RUNNING HEAD: Children and Groove

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Musical groove shapes children's free dancing

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Data availability statement: Where permission granted, the raw data (videos) from this experiment are stored at Databrary.com (volume 1129). The aggregate, anonymized data and code will be stored in an Open Science Framework repository for independent verification of the results (<https://osf.io/j8tkr/>)

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Research Highlights

- Adult-rated desire to move (“groove”) influenced the duration and energy of children’s free dancing to music in their homes
- Children’s movement tempos corresponded better to high groove than low groove musical excerpts
- Although groove condition did not affect expressions of joy, children smiled more when they danced more
- Annotating free dancing in the home is a viable paradigm for studying early auditory motor interactions

Abstract

The drive to move to music is evident across a variety of contexts, from the simple urge to tap our toe to a song on the radio, to massive crowds dancing in time at a rock concert. Though seemingly effortless, beat synchronization is difficult to master and children are often poor beat synchronizers. Nevertheless, auditory-motor integration is fundamental for many daily processes, such as speech. A topic that has been relatively understudied concerns how stimulus properties affect young children’s movement in responses to auditory stimuli. In the present study, we examined how *musical groove* (adult-rated desire to move) affected 3.0- to 6.9-year-old children’s free dancing in the comfort of their home ($n = 78$). In the high groove conditions, children danced more often and with more energy compared to the low groove conditions. Moreover, in the high groove condition, children’s movement tempos corresponded better with the tempos of the music. Results point to early childhood sensitivity to the musical features that motivate adults to move to music. High groove music may therefore prove especially effective at facilitating early auditory-motor integration.

Keywords: auditory-motor development, dance, music, children, groove

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Most adults easily tap, clap, or sway to the regular underlying pulse (the “beat”) while listening to music. Moving to rhythms, especially with other people, is common in social and cultural events around the world (Savage et al., 2015). In laboratory settings, behavioral and neural data point to a robust association between adults' auditory and motor systems: music often elicits spontaneous movement (Janata et al., 2012), movement improves performance in rhythm perception tasks (Manning & Schultz, 2013), and even in the absence of movement, motor areas of the brain are active during music listening (Grahn & Brett, 2007; Fujioka et al., 2009). Indeed, it has been proposed that the ability to perceive musical rhythms relies on motor simulation, and on strong connections between auditory and motor brain regions (Patel & Iverson, 2014).

Aligning movements to auditory rhythms requires accurate beat perception, motor anticipation, and precise motor control, which have protracted developmental timelines. Although infants are poor synchronizers, the desire to move to rhythms is present early. According to caregiver report, half of infants “dance” to music by 6 months, and 90% by their first birthday (Kim & Schachner, 2019). In experimental contexts, infants move more to music or rhythms than speech and more to familiar than unfamiliar songs (Fujii et al., 2014; Kragness et al., 2022; Zentner & Eerola, 2010). These musical movements are frequently accompanied by smiling and laughter (Kragness et al., 2021). Children's ability to drum to a beat improves with age, with dramatic improvements by age 6 (Drake et al., 2000; McAuley et al., 2006; Provasi & Bobin-Bègue, 2003), and observable improvements into adolescence (Drewing et al., 2006).

Childhood advances in auditory-motor integration may have important social and cognitive effects. Moving musically with others facilitates prosociality in infants and young children (Cirelli et al., 2014; Cirelli, 2018; Rabinowitch & Meltzoff, 2017). In the cognitive domain, early rhythm perception abilities have been linked to grammar abilities (Gordon et al., 2015). Music training – specifically, rhythmic training – is proposed to be a potentially viable

1 intervention for children with developmental disorders (Chang et al., 2021; Lense & Camarata,
2 2020; Wiens & Gordon, 2018). Proposed interventions often focus on strengthening time
3 perception mechanisms via encouraging musical movements. A recent dance intervention case
4 study supports this view, demonstrating that two months of dance training improved
5 sensorimotor and cognitive functions in children with cerebellar dysfunction (Bégel et al., 2021).
6 Little is known about what kinds of music might be optimal for these experiences.

7 In adults, not all music is equally effective at eliciting movement. Adults rate music that
8 induces a greater desire to move as high in “groove” (Janata et al., 2012; Madison, 2006). High
9 compared to low groove music generates more spontaneous movement, encourages better
10 movement timing accuracy, and activates motor regions of the brain more (Stupacher et al.,
11 2013). High groove music is also perceived as more pleasurable, activating areas of the brain
12 associated with reward (Matthews et al., 2020). No single musical feature accounts for groove,
13 but high groove is associated with high spectral flux and dynamic variation (Stupacher et al.,
14 2016). Rhythmic features also play an important role: music at a comfortable movement tempo
15 tends to be perceived as groovier (Etani et al., 2018). High groove music is also often
16 moderately syncopated, which may especially recruit the motor system to assist with processing
17 prediction error (Vander Elst et al., 2021; Vuust & Frith, 2008; Vuust & Witek, 2014).

18 Even in early life, auditory stimuli influence rudimentary motor responses. Though
19 toddlers cannot synchronize to the beat, faster tempos elicit faster movement (Rocha &
20 Mareschal, 2016; Yu & Myowa, 2021). Aside from tempo, little is known about which features
21 affect early auditory-motor responses, which may rely on experience or maturity. For instance,
22 children’s movements may not be sufficiently precise to aid in predictive processing of rhythms.
23 If so, groove might only affect movements once motor timing abilities are relatively mature.
24 Similarly, age- or culture-related changes in pitch and rhythm perception may impact groove
25 perception. Music rated by adults to be groovy, therefore, may not induce similar responses in
26 children.

Most research investigating early auditory-motor interactions require children to tap, clap or drum in a laboratory setting (Drake et al., 2000; Kirschner & Ilari, 2013; Provasi & Bobin-Bègue, 2003; Rocha & Mareschal, 2016; Yu & Myowa, 2021). These contexts enable a high degree of experimental control, but may fail to capture musical movements children produce naturalistically. Cirelli and Trehub (2019) recently developed a protocol for investigating children’s musical movements using video recordings in their homes. Here, we adapted this protocol to investigate whether music that motivates *adults* to move (“high groove”) also elicits children’s musical movements, energetic movements, and movements that correspond well to the music’s temporal structure.

In the present study, 3- to 6-year-old children listened to four instrumental excerpts varying in groove in their homes. Children were asked to dance, and their movements were video recorded. We predicted that high groove music would generate more dancing and movements with higher energy than low groove music. Further, we predicted the temporal features of their dancing - specifically, the correspondence between the tempo of their dancing and of the stimulus - would be more influenced by the high groove music. We selected high and low groove excerpts around two different tempos: approximately 120 beats per minute (bpm) and 170 bpm. 120 bpm has been used widely in groove research with adults (Stupacher et al., 2013, 2016; Witek et al., 2014), and may represent an “optimal” tempo for perceiving groove (Etani et al., 2018; Janata et al., 2012), potentially due to its proximity to adults’ spontaneous tapping tempo (e.g. Stupacher et al., 2013). 170 bpm was selected given that children have faster spontaneous tapping tempos than adults (Provasi & Bobin-Bègue, 2003). If spontaneous tapping tempo influences groove perception, children may respond specifically to groove at the faster tempo. Finally, we also explored whether children’s expressions of joy are influenced by groove given that adults rate high groove music as more pleasurable (Witek et al., 2014).

Method

Participants

Seventy-eight children (M age = 4.74 years, SD = 1.20 years, 31 boys, 47 girls; minimum age = 3.01 years, maximum age = 6.98 years) participated in this study (for a visual representation of the age distribution, see Figures 1B and 2B). Families were recruited from the University of Toronto iKids Centre Family Database, from social media ads, and through “Children Helping Science” (<https://childrenhelpingscience.com>). We tested as many children as possible in a predetermined time window (August 2020 - April 2021) and recruited evenly across the age range. Three additional children participated but were excluded because caregivers indicated that it was either their child’s second time dancing to the playlist (1) or because a family member danced with the participant (2). Children participated from Canada (71) or the United States (7). Caregivers could collect videos at their leisure and submit them to us (20), or schedule a Zoom appointment for a research assistant to record the child’s behavior (58). To thank families, they were sent a digital “junior scientist” certificate and were entered into a gift card draw (1 in 20 odds, \$30 CAD). All procedures were approved by the University of Toronto Research Ethics Board.

Stimuli

We selected four instrumental excerpts from Janata and colleagues (2012). We first considered excerpts that fell in the highest and lowest 20% of groove ratings from that study (Study 1, Appendix). From those, we selected pairs that differed in groove (high or low), but were well matched in tempo (slow, approximately 120 bpm, or fast, approximately 170 bpm). The selected excerpts were from: *Bryter Layter* by Nick Drake (low groove, 117 bpm), *Ray Dawn Balloon* by Trey Anastasio (low groove, 166 bpm), *Bad Tune* by Earth, Wind, and Fire (high groove, 122 bpm) and *In the Mood* by the Glenn Miller Band (high groove, 166 bpm). Additional details about each excerpt can be found in Supplemental Table 1, including spectral

1 flux, pulse clarity attack (Mirtoolbox 1.7.2, MATLAB 2021b; Lartillot & Toiviainen, 2007) and
2 musician-rated ($n = 7$) syncopation levels.

3 Playlists included all four excerpts (1 minute each) with a 5 s pause between each.
4 These playlists were uploaded to YouTube to facilitate sharing with families. Excerpts were
5 presented in 1 of 4 pseudo-random orders such that the same tempo was never presented
6 twice in a row and groove alternated. Each excerpt represented the first 60 s of the recorded
7 track, except for *Bad Tune*, which began directly after an extended musical prologue (00:39)
8 that is highly different in rhythm and character from the rest of the track.

10 **Procedure**

11 After consenting, caregivers were instructed to prepare an open, safe area in which their
12 child could dance. Before starting, caregivers were asked to tell their child that they were having
13 a “dance party” and they should “dance along to some music” however they liked. The
14 caregivers were instructed to avoid singing or dancing themselves, given previous studies
15 noting social facilitation effects on children’s movements (Kirschner & Tomasello, 2009).
16 Caregivers were instructed to smile and give words of encouragement if they desired (e.g.,
17 “great job!”) but to avoid specifically asking their child to dance while the music played (see
18 supplementary video 1 for examples). If caregivers recorded the videos themselves, they were
19 asked to follow their child if they moved out of frame. For families recording via Zoom, the
20 experimenter turned off their video and microphone before screen recording the experiment.

21 **Behavioral Coding**

22 Because assistants annotated trial videos on mute to ensure that they were unaware of
23 condition, videos were first divided into four 1-minute excerpts corresponding to times the music
24 played. Trial videos were then uploaded to Databrary (volume 1129). Trained assistants then
25 used ELAN Linguistic Annotator (<https://tla.mpi.nl/tools/tla-tools/elan/>, Lausberg & Sloetjes,

2009) to identify the onset and offset of windows related to dancing, rhythmic movements, and positive affect.

For dancing, annotators indicated onsets and offsets of “dance bouts”. Dance bouts were defined as times at which the annotator subjectively considered the child to be dancing. They included children’s movements that may not have been overtly “dance”-like (e.g., marching, running) but had no clear external motivator (e.g., running in a circle would count as a dance bout, but running to chase the family cat would not).

When dance bouts included a rhythmic movement that was repeated two or more times, annotators indicated the frame-level *onset* of each successive movement, 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 twirled gently, each time their body faced the starting position was identified).

For positive affect, annotators indicated windows of time when the child’s facial expressions were visible and when expressions of positive affect were evident (i.e., smiling, laughing).

Two annotators were responsible for facial affect and visibility coding, and two annotators were responsible for movement coding. Interrater agreement for 12 videos (all four videos from three children, pseudo-randomly selected such that all three contained all behaviours of interest) coded by both were very high for face variables (r 's > .92) and moderately high for movement variables (.62 > r 's > .84).

Additional coding was performed by two new annotators with audio on to identify how often caregivers provided (1) words of encouragement (e.g., “Great job!”), (2) specific requests for the child to dance, and (3) how long children left the frame (if applicable). Because vocal expressions were rare, annotator agreement was calculated over 20 videos (all four videos from five children, randomly selected) rather than 12. On average, annotators’ counts of

encouragement and requests to dance differed by .15 and .05 annotations per video, respectively. Annotated durations that the child left the frame were extremely high ($r = .99$).

In the analyses below, dance proportion was calculated as the amount of time the child spent dancing out of the amount of time they were visibly in frame (proportion). Proportion of positive affect was calculated as the amount of time they spent smiling/laughing out of the amount of time their facial expression was visible to the annotator.

Analyses

We used linear mixed effects models (LMEM; glmmTMB package; Brooks et al., 2017) in R (version 3.6.3, R Core Team, 2020) to evaluate the effects of predictors on children's behaviors. Groove condition (high, low), tempo condition (slow, fast), and child age (years) were included as fixed effects unless otherwise noted. Participant identity was included as a random effect to account for repeated measures. For full model structure and output, see the Supplemental Materials.

Results

Proportion of Time Spent Dancing

On average, children danced about 58% of the time. Six of the 78 children never danced, and 49 danced more than half the time. Despite instruction otherwise, caregivers explicitly asked their children to dance on 18% of trials. The amount of verbal encouragement did not differ significantly across conditions (p 's $> .17$). In an additional 12% of trials, caregiver vocalizations were not classifiable due to poor audio or non-English. Excluding these trials did not change statistical outcomes, so they were retained in the reported analyses.

We predicted that children, like adults, would dance more to high compared to low groove songs, regardless of tempo condition. Children danced more during the high (60%) compared to low (55%) groove conditions, $B = 0.179$, $SE = 0.053$, $z = 3.379$, $p < .001$ (Figure 1). Proportion of time spent dancing increased with age, $B = 0.420$, $SE = 0.130$, $z = 3.226$, $p = .001$ (Supplemental Figure 1). No other fixed effects nor interactions were significant, p 's $> .45$ (see Supplemental Table 2). Finally, we examined whether responses to groove changed with age. We calculated difference scores between dancing in high vs. low groove trials. Only children with at least one data point per groove condition were included. There was no significant correlation between the effect of groove on dancing and age, $r(74) = -0.062$, $p = .592$.

Figure 1. (A) Depicts the proportion of time children spent dancing in each condition. Bars represent averages, and each point represents a single trial of an individual participant. Error bars represent within-subject 95% confidence intervals. (B) Each point represents a single participants' difference in dancing to high or low groove music. Positive values indicate more dancing to high groove music. *** $p < .001$

Dance Energy

For each dance bout, annotators gave an energy rating (1 – lowest, 7 – highest). Because there could be multiple dance bouts in each trial with different durations and energy ratings, each trial was assigned an average energy rating *per second of dancing*. Trials without any dancing were omitted, leaving 72 children with full or partial data for this analysis. Children danced with more energy per second during high compared to low groove conditions, $B = 0.267$, $SE = 0.052$, $z = 5.135$, $p < .001$ (Figure 2). No other effects were significant, p 's $> .12$ (see Supplemental Table 3). Finally, we examined whether responses to groove changed with age. We calculated difference scores between energy per second in high vs. low groove trials. Only children with at least one data point per groove condition were included. There was no significant correlation between the effect of groove on dancing and age, $r(64) = 0.041$, $p = .743$.

Figure 2. (A) Depicts the average energy per second in each condition. Bars represent averages, and each point represents a single trial of an individual participant. Error bars represent 95% within-subject confidence intervals. (B) Each point represents a single

participants' difference in energy when dancing to high or low groove music. Positive values indicate more energetic dancing to high groove music. *** $p < .001$

Temporal correspondence between movements and music

For trials when dancing occurred, rhythmic movement onsets were used to calculate movement rates. We focused on temporal correspondence (tempo matching) rather than strict auditory-motor synchronization for two reasons. First, in contrast to lab-based tasks, there was no specified effector children used. Within a single dance "move", whether children intended to align their feet, head, arms, another body part, or even *no* body parts to the beat itself was unknown. Regardless, periodicities in their movements could be unambiguously identified. Second, synchronization accuracy in laboratory tapping tasks is quite low until children are 5 or 6 years of age. Overall synchronization levels might therefore be too low to reveal meaningful variability across conditions. Nevertheless, if a child *did* move synchronously with the musical beat, they would have high temporal correspondence scores.

Only trials with at least 10 inter-onset intervals total (not necessarily consecutive) were included (50 of 244 trials containing rhythmic movements were excluded), leaving 62 participants with full or partial data for analysis. Inter-onset intervals were converted to movements per minute. In a previous study of adults' free-dancing, movement tempos within a $\pm 5\%$ bpm window were considered to correspond with the temporal structure of the music (Burger et al., 2014). Here, a wider window was used ($\pm 10\%$) given that children's movements are less precise. Thus, our *temporal correspondence* variable represents the proportion of movements whose rate was within $\pm 10\%$ of the excerpt beat rate, half beat rate or double beat

rate¹ (see Supplemental Table 4 for bpm ranges and descriptive data). High temporal correspondence scores would indicate that a child's movement tempo was related to the tempo of the excerpt.

We first examined whether children's movement tempos were affected by the tempo of the stimulus without considering groove. We compared temporal correspondence scores for the concurrent stimulus with a temporal correspondence score calculated using the bpm ranges for the groove matched stimulus, which differed from the concurrent stimulus by approximately 50 bpm at the beat rate. The latter was essentially a control condition representing the amount of incidental correspondence between children's movement tempo and a stimulus at a completely different tempo from one they were hearing. If children's movement tempos were not affected by the stimulus tempo, we would expect similar correspondence scores for the stimulus and control tempos. If children's movement tempo was affected by the stimulus tempo, we would expect more correspondence to the stimulus than the control tempo. Indeed, children's movement tempos corresponded more with the stimulus than control tempo, $B = 0.032$, $SE = 0.008$, $z = 3.909$, $p < .001$, regardless of whether the stimulus tempo was fast or slow ($p = .164$), indicating that our participants demonstrated tempo flexibility in their free dancing (see Supplemental Table 5).

We investigated whether temporal correspondence was predicted by groove and age. As predicted, there was greater temporal correspondence between the music and movement tempos for high compared to low groove conditions, $B = 0.033$, $SE = 0.012$, $z = 2.712$, $p = .007$ (see Figure 3). In other words, a greater proportion of the movement tempos fell within the tempo-relevant windows when listening to high groove music. Unexpectedly, age was not a

¹ To ensure that the results were not an artefact of the window size we selected, we also obtained average proportions of temporal correspondence using window sizes of 5%, 7.5%, 12.5% and 15%. In all cases, the proportion of temporal correspondence was larger in high than low groove conditions.

significant predictor, $p = .093$. No other effects were significant, p 's $> .37$ (see Supplemental Table 6).

Finally, we examined whether responses to groove changed with age. We calculated difference scores between temporal correspondence in high vs. low groove trials. Only children with at least one data point per groove condition were included. There was no significant correlation between the effect of groove on dancing and age, $r(39) = 0.057$, $p = .725$.

Figure 3. (A) Depicts the proportion of temporal correspondence (10% window around beat, double, and half rate). Error bars represent 95% within-subject confidence intervals. (B) Each point represents a single participants' difference in temporal correspondence when dancing to high or low groove music. Positive values indicate more temporal correspondence in high groove conditions. $**p < .01$

Positive Affect

Children expressed positive affect (e.g., smiling or laughing) on 75% of trials. In trials containing positive affect, children expressed joy almost half the time (45%). We explored

whether expressions of positive affect were affected by groove/tempo condition or age, but no effects reached significance, all p 's > .60 (see Supplemental Table 6).

We also explored associations between movement variables (*proportion dancing*, *energy per second*, and *temporal correspondence*) and proportion smiling, including participant as a random effect to account for repeated measurements. Both proportion dancing and energy per second were positively associated with smiling (p 's < .001), but temporal correspondence was not, $p = .909$ (see Supplemental Table 7).

Discussion

Research investigating children's auditory-motor responses to music typically involve drumming, tapping, or clapping to a beat in constrained laboratory experiments. Here, we asked caregivers to record their children freely dancing in their homes. This new paradigm overcomes numerous barriers to diverse data collection, requires a minimal time commitment (< 5 minutes) from families and gives children the opportunity to demonstrate the breadth of their abilities. Results show that children, like adults, are sensitive to the construct of "groove", and that it affects their self-selected movements to music. High groove music elicited more dancing and more energetic movement, across both tempo conditions. The present results build on previous studies demonstrating that children's movements are affected by tempo, and further show that children's musical movements are also affected by other musical characteristics: namely, those that induce a desire to move in adults.

Critically, high groove music generated more temporally correspondent movements than low groove music. This result that parallels adults' superior synchronization to high than low groove music (Janata et al., 2012; Leow et al., 2014), and is consistent with theories of beat perception that emphasize the importance of auditory-motor connections (Patel & Iverson, 2014). Although the view that the motor system is important for beat perception continues to garner support from studies with adults, it is not clear when these auditory-motor connections

1 emerge or how they are influenced by motor development, neural development, and
2 socialization. The present results demonstrate that the mechanisms driving motor responses to
3 groove are sufficiently operational by at least age 3, before children can reliably synchronize
4 their movements to musical beats.

5 Despite early emerging tempo flexibility, synchronization accuracy remains low and
6 inconsistent into early childhood. To account for this limitation, we focused on general tempo
7 matching instead of synchronization in the broad age group (3 to 7 years) investigated here.
8 The older children in our sample danced more (which may reflect improved compliance), but we
9 found no evidence suggesting that age interacted with the effects of groove on any dependent
10 variable. Future research is needed to determine if children under 3 also move more to high
11 groove music, and to explore potential effects of motor development and musical exposure on
12 groove sensitivity.

13 Consistent with previous studies, children's movement tempos were affected by the
14 stimulus tempo – that is, they demonstrated tempo flexibility. We found no evidence that either
15 tempo was easier for children to move along to, as both induced approximately similar
16 proportions of movements corresponding with the target tempos (~25%). Adults find it easiest to
17 align movements to tempos that correspond to their spontaneous motor tempo (usually around
18 120 bpm). Accordingly, we predicted that children would find it easier to move to faster music,
19 given their faster spontaneous motor tempo (Drake et al., 2000). There may be several reasons
20 why we did not observe this. First, research on spontaneous tempo usually uses tapping. Here
21 children danced freely with many different effectors. Second, children may have focused on
22 different levels of the metrical hierarchy – while the 170 bpm excerpts were “faster” at the beat
23 level, if children danced to the half beat level, then they would have been moving at a rate even
24 further from their spontaneous tempo (85 bpm). Whether children's spontaneous tempos relate
25 to their auditory-motor abilities in free dance remains unknown.

Overall, temporal correspondence was quite low, perhaps reflecting the unconstrained nature of free dance and developmental difficulties with synchronization. Temporal correspondence did not improve with age, which is surprising given the improvements in rhythm perception and production frequently found in constrained laboratory tasks with these age groups. The temporal correspondence measure used here may not be sufficiently sensitive to detect age-related differences, which might be small in free dance contexts. Children may also incorporate more advanced and complex movements into their dance repertoire as they age. Alternatively, younger children might display superior temporal abilities in naturalistic contexts compared to constrained laboratory tasks, as found with children's singing abilities (Gudmundsdottir & Trehub, 2018). Future research is needed to understand how children select the motor patterns to use in free dancing, and how the development of rhythm perception and production facilitate tempo matching across effectors and task demands.

Across both tempos, adult-rated groove induced greater duration, energy, and temporally correspondent movements. What musical factors might underlie these effects? Compared to low groove music, high groove music tends to have more variability in the frequency spectrum over time (especially in low frequencies) and higher pulse clarity (Stupacher et al., 2016). Here, we used unmanipulated musical excerpts which varied on many musical and acoustic dimensions. However, no single dimension measured here (aside from adult-rated groove), accounted for the observed differences. For instance, while spectral flux was highest for the two high groove excerpts, low groove *Ray Dawn Balloon* had nearly twice as much spectral flux as low groove *Bryter Layter*, but behavioral responses to these two excerpts did not differ. Likewise, other features that tend to vary with groove ratings – pulse clarity and musician-rated syncopation – did not clearly differ between the high and low groove excerpts used here. The concept of groove itself is not linked to any specific acoustic feature and probably results from an interaction between many features that optimally engage auditory-motor connections. The developmental trajectory of how these individual features contribute to the concept of

1 groove is a promising avenue for future research – in fact, preliminary evidence shows that 5-
2 and 6-year-old children rate moderately syncopated rhythms as “better for dancing” than low
3 syncopation rhythms (Cameron et al., 2021).

4 Identifying types of music that facilitate temporally correspondent movements and
5 ultimately, synchronization, has important implications on rhythmic intervention programs. For
6 example, training children to move in synchrony to musical rhythms is proposed as one pathway
7 to remediate language skills, coordination skills, and social skills for children with deficits
8 (Chang et al., 2021; Lense & Camarata, 2020; Wiens & Gordon, 2018). More generally, moving
9 synchronously to music with others can help toddlers and young children forge social
10 connections with their movement partners (Cirelli et al., 2018). Children enrolled in rhythm-
11 based interventions – especially those with deficits in time perception – might especially benefit
12 from musical selections that more readily enable auditory-motor engagement.

13 In adult participants, groove is characterized not only by eliciting the desire to move, but
14 the pleasurable desire to move (Matthews et al., 2020). Here we found no effect of groove on
15 expressed joy, despite the apparent effects of groove on proportion of time dancing, and the
16 positive associations between smiling and dancing. This dissociation suggests that the effect of
17 groove on dancing may not be driven by affective responses to the high compared to low
18 groove music. This interpretation is tentative, however, given that there is not a one-to-one
19 mapping between felt and expressed emotion. We did, however, find that children expressed
20 more joy during trials when they danced more and when they danced with more energy. Similar
21 correlations have been previously reported with infants and toddlers (Cirelli & Trehub, 2019;
22 Kragness et al., 2021). Though the direction of causality remains unclear, the present results
23 highlight the link between early musical movements and expressions of joy.

24 To summarize, Western children’s motor responses to musical groove parallel findings
25 with Western adults – high groove music encourages them to dance more, to dance with higher
26 energy, and to align their movements more closely to the temporal structure of the music.

1 Improved temporal correspondence for the high groove excerpts further supports that the
2 auditory-motor connections necessary for tempo matching and later, synchronization, emerge
3 early in childhood and are influenced by musical features. These free dance responses were
4 captured naturalistically in children's own homes. High groove music may be especially
5 effective, even very early in life, at generating musical movements, facilitating beat perception,
6 and forging social and emotional bonds with those around us.

7

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Figure Legends

Figure 1. (A) Depicts the proportion of time children spent dancing in each condition. Bars represent averages, and each point represents a single trial of an individual participant. Error bars represent within-subject 95% confidence intervals. (B) Each point represents a single participants' difference in dancing to high or low groove music. Positive values indicate more dancing to high groove music. $*p < .05$

Figure 2. (A) Depicts the average energy per second in each condition. Bars represent averages, and each point represents a single trial of an individual participant. Error bars represent 95% within-subject confidence intervals. (B) Each point represents a single participants' difference in energy when dancing to high or low groove music. Positive values indicate more energetic dancing to high groove music. $***p < .001$

Figure 3. (A) Depicts the proportion of temporal correspondence (10% window around beat, double, and half rate). Error bars represent 95% within-subject confidence intervals. (B) Each point represents a single participants' difference in temporal correspondence when dancing to high or low groove music. Positive values indicate more temporal correspondence in high groove conditions. $**p < .01$