MOVING MUSIC: CORRESPONDENCES OF MUSICAL PARAMETERS AND MOVEMENT DIMENSIONS IN CHILDREN’S MOTION AND VERBAL RESPONSES

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We examined how children (5- and 8-year-olds) associate changes in musical parameters with bodily motion, using movement and verbal tasks. In Task 1, participants moved to short musical stimuli involving bidirectional changes in pitch, loudness, or tempo. In Task 2, participants selected motion features appropriate to the same stimuli (forced-choice verbal task). In Task 1 the distribution of movement features significantly varied for different musical parameters: pitch change associated most strongly with vertical motion, loudness change with muscular energy and vertical motion, and tempo change with speed and muscular energy. In both tasks and for both ages, directions of change in motion and musical parameters correlated, e.g., increase in loudness was associated with increasing speed, increasing muscular energy, and spatial rise. The effect of pitch direction was mediated by temporal order, suggesting that overall pitch contour, rather than local direction only, affects bodily motion. Age affected responses to pitch direction, rather than loudness or tempo change. Results suggest that children consistently correlate musical and movement features through both verbal and motion responses, presenting an intricate web of auditory-motor-cognitive mappings.

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Music associates with human motion in diverse ways, generating bodily movement both spontaneously (e.g., tapping, body-swaying) and through culturally mediated channels such as dance, marches, or work-songs. While the coordination of movement with aspects of rhythm and tempo has been widely studied empirically (e.g., Phillips-Silver & Trainor, 2005; Zentner & Erola, 2010), recent studies also suggest correspondences between other auditory parameters, such as loudness and pitch, and particular movement features, such as its directions (e.g., up/down, forward/backward) or speed (for reviews of recent research see Eitan, 2013a; Godøy & Leman, 2010).

Loudness, primarily associated in perception with distance (Blauert, 1997), has also been shown to correspond with other movement-related dimensions. Children and adults matched louder sounds with larger visual size (Burro & Grassi, 2001; Lipscomb & Kim, 2004; Smith & Sera, 1992; Walker, 1987). An association of loudness with spatial height (and of loudness change with vertical direction) is reflected by experimental results, language (e.g., “raising” one’s voice), and the design of artefacts, such as the vertical orientation of dB meters on audio equipment. Such associations were found in verbal tasks (Eitan & Granot, 2006), as well as nonverbal speeded discrimination tasks (Eitan, Schupak, & Marks, 2008).

Pitch is often associated with spatial height, and pitch change – with motions up or down. The perceptual reality of this mapping, expressed in diverse languages (as in Western musical notation), has been established using varied behavioral paradigms. Thus, “higher” pitch is actually perceived as being emitted from a higher location in space (Cabrera, Ferguson, Tilley, & Morimoto, 2005; Pratt, 1930; Roffler & Butler, 1968). Pitch/height correspondence also affects perception and action in a variety of implicit ways, as suggested, for instance, by studies utilizing speeded discrimination (Ben-Artzi & Marks, 1995; Bernstein & Edelstein, 1971; Evans & Treisman, 2010; Melara & O’Brien, 1987) and stimulus-response compatibility paradigms (Lidji, Kolinsky, Lochy, Karnas, & Morais, 2007; Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006).

In addition to spatial height, some studies suggest that pitch is also associated with lateral position, and respectively with motion in the lateral axis: higher pitch is associated with right-side position and with motion to the right, and lower pitch—to left-side position and motion to the left (Mudd, 1963; Rusconi et al., 2006; Stevens & Arieh, 2005). Other studies, however, delimit pitch-laterality correspondences for trained musicians.
only, suggesting that they are acquired primarily through experience with musical keyboards; see Lidji et al., 2007; Stewart, Walsh, & Frith, 2004. Pitch also associates with physical size, such that larger size corresponds with lower pitch. For instance, the congruence of visual size with pitch affected size estimation (Gallace & Spence, 2006) and speeded discrimination of visual size (Evans & Treisman, 2010). Importantly, however, when participants associated dynamic pitch (ascending or descending pitch glides or melodies) and changing size, the direction of congruence was reversed: pitch rise was associated with increase, rather than decrease in size (Antovic, 2009; Eitan et al., 2015; Kim & Iwamiya, 2008).

Sound-motion correspondences in musical contexts. Most empirical studies examining correspondences of sound and motion features have used very simple auditory stimuli — typically, isolated sine tones or pitch glides; hence, their relevance to musical contexts could be questioned. Eitan and associates examined such correspondences using music-like stimuli in experiments involving musically trained and untrained adults (Eitan & Granot, 2006, 2011), children aged 6 and 11 (Eitan & Tubul, 2010), and congenitally blind adults (Eitan, Ornoy, & Granot, 2012). Participants were asked to associate melodic stimuli in which pitch direction, loudness change, and tempo change were systematically manipulated with imagined motions of a human character, and to specify features of that motion, such as its type (e.g., walk, run), directions in the three-dimensional space, energy level, or speed change.

Beyond corroborating established music-motion associations (e.g., pitch change and vertical direction, tempo change and speed), these studies reveal a complex yet consistent web of relationships among musical and movement dimensions. Most musical parameters significantly affected several dimensions of motion imagery. Pitch direction, for instance, affected imagined motion along all three spatial axes (not only verticality), as well as the velocity and “energy” of the imagined motion. Loudness change was associated not only with distance and energy, but also with height and speed change.

Developmental Aspects of Sound-Motion Correspondences

Child development theories acknowledge that “the very young child communicates through movement long before his vocabulary develops” (Zimmerman, 1981, p. 50). A relationship between music and movement indeed starts very early in life: infants move in reaction to music and other regular sounds significantly more than in reaction to speech (Zentner & Eerola, 2010), while induced bodily movement affects the way infants encode musical rhythm (Phillips-Silver & Trainor, 2005).

An important basis for such early music-motion relationship may be sensorimotor synchronization (SMS) — the coordination of an action with a predictable external event, an ability fundamental to musical activity that emerges early in infancy (Malloch, 2000; Maurer, 1993; McDonald & Simons, 1989; Metz, 1988; Moog, 1976; Papousek, 1996). As suggested by Stern (2000) and Trevarthen (2000), such dispositions may be generated or enhanced by early infant-caregiver interaction through gestures, vocalizations, and facial expressions; these may lead to the perception of analogous gestures using different modes of communication (somatic, auditory and visual) as a unified, amodal patterns of change (Stern’s “vitality affects”; see also Kühl, 2011).

Children as young as three years old express musical tempo and dynamics in their locomotive movements, i.e. running and walking (McDonald & Simons, 1989; Metz, 1988; Moog, 1976; Sims, 1988), responding, for instance, to louder sounds with more energetic movements (Gorali-Turel, 1997; Gluschankof, 2005). Correspondingly, studies in music education suggest that music perception and understanding are enhanced by kinesthetic responses that match characteristics of the music (Fung & Gromko, 2001; Sims, 1988).

Movement responses to different musical parameters may differ in their developmental course. For instance, fourth grade subjects reflected changes in musical duration and loudness, but not pitch changes, in their movement responses to short musical excerpts (Andrews & Diehl, 1970). Indeed, the sources and developmental course of correspondences between pitch and movement features, particularly the correspondence of pitch and vertical direction, are still in dispute. Infant studies indicate that this correspondence is inborn or at least learned in infancy, prior to language acquisition (Dolscheid, Hunnius, Casasanto, & Majid, 2014; Jeschonek, Pauen, & Babocsai, 2013; Wagner, Winner, Cicchetti, & Gardner, 1981; Walker et al., 2010). However, other works suggest that this association – at least as manifested verbally — is acquired fairly late in childhood, possibly only around age 8 (Hair, 1977, 1981; Stalinski, Schellenberg & Trehe, 2008; Zimmerman & Sechrest, 1970).

A developmental study particularly relevant to the present experiments is Eitan and Tubul (2010), which applied Eitan and Granot’s (2006) motion imagery
This study investigates whether music parameters are significantly associated with specific motion dimensions, examining children’s motion to musical stimuli in which changes in specific parameters are salient. Taking into account earlier findings, we propose two main hypotheses:

A. The distribution of movement features would significantly differ for different musical parameters. Based on earlier studies, we expected that loudness change would be mainly associated with motion in the distal axis (forward/backward), pitch change – with motion in the vertical axis, and tempo changes – with changes in speed. However, as Eitan and Granot (2006) and Eitan and Tubul (2010) indicate, each musical parameter may activate several motion dimensions.

B. The directions of change in musical and movement parameters would correlate. Musical intensifications (pitch rises, crescendi, and accelerandi) would be associated with “growing” movements (upward, forward, spreading) and with movements increasing in speed and muscular energy; musical abatements – with shrinking movements (downward, backward, enclosing) and with movements decreasing in speed and muscular energy (for previous studies supporting this hypothesis see Eitan & Granot, 2006; Eitan et al., 2012; Eitan & Timmers, 2010; Eitan & Tubul, 2010).

As noted, we compared two age groups, 5 vs. 8, examining whether and how the above hypotheses apply to both. However, since relevant developmental studies are scarce and their results sometimes conflicting, we do not propose specific hypotheses concerning age-related effects. The effects of gender and music training were also examined (the latter only for the older group). In addition, we examined whether the type of musical stimulus (“real” music vs. synthetic, controlled stimuli) affects motion responses. Results of the movement task (Task 1) were compared with results of the verbal task (Task 2).

The development of music-motion association is another focus of this study. In view of the conflicting results (particularly those concerning movement responses to pitch changes), we have selected two age groups, 5 and 8, for comparison. Five-year-olds approach adults’ movement abilities (Gallahue, 1982); however, the two age group are assumed to represent different stages of cognitive development (pre-operational vs. concrete operational; Piaget, 1983). Furthermore, as noted above, while studies suggest that these two age groups may differ in the ways they associate movement and sound features, particularly pitch, such differences may be due, as infant studies suggest, to the use of verbal response methods. Hence, directly examining movement responses may elucidate the somewhat conflicting results of these earlier developmental studies.
Method

Participants
One hundred and six children, residents of the Tel Aviv area (Israel), participated in the experiment. They included 60 children aged 8 (25 females, 35 males) who were 3rd grade students in an elementary school; 29 of these children (15 females, 14 males) had studied and played a musical instrument for at least one year. A second group included 46 children aged 5 (23 females, 23 males), who were pupils in a preschool. Participants were mostly from a middle class socio-economic background. None had had known hearing, learning, or motor deficiencies. Children’s parents received a detailed explanation of the experiment. Only children whose parents completed a consent form were invited to participate in the experiment.

Stimuli
The stimuli comprised nine musical excerpts involving bidirectional changes in pitch, loudness, and tempo. Four of the stimuli were synthetically constructed, while five were taken from commercial recordings of standard classical repertory. As noted in the introduction, the parameter of pitch elicits complex issues concerning the nature and development of its associations with physical space and motion. To examine these issues, following a pilot study, more stimuli involving changes in pitch (particularly, both rise-fall and fall-rise stimuli) were presented than stimuli involving loudness and tempo (particularly, both rise-fall and fall-rise stimuli) were elongated. The fourth synthetic stimulus (ST), 22 s long, consisted of repeated tones (C4) first gradually decreasing in duration from 1200 to 300 ms, then gradually increasing in duration back to 1200 ms.

Five musical excerpts from Western compositions were used, ranging in duration from 14 to 20 s. Each excerpt demonstrated a salient, continuous bidirectional change in one of the selected musical parameters (pitch, loudness, or tempo), while changes in other parameters were minimal. Three excerpts (MP1-MP3) from Paganini’s Capriccio No. 5 for violin (the 7th and 8th phrases of the opening part), Saint-Saens’s Aquarium from The Carnival of the Animals (mm. 35-39) and the 2nd movement of Stamitz’s Concerto No. 7 in E-flat for clarinet and orchestra (from m. 75), presented pitch rise and fall (the first and third featuring rise followed by fall, the second featuring fall followed by rise). One excerpt (ML), from the 2nd movement of Vaughan Williams’s Symphony No. 6 (mm. 92-97), presented changes in loudness (crescendo followed by diminuendo), and one excerpt (MT) from Brahms’ Hungarian Dance No. 7 in A (arranged for violin and piano, mm. 1-8) presented changes in tempo (accelerando followed by ritardando). All five segments were excerpted from commercial music CDs. Table 1 summarizes the features of all nine stimuli.

Procedure
The experiment took place in the school’s music room and the activities area of the kindergarten, environments familiar to the children. Participants performed two tasks: a movement task (Task 1) and a verbal task.

### TABLE 1. Active Musical Parameters, Change Direction, and Source for the 9 Musical Stimuli Used in Both Experiments

<table>
<thead>
<tr>
<th>Stimulus code*</th>
<th>Parameter</th>
<th>Directions</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1</td>
<td>Pitch</td>
<td>Rise-fall</td>
<td>Synthetic</td>
</tr>
<tr>
<td>SP2</td>
<td>Pitch</td>
<td>Fall-rise</td>
<td>Synthetic</td>
</tr>
<tr>
<td>MP1</td>
<td>Pitch</td>
<td>Rise-fall</td>
<td>Excerpt</td>
</tr>
<tr>
<td>MP2</td>
<td>Pitch</td>
<td>Fall-rise</td>
<td>Excerpt</td>
</tr>
<tr>
<td>MP3</td>
<td>Pitch</td>
<td>Rise-Fall</td>
<td>Excerpt</td>
</tr>
<tr>
<td>SL</td>
<td>Loudness</td>
<td>Crescendo-Diminuendo</td>
<td>Synthetic</td>
</tr>
<tr>
<td>ML</td>
<td>Loudness</td>
<td>Crescendo-Diminuendo</td>
<td>Excerpt</td>
</tr>
<tr>
<td>ST</td>
<td>Tempo</td>
<td>Accelerando-Ritardando</td>
<td>Synthetic</td>
</tr>
<tr>
<td>MT</td>
<td>Tempo</td>
<td>Accelerando-Ritardando</td>
<td>Excerpt</td>
</tr>
</tbody>
</table>

*Note: SP = synthetic stimulus/pitch change; MP = musical excerpt/pitch change; SL = synthetic stimulus/loudness change; ML = musical excerpt/loudness change; ST = synthetic stimulus/tempo change; MT = musical excerpt/tempo change.

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1. The initial sample included 128 children, half of them 5-years-old and half 8-years-old. Only children who participated in all the tasks were taken into account for the data. Thus, four 8-year-old subjects and fourteen 5-year-old subjects were excluded from the initial sample. Due to Ministry of Education restrictions, we were unable to increase the young subjects’ group.
Movement task (Task 1). Following an introductory group meeting between the 1st author (D.K.) and the children, each participant took part in two individual sessions, five stimuli presented in the 1st session, and four in the second. Stimuli order was randomized for each participant. Participants were instructed as follows:

“You will hear a short bit of music. Right after the first listening you will hear it again, and then, while listening to the music, move to it in an appropriate way, such that another child could recognize the music while watching your movements without sound.”

Each musical segment was repeated twice. Children moved to the music in the 2nd hearing. All movement responses were video recorded, using a single camera (Sony Digital Video Camera Recorder, DCR-TRV255E), located approximately 3 meters from participants on a fixed tripod.

Data coding and analysis. To analyze the children’s movement responses, we applied categories adapted from Laban Movement Analysis (LMA), a method widely used in diverse disciplines, including dance, drama, physical therapy, and nonverbal behavior research in psychology, anthropology, ergonomics, and other fields (Laban, 1971; Moore & Yamamoto, 1988). Following consultations with a LMA expert and an informal pilot study observing the salience of various motion categories in children’s movements, we selected the following six bipolar movement categories:

1) Vertical (up/down)
2) Horizontal (left/right)
3) Sagittal (forward/backward)
4) Horizontal shape (spreading/enclosing)
5) Muscular energy (increasing/decreasing)
6) Speed (accelerating/decelerating)

Three referees, blind to the aims and hypotheses of the experiment, watched in random order each participant’s videotaped movements without sound, and independently encoded these movements according to the above categories. All referees were trained and tested by an LMA expert (Dr. Nava Lotan) in coding movement according to LMA principles and categories. For each recording, referees first observed whether there was a salient visible change in the child’s movement. Using video editing software, which allows watching the video frame by frame (Adobe Première Pro CS3, version 3.2.0), they recorded the point in time in which this change occurred. Referees then marked, separately for the movement phase preceding the change point (Phase 1) and the phase following it (Phase 2), all movement dimensions activated, and the direction of motion in each dimension. For each direction of motion in each motion dimension (e.g., vertical rise), referees marked whether it was present throughout the entire phase, or during a part of it. They also marked cases in which both directions of movement in a particular dimension were equally present within the same phase.

Data was converted into a numerical scale. In each movement dimension, (except lateral motion), “increasing” movements (ascent, spreading, motion forward, increase in muscular energy, acceleration of speed) were positively coded, while “decreasing” movements (descent, enclosing, motion backwards, decrease in muscular energy, deceleration of speed) received a negative rating. Usage of a movement dimension throughout a movement phase received a whole rating “point” (+1 or −1), while partial usage received half a point (+0.5 or −0.5). Rating was performed independently for each participant by each of the three referees (α = .898 to .984); scores of the three referees were averaged.

Verbal task (Task 2). Participants heard each stimulus twice and then designated in a forced choice questionnaire the motions most appropriate to that stimulus. Motion categories included parameters defined by LMA, so that movement responses (as coded by referees in Task 1) could be compared with the verbal responses of Task 2. The “Muscular energy” category was not included in the verbal task, since the concept was not clear to children (as evidenced in a pre-test). In their response sheet, participants were asked to mark for each movement category the most appropriate of three choices, including the two antonyms (e.g., ascending, descending) and “neither.” The order of stimuli, categories, and polar opposites in each category was randomized among participants.

Two caveats regarding the comparison of Tasks 1 and 2 should be mentioned. First, Task 2 (Verbal Task) involved only the older (8-year-old) group, since a pre-test suggested that most of the younger children would be unable to perform the task as required. Second, in the verbal task, children were asked to choose an appropriate description of their imagined motion among five possible answers (forced choice questionnaire); that

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LMA employs a distinct vocabulary for Shape qualities in the three spatial dimensions: spreading/enclosing for the horizontal dimension (which we use), rising/sinking for the vertical dimension, and advancing/retreating for the sagittal dimension. Here, we have merged concepts for the vertical and sagittal dimensions, and chose to use the direction terminology up/down and forward/backward to represent both direction and shape categories.
is, they were explicitly presented with all five movement categories. In the movement task, no movement terms were explicitly presented. Furthermore, due to bodily constraints, children's movements could express only a few movement dimensions at a time, while verbal responses to the same stimulus could include all dimensions presented.

Results

**Task 1 (Movement Task)**

Musical parameters and movement dimensions (Hypothesis A). To test hypothesis A, we examined whether participants' choices of movement dimensions significantly differed for the three musical parameters activated (pitch, loudness, and tempo). Using the coding described above, we calculated for each group of stimuli activating a musical parameter (e.g., the five stimuli MP1, MP2, MP3, SP1 and SP2, all activating pitch change), for each participant, the frequency of usage of each movement dimension. Using a Friedman test with Bonferroni corrections, we then compared participants' average usage of each movement dimension in the three musical parameters, (see Table 2).

For all movement dimensions but one, the frequency of use was significantly affected by the musical parameters activated. Thus, motion in the vertical dimension was applied more frequently in relation to pitch changes, as compared to loudness and tempo changes. Changes in speed were applied mostly, as expected, to tempo changes, and least to pitch changes. Changes in muscular energy were affected by tempo (most frequently), as well as by loudness, and least by pitch. Horizontal direction (right-left) was applied less frequently in relation to loudness changes, as compared to pitch or tempo changes. Sagittal motion (forward-backwards) was applied more in reaction to tempo changes than to either pitch or loudness (though it is loudness that is acoustically associated with distance change, and thus with sagittal motion). Only the movement dimension of shape (spreading/enclosing) was not differentially affected by musical parameters.

Complementarily, the data presented in Table 2 indicate that different musical parameters indeed tend to activate different movement dimensions, as hypothesized in Hypothesis A. Loudness most commonly activated muscular energy and vertical motion, pitch mostly activated vertical motion and tempo – speed and muscular energy.

Demographic variables. No significant differences were found concerning age and music training, based on chi-square analysis.

Directions of change in music and movement parameters (Hypothesis B). To examine whether the directions of change in musical parameters are significantly associated with the directions of change in movement dimensions, we subtracted for each stimulus the average rating for phase 1 from that of phase 2 (averages calculated for each participant, in each movement dimension; see “data encoding” above for encoding procedure). Wilcoxon tests with Bonferroni corrections (summarized in Table 3) determined, for each movement dimension in each stimulus, whether these rating differences deviate significantly from 0.

Table 3 demonstrates significant associations between the “directions” of change in pitch, loudness, and tempo and those in three movement dimensions – verticality, muscular energy, and speed. No significant associations were found for the sagittal and shaping dimensions.

| TABLE 3. Task 1: Mean Differences in 3 Movement Dimensions between Scores for Movement Phases 1 and 2 of Each Musical Stimulus |
|---------------------------------|------------------|----------------------|---------------------|
|                                | Vertical | Speed | Energy |
| SP1                             |          |       |        |
| rise-fall                       | -0.812*  | -0.150 | -0.250  |
| SP2                             | -0.052   | 0.0310 | -0.150  |
| fall-rise                       |          |       |        |
| MP1                             | -0.793*  | -0.132 | 0.017   |
| rise-fall                       | 0.217    | -0.680* | -0.927* |
| MP2                             |          |       |        |
| fall-rise                       | -0.830*  | -0.770* | -0.901* |
| MP3                             |          |       |        |
| rise-fall                       | -0.661*  | -0.900* | -1.000* |
| SL                              |          |       |        |
| cresc.-dim                      | -0.519*  | -1.240* | -1.585* |
| ML                              |          |       |        |
| cresc.-dim                      | -0.257   | -1.750* | -1.495* |
| ST                              |          |       |        |
| accel.-rit.                     | -0.301   | -1.210* | -1.135* |
| MT                              |          |       |        |
| accel.-rit.                     |          |       |        |

*p < .05, following Bonferroni correction.
Associations between growth and decay in movement and music were found for the three musical dimensions examined. Pitch rise and fall are associated with bodily ascent and descent, respectively (notably, this relationship was observed only when pitch rise precedes pitch fall, as in stimuli SP1, MP1, MP3, and not when this order is reversed as in SP2, MP2; this finding is presented and discussed below). Loudness increase and decrease are associated with the directions of change in several movement dimensions – spatial ascent and descent, speed acceleration and deceleration, and increase and decrease in muscular energy, respectively. Changes in musical Tempo — accelerando and ritardando — are associated with acceleration and deceleration of movement speed, respectively, and with increase and decrease in muscular energy, but not with spatial ascent and descent.

**Directions of change in music and movement: Demographic variables.** We calculated phase differences (as described above) separately for each age group (5- and 8-year-olds). Age mostly affected the vertical movement dimension (Table 4). While for the older group significant phase differences for verticality were found in three of the pitch-change stimuli (those presenting pitch rise followed by fall) and in both loudness stimuli, no comparable significant differences were found for the younger group. This suggests that 8-year-olds associate pitch rise and fall, respectively (as well as crescendo and diminuendo), with bodily ascent and descent, while 5-year-olds do not. This age-related difference is noteworthy, since the frequency of use of the vertical movement dimension per se did not significantly vary with age. Thus, 5-years-old children, just like their older peers, associated motion in the vertical dimension with pitch change, but only the older children consistently associated the directions of change in these movement and musical dimensions.

**Synthetic stimuli vs. musical excerpts.** Using paired Wilcoxon tests, we compared for each of the three musical parameters (pitch, loudness, and tempo) the mean scores for synthetic and actual music. Significant differences between synthetic and actual music stimuli were found for the movement dimensions of verticality, speed and muscular energy, but only in the rising segments of the pitch stimuli (p < .01, following Bonferroni corrections); in all these comparisons, mean scores were significantly higher for the “real” music excerpts, as compared to the synthetic stimuli.

**Musical parameters and overall movement growth: the movement growth index.** Hypothesis B suggests that the directions of change in musical and movement parameters would correlate. As Table 3 indicated, growth and decay (or “increase” and “decrease”) in specific movement dimensions were indeed significantly associated, respectively, with growth and decay in musical dimensions. To examine whether this relationship may be generalized to an overall measure of movement, we created a new variable: movement growth index (MGI). MGI averages for each of the two segments of each stimulus the scores of all movement categories (excluding horizontal direction), thus expressing the overall level of bodily growth or decay in response to changes in a musical segment. Like scores for the separate movement dimensions, MGI ranges from −1 to +1.

To examine the effects of musical parameters and their change direction on overall movement growth and decay, we conducted an analysis of variance (ANOVA) with repeated measures. Musical parameter (pitch, loudness, tempo) and musical change direction (increase or decrease) were within-participant independent variables, and age (5 or 8) — a between-participants independent variable. Mean MGI served as the dependent variable. Since the two fall-rise stimuli (SP2, MP2) differed from all other stimuli in the order of musical change directions (decrease precedes increase, rather than vice versa), we excluded these stimuli from this analysis, comparing

| TABLE 4. Task 1: Mean Phase Differences in Each Age Group (Vertical Movement Dimension) |
|---------------------------------|-----------------|-----------------|-----------------|
|                                 | Mean phase dif. (5) | Mean phase dif. (8) | p for age comparison (Wilcoxon) |
| SP1 rise-fall                   | −0.37            | −1.12***         | .01             |
| SP2 fall-rise                   | 0.25             | −0.23            | .18             |
| MP1 rise-fall                   | −0.48            | −0.98***         | .04             |
| MP2 fall-rise                   | 0.16             | 0.26             | .73             |
| MP3 rise-fall                   | −0.41            | −1.08***         | .003            |
| SL cresc.-dim. ML               | −0.25            | −0.99***         | .001*           |
| ST acc.-rit.                    | −0.08            | −0.82*           | .09             |
| MT acc.-rit.                    | −0.10            | −0.44            | .20             |

Note: Significant phase differences for each age group are marked by asterisks (*p < .05; **p < .001, following Bonferroni corrections). p values for age comparisons are marked separately (right-hand column).
them to the other pitch-change stimuli in a separate ANOVA (see below).

Following BH correction, significant main effects of musical parameter, $F(2, 204) = 13.97, p < .0001$, and direction, $F(1, 102) = 515.24, p < .0001$, were found. Age was not significant, $F(1, 102) = 1.42$. However, age significantly interacted with both direction, $F(1, 102) = 34.68, p < .0001$, and musical parameter, $F(2, 204) = 20.50, p < .0001$.

To elucidate the musical parameter effect, we calculated for each participant the phase differences in MGI, separately for each musical parameter; Friedman post hoc tests compared these phase differences for each pair of musical parameters. Tempo ($M = .19, SE = .02$) generated significantly larger phase differences than both pitch ($M = .08, SE = .02, p < .001$) and loudness ($M = .09, SE = .02; p < .001$); pitch and loudness did not significantly differ.

For the direction variable, we calculated the means of all increasing (pitch rise, crescendo, accelerando) and decreasing (pitch fall, diminuendo, ritardando) musical changes, and performed a Friedman post hoc test on the differences of these means. Results ($M = .73, SE = .04, p < .0001$) indicate that the overall direction of musical change correspondences with that of bodily movement. For the age X direction interaction, we first examined in each age group, for each movement phase, whether MGI significantly differs from zero (Wilcoxon tests with Holm’s correction). While results in both phases were significant for both age groups ($p < .01$), the average phase difference of the older group is significantly larger than that of the younger group (.92 vs. .49; $p < .0001$), suggesting that older children responded to musical change “direction” more strongly and consistently than younger ones.

For the musical parameter X direction interaction we calculated mean MGI for each phase, and then the phase differences for each of the three musical parameters. A Friedman test compared these phase differences for each pair of parameters. Phase differences for both loudness and tempo proved significantly larger than that for pitch ($p < .0001, p < .001$, respectively); no significant difference between loudness and tempo was found.

The effect of overall pitch contour on MGI. To examine whether the temporal order of pitch directions – rise followed by fall (convex curve) or fall followed by rise (concave curve) – affects movement growth or decay, we performed an ANOVA with repeated measures on data for the five pitch-change stimuli. Phase order (1st, 2nd), and musical change direction (increase or decrease) were within-participant independent variables, and age (5 or 8) — between-participants independent variables. Mean MGI for each phase served as the dependent variable.

Results revealed a significant main effect of direction, $F(1, 102) = 14.03, p < .0005$. Neither order ($F = 1.20$) nor age ($F < 1.00$) presented significant main effects. Importantly, however, the interaction of order and direction was highly significant, $F(1, 102) = 57.21, p < .0001$. This interaction was mediated by age, as a three-way interaction between order, direction, and age, also proved significant, $F(1, 102) = 12.77, p < .001$.

To elucidate the direction X order interaction, Wilcoxon tests examined whether mean MGI for each direction X order combination (rising segment first, rising segment last, falling segment first, falling segment last) significantly differs from 0. Pitch rise was significantly associated with movement growth in convex contours, where rise precedes fall ($M = .35, SE = .04, p < .0001$), but not in concave contours, where fall precedes rise ($M = .02, SE = .04, p = .61$). Comparably, pitch fall was significantly associated with movement decay in convex contours ($M = -.18, SE = .04, p < .0001$), but with movement growth in concave contours ($M = .14, SE = .04, p < .001$). These results may suggest an interaction between two tendencies: the tendency to associate pitch rise and fall, respectively, with movement growth and decay, and a tendency to perform a “convex” movement contour — growth (e.g., bodily ascent or acceleration) followed by decay (e.g., bodily descent or deceleration).

**TASK 2 (VERBAL TASK)**

Musical parameters and movement dimensions (Hypothesis A). As mentioned, participants chose for each stimulus one of three responses for each movement dimension: two antonyms (e.g., ascent, descent) and a neutral “neither” response. To investigate whether participants tend to associate specific movement and musical dimensions, we computed for each participant the frequency of non-neutral responses in each movement dimension; this was done separately for each group of stimuli groups activating a specific musical dimension (pitch, loudness, and tempo). For each movement dimension, we compared the frequencies of non-neutral responses in these three stimuli groups, using Friedman tests (Table 5).

Unlike the results in Task 1, speed was the only movement dimension significantly related to musical parameters, selected more often for tempo change, as compared to loudness or pitch change. Tendencies to associate vertical motion with pitch also emerged, yet did not reach significance.
TABLE 5. Task 2: Mean Proportions and Standard Errors (in Parentheses) of Participants who Chose Non-neutral Responses for Each Movement Dimension in Each Activated Musical Parameter.

<table>
<thead>
<tr>
<th>Movement Dimension</th>
<th>Loudness</th>
<th>Pitch</th>
<th>Tempo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal direction</td>
<td>0.24 (0.10)</td>
<td>0.29 (0.09)</td>
<td>0.31 (0.10)</td>
</tr>
<tr>
<td>Horizontal Shaping</td>
<td>0.56 (0.11)</td>
<td>0.53 (0.10)</td>
<td>0.56 (0.11)</td>
</tr>
<tr>
<td>Sagittal direction</td>
<td>0.60 (0.11)</td>
<td>0.61 (0.10)</td>
<td>0.64 (0.11)</td>
</tr>
<tr>
<td>Speed change</td>
<td>0.71 (0.11)</td>
<td>0.72 (0.09)</td>
<td>0.89 (0.07)</td>
</tr>
<tr>
<td>Vertical direction</td>
<td>0.81 (0.10)</td>
<td>0.84 (0.07)</td>
<td>0.75 (0.01)</td>
</tr>
</tbody>
</table>

Note: Proportions significantly differing for different musical dimensions (p < .0001, Friedman test) are printed in bold typeface.

Directions of change in musical and movement parameters (Hypothesis B). To examine whether the directions of change in musical parameters are significantly associated with those of movement dimensions, we first applied to the data a coding method similar to that used in Task 1, encoding “increasing” motions (ascent, spreading, motion forward, acceleration) as +1, “shrinking” motions (descent, enclosing, motion backwards, deceleration) as −1, and “neither” selections as 0. Then, for each participant, the average rating for phase 1 was subtracted from that of phase 2 in each musical stimulus. Wilcoxon tests were performed to determine whether these rating differences deviate significantly from 0. As Table 6 indicates, a highly significant relationship (retained following Bonferroni correction) emerged between the directions of musical and movement changes in 7 of the 9 segments. Only for horizontal direction (right/left) there was no tendency to deviate from 0 in most segments. Notably, as in Task 1, the relationship between musical and movement directions is disrupted in responses to MP2 and SP2 stimuli, in which pitch first falls and then rises (concave contour).

Musical parameters and overall movement growth. As in Task 1, we examined the movement growth index (MGI), assessing whether growth and decay in musical parameters is associated with overall growth and decay in movement. MGI was calculated as the average directional score (see above) for the movement dimensions, (vertical, sagittal, speed, and horizontal shaping; horizontal direction was excluded). We performed an ANOVA with repeated measures, where musical parameter (pitch, loudness, tempo) and the direction of musical change (increase, decrease) served as independent within-participant measures. MGI scores served as the dependent measure. As in Task 1, data for the two fall-rise pitch stimuli were analyzed separately (see below).

Results, like those of Task 1, present a highly significant main effect for direction, F(1, 57) = 138.94, p < .0001. A post hoc Friedman test indicates a significant relationship between musical increase (mean MGI = .43, SE = .04) and decrease (M = −.38, SE = .04) and movement growth and decay, respectively (p < .0001). ANOVA results also present a significant interaction of musical parameter and direction, F(2, 114) = 5.6, p < .01. To elucidate this interaction, we computed the mean MGI in each direction (increase, decrease) of each musical parameter (pitch, loudness, tempo), and compared in each pair of parameters the increase – decrease difference. Post hoc Friedman tests on these data indicate a significantly larger effect of loudness, as compared to pitch, on movement growth (M = .22, SE = .08, p < .05, Friedman Test).

The effect of overall pitch contour on MGI. As in Task 1, we examined whether the temporal order of pitch directions – rise followed by fall (convex curve) or fall followed by rise (concave curve) affects movement growth or decay, performing an ANOVA with repeated measures on data for the five pitch-change stimuli. Segment order (1st, 2nd) and musical direction (increase or decrease) were within-participant independent variables. Mean MGI served as the dependent variable. As

TABLE 6. Task 2: Mean Phase Differences for Each Movement Dimension in Each Musical Stimulus

<table>
<thead>
<tr>
<th>Movement Dimension</th>
<th>Vertical</th>
<th>Horizontal Shaping</th>
<th>Sagittal</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1 (rise-fall)</td>
<td>1.05*</td>
<td>0.17</td>
<td>0.59*</td>
<td>0.66*</td>
</tr>
<tr>
<td>MP1 (rise-fall)</td>
<td>1.09*</td>
<td>0.12</td>
<td>0.49*</td>
<td>0.63*</td>
</tr>
<tr>
<td>MP3 (rise-fall)</td>
<td>1.25*</td>
<td>0.15</td>
<td>0.59*</td>
<td>0.41*</td>
</tr>
<tr>
<td>SP2 (fall-rise)</td>
<td>−0.17</td>
<td>−0.34*</td>
<td>−0.12</td>
<td>−0.09</td>
</tr>
<tr>
<td>MP2 (fall-rise)</td>
<td>0.14</td>
<td>−0.09*</td>
<td>−0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>SL (cresc-dim)</td>
<td>1.14*</td>
<td>0.17</td>
<td>0.71*</td>
<td>0.64*</td>
</tr>
<tr>
<td>ML (cresc-dim)</td>
<td>1.25*</td>
<td>0.17</td>
<td>0.93*</td>
<td>0.81*</td>
</tr>
<tr>
<td>ST (accel-rit)</td>
<td>1.00*</td>
<td>−0.10</td>
<td>0.59*</td>
<td>0.56*</td>
</tr>
<tr>
<td>MT (accel-rit)</td>
<td>0.49*</td>
<td>0.10</td>
<td>0.66*</td>
<td>0.61*</td>
</tr>
</tbody>
</table>

Note: Results of Wilcoxon tests examining whether these differences significantly deviate from 0 are shown. *p < .05 following Bonferroni correction.
in Task 1, a significant effect of direction, $F(1, 57) = 26.97, p < .001$, and a significant segment order X direction interaction emerged, $F(1, 57) = 42.58, p < .001$. While convex (rise-fall) contours featured a large difference between MGIs for pitch rise ($M = .38, SE = .04$) and fall ($M = -.36, SE = .05$), for concave (fall-rise) contours mean MGIs were similar for both pitch directions ($M = .04, SE = .06; M = .02, SE = .06$). Indeed, the rise-fall differences in convex and concave diverged significantly ($M = .76, SE = .12, p < .0001$, Friedman Test).

**Comparing Movement and Verbal Tasks**

We conducted two ANOVAs with repeated measures on the combined data of the two tasks. Since the younger children (5-year-olds) did not participate in Task 2, we used only data of the older group (8-year-olds).

*Musical parameters and overall movement growth.* To examine the effect of music on overall movement growth and decay, as expressed through both movement and verbal responses, we performed an ANOVA with repeated measures on the pooled data of the two tasks, with task (Task1: movement, Task2: verbal), musical parameter (pitch, loudness, tempo), and direction (increase, decrease in musical parameters) as independent within-participant measures. MGI scores served as the dependent measure. The analysis did not include the two concave (fall-rise) pitch stimuli, analyzed separately (see below).

Results replicated effects and interactions found in the separate analyses of Tasks 1 and 2: main effects of musical parameter, $F(2, 114) = 6.08, p < .005$, and direction, $F(2, 57) = 224.24, p < .0001$, and an interaction of musical parameter and direction, $F(2, 114) = 6.19, p < .005$. In addition, two interactions involving task emerged: task X direction, $F(1, 57) = 55.09, p < .0001$, and a three-way interaction, task X direction X musical parameter, $F(2, 114) = 7.19, p < .001$. Post hoc Friedman analysis of the task X direction interaction indicated that mean direction differences for the verbal task were significantly higher than those for the movement task (mean difference between tasks: .49, $SE = .07, p < .0001$).

*The effect of overall pitch contour on MGI.* As in the separate analyses for Tasks 1 and 2, we examined for the pooled data whether the temporal order of pitch directions – convex (rise-fall) or concave (fall-rise) – affects movement growth or decay, performing an ANOVA with repeated measures on data for the five pitch-change stimuli. Task (Task1: movement, Task2: verbal), segment order (1st, 2nd) within stimulus, and musical direction (increase or decrease) were within-participant independent variables. Mean MGI served as the dependent variable. As in analyses for the separate tasks, a significant effect of direction, $F(1, 57) = 38.90, p < .0005$, and a significant segment order X direction interaction, $F(1, 57) = 52.24, p < .0001$, emerged. Two interactions involving task were also significant: task X direction, $F(1, 57) = 11.99, p < .005$, and task X direction X segment order, $F(1, 57) = 23.99, p < .0005$. A post hoc Friedman test indicates that the segment order X direction interaction (evident in both tasks) is stronger in the verbal task ($M$ [mean difference between tasks] = .51, $SE = .10, p < .0001$).

**General Discussion**

In this section, we first reexamine our hypotheses in light of this study’s results, and then discuss some intriguing findings concerning the associations of pitch and loudness with bodily movement.

**Main Findings**

Hypothesis A, predicting that musical parameters would differentially affect children’s choice of movement dimensions, was strongly corroborated in the movement task (Task 1). Each musical parameter was characterized by a different profile of movement dimensions: Changes in pitch (rise or fall) elicited mostly movement in the vertical plane, changes in musical tempo elicited mostly changes in speed and muscular energy, while changes in loudness emphasized movement in the vertical plane and changes in muscular energy.

Hypothesis B, predicting that “directions” of change in music and movement parameters would correspond, was corroborated for both tasks. In line with results concerning Hypothesis A, the specific correspondences between musical and movement directions differed among musical stimuli and parameters. While rise and fall in pitch corresponded mainly with rise and fall in the vertical plane, respectively, increase and decrease in tempo corresponded with increase and decrease in speed and muscular energy. Changes in loudness had the most versatile effects, eliciting significant correspondences of direction with 4 movement dimensions (vertical, sagittal, speed, and muscular energy). Notably, correspondences between pitch directions and directions in the vertical plane were presented only when pitch rise preceded pitch fall, a finding we further discuss below.

Effects of age. While there was no age effect on the choices of movement dimensions (hypothesis A), age (5 vs. 8 years) did affect the choice of movement directions (hypothesis B), particularly in the vertical plane.
While children of both ages associated pitch and loudness changes with movement in the vertical plane, associations of increase and decrease in pitch and loudness with bodily rise and fall were found for the 8-year-old group only.

Movement vs. verbal tasks. Data suggests considerable similarity of the two response types. In particular, children associate change directions in music and movement similarity in verbal responses (Task 2) and through music-induced bodily movement (Task 1). Notably, the effects of overall pitch contour (convex vs. concave) were also similar in both tasks. These similarities suggest that music-motion correspondences revealed in verbal tasks (here and in previous studies) are not merely artifacts of language (e.g., using spatial metaphors for sound), but may stem from shared mappings of sound and movement activating motor, perceptual, and cognitive mechanisms.

The effect of overall pitch contour: convex vs. concave curves. A noteworthy effect, observed in both tasks, involves responses to two contrasting pitch contours: convex (rising and then falling pitch) and concave (falling and then rising). While both contours tended to elicit movement in the vertical plane, only convex contours were significantly associated with corresponding vertical directions (first ascending, then descending). Comparable patterns are demonstrated (in both tasks) using the generalized movement growth index (MGI), suggesting that the effect of overall pitch contour is not limited to vertical motion responses.

One interpretation of this pattern of responses is that beyond responses to the immediate pitch direction, preference for rise-fall over fall-rise bodily movement might have affected results. In concave contours, this movement tendency would conflict with the tendency to associate rising and falling pitch and movement, annulling both effects. Indeed, a natural tendency of the human body to grow first and then shrink has been suggested by Kestenberg (1967, as cited in Kestenberg Amighi, Loman & Mark Sossin, 1999, p. 111), who argued that this process of alternations between growing and shrinking of body shape (“bipolar shape flow”) is closely related to respiration, as well as to the operation of the heart and other body organs.

Importantly, however, the corresponding (and even stronger) results obtained in the verbal task (Task 2) suggest that the discrepancy between responses to convex and concave contours does not simply stem from a motor tendency. Rather, results may suggest an interaction between a tendency to favor a “convex” (growth followed by decay) shape over its “concave” opposite...
Most of the movement for some qualification so that this not notion, particularly for musical contexts, see Eitan (2013b).

LOUDNESS CHANGE AND BODILY MOVEMENT: ONE-TO-MANY RELATIONSHIPS

As discussed earlier, loudness is experientially associated with distance and force. In this study, however, loudness change also elicited changes in additional motion dimensions, not obviously related to acoustic reality or daily experience: vertical motion and speed change. These findings corroborate earlier results, where multiple spatial mappings for loudness, including mappings of loudness change onto vertical direction and tempo change, were found for both adults (Eitan & Granot, 2006; Eitan et al., 2008, 2012) and children (Eitan & Tubul, 2010).

As Trevarthen (2000) suggests, kinesthetic and cross-modal associations of music may stem from intermodal gestural interaction in infancy and early childhood. Loudness-motion correspondences may demonstrate such gesture-based mapping. In actions such as tapping or clapping, children would perform larger movements either by raising their hands higher or by increasing the opening distance between palms. Indeed, responses to crescendo and diminuendo in our study often comprised of repeated clapping, body patting, and stomping: children repeated a specific sound-producing movement throughout the musical segment, while increasing muscular energy by enlarging motion range in response to a crescendo, and decreasing energy by diminishing motion range in diminuendo. As a result, the hand rise preceding each tap, or the foot rise preceding each stomp, became progressively higher or wider in crescendo, and progressively lower in diminuendo. Similar sound production experiences may also associate loudness and speed, since increased impact velocity would produce louder impact sound.

MUSICAL PARAMETERS, MOTION RESPONSES, AND GENERALIZED MAGNITUDE MAPPINGS

The idea that the processing of different bipolar perceptual dimensions, experienced in terms of relative magnitude, may be underlined by shared mechanisms or representations (e.g., Stevens, 1975) has recently been supported by converging behavioral and neuropsychological evidence (e.g., Cohen Kadosh, Lammertyn, & Izard, 2008; Feigenson, 2007; Gallistell & Gellman, 2000; Walker, Walker, & Francis, 2012). Such notions of “generalized magnitude mapping” (Walsh, 2003) are consistent with developmental research, suggesting that infants’ perception and affective responses are underlined by a-modal dynamic patterns (e.g., “vitality effects”; Stern, 2000).

Beyond effects of sound production experiences, discussed above, one-to-many correspondences of music and movement may be accounted for by such generalized mappings of magnitude. The three auditory parameters used in this study may be organized along a bipolar continuum, in which change in one direction (crescendo, accelerando, pitch rise) is conceived as an increase, and change in the other (diminuendo, ritardando, pitch fall) as a decrease. Most of the movement dimensions examined here may also be conceived in a comparable way: growth and decay in muscular energy, speeding up vs. slowing down, rise vs. fall, opening vs. enclosing, and forward vs. backwards. Our findings that increase and decrease in diverse musical parameters correlate with growth and decay in diverse dimensions of movement, as well as an overall measure of movement growth, the movement growth index, suggest that young children indeed associate dynamic musical patterns with overall dynamic patterns of motion.

Results may thus indicate, beyond the specific analogies between musical and movement dimensions reported here, a general, a-modal tendency to relate the “directions” of change in music and motion. Thus, increase and decrease in a single musical parameter are mapped, respectively, onto increase and decrease in several dimensions of motion, while increase and decrease in a single movement parameter (such as bodily ascent

3 For some qualifications of this notion, particularly for musical contexts, see Eitan (2013b).
or descent) may be expressed via analogous changes in
a number of motion dimensions.

EDUCATIONAL IMPLICATIONS
Methods of elementary music education utilize analogies
to music and movement in diverse ways (e.g.,
Abril, 2011; Cohen, 1997; Seitz, 2005). By investigating
the actual motion reactions of young children listening
to music, this study — while not itself an applied study
in music education — may provide some insights con-
cerning the use of such analogies.

First, the present study suggests that children indeed
use movement dimensions in reaction to musical
changes in a non-arbitrary, structured way, such that
specific music and motion parameters correspond; it
thus empirically supports methods of music education
attempting to utilize such correspondences. Particularly,
our study explores children’s music-induced motion
directly through non-verbal movement tasks, while
controlling for changes in musical parameters. Hence,
results may suggest that synchronized self-motion can
provide young children with insights into musical struc-
ture, surpassing the mediation of language or musical
notation.

The study also suggests that the range of music-
movement correspondences utilized in basic music edu-
cation may be considerably expanded. Results point to
a variety of music-motion correspondences, well
beyond established associations such as those between
tempo and speed or pitch and spatial height. Specifi-
cally, loudness changes were found to affect multiple
dimensions of motion — not only “energy” and dis-
tance change, but vertical direction and speed as well.

However, some of the findings presented here may
also constrain and problematize the use of movement
analogies in early musical education. Such constraints
particularly involve the culturally entrenched analogy of
pitch and spatial height. While an association of pitch
and vertical motion was found for both age groups
examined, correspondences of pitch and vertical direc-
tions were established for the older group only. Further-
more, pitch/height correspondences were affected by
overall pitch contour (concave vs. convex) — only
convex contours elicited such correspondences. Thus,
while children’s expression of loudness changes signif-
ically affected multiple movement dimensions, their
expression of changes in pitch was more limited, con-
strained by both age and overall contour.

Another cautionary point for music education stems
from the one-to-many and many-to-one relationships
our results reveal. Children may express different musical
features through similar movements (e.g., both cres-
cendo and pitch rise expressed by bodily rise), or the
same musical feature using different movements (e.g.,
a crescendo may be expressed through bodily rise, for-
ward motion, or acceleration of motion). Using precon-
ceived one-to-one analogies — e.g., requiring the
children to express melodic contour through ascending
and descending hand gestures — may not only bound
children’s creativity, but limit their perception of musical
processes. Allowing the child to reflect her own
musical experience through free movement responses
(as in the current research) may enable both teachers
and researchers to better understand the development
of children’s perception of music, letting children
express their musical experience unbiased by adults’
preconceived notions.

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