpm difference scores were calculated for the fastest (150 bpm) compared to the slowest (90 bpm) trials. We predicted that older children would have a larger difference score in median movement bpm across these two tempo conditions than younger children. Children with rhythmic bursts for at least one of the fastest and slowest excerpts were included in the analysis, leaving 53 children. This analysis did not reveal a significant association between age and tempo flexibility, $r(51) = .051$, $p = .717$.

Figure 1. Depicts the average movement tempo of children's rhythmic movements (each trial's median bpm). Error bars are 95% within-subject confidence intervals. Black stars signify the excerpt tempo.

Temporal Correspondence

1 The previous analysis demonstrated that on average, children's movements were faster
 2 when the music was faster. Next, we assessed whether children's movements were closer to
 3 the excerpt tempos at different levels of tempo and familiarity. To do this, we used a measure
 4 we call "temporal correspondence", which reflects the proportion of a children's movements
 5 that are at a rate near any of the metrical levels of the musical excerpts. To assess whether
 6 children were more successful at matching the temporal structure for favorite compared to
 7 unfamiliar music, we used inter-movement-intervals to calculate a temporal correspondence
 8 measure per trial. This measure represents the percentage of rhythmic movements that
 9 corresponded to any level of the musical meter for each excerpt (Kragness, Anderson, Chow,
 10 Schmuckler, & Cirelli, 2022). For each tempo condition, all inter-movement-intervals falling
 11 within a +/-10% window around the beat rate (i.e., target tempo), half beat rate, or double beat
 12 rate were considered to be temporally correspondent. On average, 28% of children's
 13 movements fell within these windows ($SD = 15\%$). To receive a temporal correspondence
 14 score, children needed to produce a minimum of 10 rhythmic movements total in that trial (not
 15 necessarily consecutive). This left 57 children in the analysis. We found no effect of age,
 16 musical familiarity, or tempo on temporal correspondence scores (all p 's $> .372$; see Figure 2
 17 and Supplemental Table 2).

18 While our planned hypotheses considered linear effects of tempo, visualizing temporal
 19 correspondence across conditions (Figure 2) suggested that a quadratic fit might be more
 20 reflective of the data, especially for the favorite music condition. In an exploratory analysis, we
 21 tested a model including a tempo (quadratic) by familiarity interaction, which reached
 22 significance, $B = 0.244$, $SE = 0.101$, $z = 2.408$, $p = .016$ (note, however, that a direct
 23 comparison of the models with and without an interaction term only provided tentative support
 24 for including the interaction, $p = .051$). To break down this interaction, we explored the quadratic
 25 effect of tempo for each level of musical familiarity separately. There was no effect of tempo for
 26 unfamiliar music ($p = .634$). In the favorite music condition, there was a significant quadratic

effect of tempo such that children had the lowest temporal correspondence scores for the 120 bpm condition, $B = 0.449$, $SE = 0.135$, $z = 3.326$, $p < .001$ (see Supplemental Table 3). Given the exploratory nature of this analysis, we caution against over-interpretation.

For the favorite music, we next asked whether their temporal correspondence scores were affected by how close the tempo of the music was, compared to the original tempo of the music. Unfamiliar excerpts were omitted for this analysis, given that children should not have any particular expectations for the tempo of music they have never heard. Common songs that did not have a definitive recorded version associated with them were likewise omitted. Temporal correspondence was numerically higher for songs further from the original tempo, but this association did not reach significance, $B = 0.008$, $SE = 0.004$, $z = 1.840$, $p = .066$.

Figure 2. Depicts the proportion of rhythmic movements that corresponded to one of three metrical levels of the musical excerpt in that trial (beat rate, half beat rate, or double beat rate). Movements were considered temporally correspondent if they fell within a $\pm 10\%$ window of those rates. Individual points represent individual participants, bars represent group averages, and error bars represent 95% within-subject confidence intervals.

Proportion of Time Dancing

There was a significant effect of age on the proportion of time children danced, such that older children danced more, $B = 0.883$, $SE = 0.132$, $z = 6.676$, $p < .001$. There was also a significant interaction between tempo and familiarity, $B = -0.197$, $SE = 0.095$, $z = -2.088$, $p = .037$ (see Figure 3 and Supplemental Table 4). To break down the interaction, we investigated

1 the effect of familiarity separately in each tempo condition. In the 90 bpm condition, children
2 spent significantly more time dancing to the favorite music (~30%) than the unfamiliar music
3 (~22%), $B = 0.245$, $SE = 0.096$, $z = 2.548$, $p = .011$. There was no significant difference in the
4 proportion of time children spent dancing to favorite vs. unfamiliar music in the 120 bpm or 150
5 bpm conditions, p 's $> .426$.

6 As with temporal correspondence, we asked whether dancing was affected by how close
7 the tempo of the music was, compared to the original tempo. Unfamiliar excerpts were omitted
8 for this analysis, given that children should not have any particular expectations for the tempo of
9 music they have never heard. Common songs that did not have a definitive recorded version
10 associated with them were likewise omitted. Consistent with the lack of effect in tempo above,
11 there was no significant effect on the proportion of time dancing based on whether the music
12 was closer to the "correct" tempo ($p = .793$).

Figure 3. Depicts the proportion of time participants spent dancing. Individual points represent individual participants, bars represent group averages, and error bars represent 95% within-subject confidence intervals. $*p < .05$

Expressions of Joy

Expressions of joy (smiles or laughter) were identified in 55% of trials. For proportion of time spent smiling, we found no significant linear effect of tempo ($p = .221$) nor effect of age ($p = .389$), but there was a significant effect of familiarity, $B = 0.094$, $SE = 0.048$, $z = 1.977$, $p = .048$ (Figure 4; see Supplemental Table 5). In aggregate, children smiled about 10% of the time during favorite music, and about 8% of the time during unfamiliar music.

For the favorite music, we next asked whether children's expressions of joy were affected by how close the tempo of the music was, compared to the original tempo of the music.

Unfamiliar excerpts were omitted for this analysis, given that children should not have any particular expectations for the tempo of music they have never heard. Common songs that did not have a definitive recorded version associated with them were likewise omitted. Similarity to the original tempo was not a significant predictor of expressions of joy, $B = 0.004$, $SE = 0.004$, $z = 1.203$, $p = .229$.

Several previous studies of musical movement observed associations between dancing and smiling (see Introduction). Here, too, trials with higher proportions of time spent dancing also had higher proportions of time expressing joy, $B = 1.155$, $SE = 0.205$, $z = 5.637$, $p < .001$.

Figure 4. Depicts the proportion of time participants spent smiling. Individual points represent individual participants, bars represent group averages, and error bars represent 95% within-subject confidence intervals. $*p < .05$

Discussion

Prominent theories of rhythm perception argue that the motor system plays a significant role (e.g., Patel & Iverson, 2014). Previous studies of caregiver-reported “dance” in infancy, as well as lab studies of infants’ rhythmic capabilities, suggest that the motor system is stimulated by auditory input early in life. Here we observed that 1- to 3-year-old children demonstrate tempo flexibility when free dancing in a naturalistic home setting. Favorite music also elicited faster dancing than unfamiliar music across tempo conditions, and more dancing specifically in the slowest tempo condition (90 bpm). Children also smiled more frequently in response to their favorite compared to unfamiliar music, even though the favorite music was played at a different tempo from what they were used to hearing. Paralleling laboratory research with younger infants (Kragness, Johnson, & Cirelli, 2022), we also found that children smiled more frequently on trials when they danced more, highlighting the connection between musical movement and expressions of joy in early life.

Many studies examining auditory-motor abilities in adults involve highly constrained tasks which require participants to clap, tap, or drum along to a beat or metronome (see Repp & Su, 2013 for a review). Because these tasks are clearly inappropriate for young children and infants, investigations with these populations have opted to use bell-ringing, drumming, or motion capture of spontaneous movements (Rocha & Mareschal, 2017; Yu & Myowa, 2021; Zentner & Eerola, 2010). The current work points to home-based recordings of free dancing as a fruitful methodology for investigating early musical movements. Children are recorded in the comfort of their homes, at a time that is convenient for their mood and compliance, using only equipment commonly found in typical Canadian households. Nearly 90% of participants danced at some point in the home-based experiment, compared to only ~60% of children in a previous free dancing study conducted in the lab (Eerola et al., 2006). This home-recording method is easy for caregivers to implement, likely accessible to a more diverse sample of families, and may improve children’s motivation to demonstrate their abilities.

Children in this study demonstrated tempo flexibility in their free dancing – that is, they danced faster to the faster music than to the slower music. An open question is whether this was driven by beat perception. Beat perception involves extracting an underlying, regular pulse from the musical rhythm, and is characterized by the ability to form predictions about when musical events should occur. Neural tracking of the beat appears to emerge early in life: sleeping newborns and alert 7-month-old infants' neural responses appear to reflect pre-attentive beat tracking when listening to auditory rhythmic sequences (Cirelli et al., 2016; Háden et al., 2015; Winkler et al., 2009). By 2 to 4 months of age, infants can detect a 15% shift in tempo in a 100 bpm isochronous auditory sequences (Baruch & Drake, 1997). The early tempo flexibility demonstrated here may reflect beat perception, but could alternatively be driven by stimulus features, such as event density. Future studies could manipulate both tempo and event density using novel composed rhythms to examine the relative influence of each on children's musical movements.

Previous work with bell ringing and finger tapping suggests that by 1.5 years of age, children's spontaneous motor tempo is roughly 120 bpm, increasing to about 150 bpm and by 3.0 years (Rocha et al., 2021) before slowing across childhood and adulthood (Drake et al., 2000; McAuley et al., 2006). Adults show more synchronization accuracy when moving to music that is closer to their spontaneous motor tempo (Delevoye-Turrell et al., 2014). If children's spontaneous motor tempo influences movement accuracy, we would expect that children's movement tempos here would be more similar to the target tempos in the faster music conditions, but found no evidence to support this prediction. Across tempo conditions, the rate of children's movements corresponded to the beat rate, half beat rate, or double beat rate about 30% of the time. We also found evidence that the older children in our sample danced slower on average than the younger children. One important consideration is that our children always danced with music, which might elicit a qualitatively different response from moving rhythmically

in silence. Alternatively, children’s full-body spontaneous motor tempo may be quite different from their spontaneous motor tempos during bell-ringing or finger tapping (Rocha et al., 2021).

Annotators observed a wide range of dance “moves” - for example, twirls, claps, wiggles, twists, bounces, and arm-waves. These self-selected “moves” that children produce when free dancing might also provide a unique window into auditory-motor development. Children may be better able to demonstrate their auditory-motor synchronization abilities with actions they are comfortable producing. Across childhood, both gross and fine motor skills are highly in flux. As children mature, they may find it pleasantly challenging to incorporate new body parts into their dance repertoire. Age-related increases in dance complexity may explain why we did not observe increases in tempo flexibility across our tested age range, such as those seen when children across the age range are encouraged to perform the same action (Provasi & Bobin-Bègue, 2003; Rocha & Mareschal, 2017; Yu & Myowa, 2021). In future research, we plan to use this home-recording method to investigate patterns of self-selected dance movements and increasing dance complexity across childhood.

In one previous case study of a dancing toddler, V (Cirelli & Trehub, 2018), researchers observed dancing closer to the target tempo for unfamiliar music, with favorite music eliciting fast dancing regardless of tempo. They hypothesized that the stimulating effects of favorite music may have overridden tempo flexibility. In the present study, we also observed that favorite music elicited more smiling and faster dancing across tempo conditions, supporting this proposal. In some contexts, this increased arousal may artificially bring children closer or farther to the target tempo depending on their prior level of physiological arousal, musical tempo, and the child’s individualized spontaneous motor tempo. We found only suggestive evidence that tempo matching differed as a function of musical familiarity. Exploratory analyses revealed that children were further from the target tempo for favorite music played at 120 bpm. While we caution against over-interpreting this exploratory result, this tempo condition was often closest to the original tempo ($M_{\text{original tempo}} = 115 \text{ bpm}$), and therefore arguably the most familiar

1 version of the favorite music. This may have made it especially exciting, which may have
2 detracted from tempo matching much like what was observed with V (Cirelli & Trehub, 2018).

3 Children may have also demonstrated more joy and faster dancing for their favorite
4 music because they likely have extensive prior experience listening to and moving to these
5 pieces of music in social contexts. By age 4, children show better beat synchronization when
6 drumming with an adult partner (Kirschner & Tomasello, 2009). Here, caregivers were instructed
7 to refrain from dancing with their child. In future research, it would be interesting to explore
8 whether moving with a partner to favorite compared to unfamiliar music differentially influences
9 tempo alignment.

10 These findings contribute to a growing body of work documenting the social-emotional
11 importance of familiar music in early childhood, and the flexibility with which young children can
12 identify familiar music. For example, 9- to 12-month-old infants listen longer and move
13 rhythmically more when listening to familiar songs, whether they are sung by their own caregiver
14 or by a stranger (Kragness, Johnson, & Cirelli, 2022), and toddlers help a stranger more if they
15 are familiar with a song she is singing (Cirelli & Trehub, 2018). Songs are proposed to be strong
16 signals for shared culture and group belonging, and this early responsiveness to favorite songs
17 suggests that young children already integrate these songs into their musical identities.

18 Intervention studies harnessing rhythmic coordination are gaining attention as avenues
19 to facilitate language abilities, social abilities, and self-regulation skills in children with hearing
20 loss, developmental disorders, and socio-economic risk factors (Hidalgo et al., 2017; Morris et
21 al., 2021; Williams & Berthelsen, 2019). The results presented here suggest that children may
22 be more engaged with interventions that include familiar or preferred music. Intervention
23 planning should also consider encouraging both whole body free dancing and discrete
24 movements, such as drumming. Free dance may be especially fruitful for the youngest toddlers.
25 Notably, even in laboratory drumming studies with toddlers, younger children are more likely to
26 make extraneous “free dance” movements (such as bouncing and nodding) than older children

(Rocha & Mareschal, 2017; Yu & Myowa, 2021). These free dancing movements, even when they are considered extraneous to the task at hand, may themselves contain useful information about the nature of early auditory-motor integration.

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