Musical Parameters and Children's Movement Responses

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ABSTRACT

The effects of dynamic musical parameters (e.g., pitch rise/fall, crescendo/diminuendo) on aspects of bodily motion, such as spatial directions or speed, have recently been investigated empirically, as Eitan & Granot (2006) examined, using participants' verbal reports, how such relationships affect motion imagery. Here we examine the effects of musical parameters on actual bodily movement. 106 children (46 aged 5, 60 aged 8) heard 9 short musical stimuli (4 synthetically constructed, 5 excerpts from classical repertory) involving bi-directional changes in pitch, loudness and tempo. Participants were asked to move to each excerpt in an "appropriate way." Movement responses were videotaped, and their spatio-kinetic features analyzed independently by 3 referees (watching with sound muted), applying bi-polar categories based on Laban Movement Analysis, including spatial directions, speed and muscular energy. Results indicate that different musical parameters activate different motion dimensions: pitch changes are mainly associated with vertical motion, loudness change with both muscular energy and vertical motion, and tempo change with speed and muscular energy. The direction of change in each musical parameter was significantly associated with the direction of change in motion dimensions, e.g., increase in loudness is associated with increasing speed, increase in muscular energy, and spatial rise. While there was no age effect on the choices of movement dimensions, age did affect the choice of directions within these dimensions, particularly regarding the movement in vertical plane. This suggests a two-stage process, in which overall relationships of auditory and movement dimensions develop early, while associations of auditory and motion directions develop later.

I. BACKGROUND

Few would argue with the notion that music associates strongly and meaningfully with the spatial and kinetic domains, and specifically with human motion. The relationship of music and motion has been discussed by music scholars for centuries, and approached from a variety of directions, regarded variously as metaphorical (Lakoff & Johnson, 1980; Johnson & Larson, 2003; Zbikowski, 1997), semiotic (Lidov, 1987; Hatten, 2005), perceptual (Clarke, 2001, 2005), physiological and neuro-physiological (Todd, 1995, 1999; Zatorre, Chen & Penhune, 2007).

This wealth of research notwithstanding, a central question regarding the relationships of music and human motion has not yet received sufficient empirical attention: how are changes in specific musical (and auditory) parameters, such as increase or decrease in loudness, pitch and tempo, related to human motion parameters, such as its directions (up or down, forward or backward, right or left) or speed? Perceptual studies have indeed suggested that auditory parameters such as pitch height or loudness, and spatio-visual features such as size and height, interact in perception in a fairly consistent manner. Thus, **aspects of timing** are strongly related to **speed** (Friberg & Sundberg, 1999); **loudness** is associated with **distance** and **energy**, as its acoustic properties would suggest (Blauert, 1997); and **pitch height** is related to **spatial height** (Walker, 1987; Lipscomb & Kim, 2004; Widmann et al., 2004), in line with the Western tradition of notation and musical discourse (Cox, 1999, Scruton, 1997), and also to **laterality**, such that higher pitch was found to be related to right-side position (Mudd, 1963; Stevens & Arieh, 2005). However, these studies involved simple, mostly static auditory stimuli; little research has investigated in a systematic way how auditory parameters affect human motion in a dynamic, musical or music-like context.

One of the few studies examining systematically how listeners associate musical and motional parameters is Eitan & Granot (2006), which investigated how changes in musical parameters (e.g., rise or fall in pitch, crescendo or diminuendo, accelerando or ritardando) affect adult listeners' visuo-spatial imagery. In that study, 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 the cognitive reality of established music-motion associations, such as pitch and height, Eitan and Granot's results portrait a complex, yet systematic web of relationships among musical and motional dimensions. Thus, most musical parameters significantly affect several dimensions of motion imagery; for instance, pitch direction affected imagined motion along all three spatial axes (not only verticality), as well as the velocity and “energy” of the imagined motion. A surprising finding of the study was that musical-spatial analogies are often asymmetrical, as a musical change in one direction evokes a significantly stronger spatial analogy than its opposite. Such asymmetries include even the entrenched association of pitch change and spatial verticality, which applies mostly to pitch falls, but only weakly to rises.

Eitan & Tubul (2007; see also Tubul, 2008) applied the motion imagery paradigm to 6 and 11 years old children. Comparison of results in both children groups with those of non-musician adults in Eitan & Granot (2006) suggests that several music-motion associations (dynamics and distance, pitch and verticality, IOI and speed) are shared by adults and children of both ages; some of the asymmetries reported for adults were also found for children. However, noteworthy differences between children and adults emerged as well. Unlike adults, children of both age groups related sound and motion primarily through changes in loudness, mapped onto all facets of motion. Loudness was associated not only with distance, but with verticality (more strongly than pitch), speed (as strongly as tempo), and energy (most strongly of all dimensions). In contrast, pitch contour and tempo evoked fewer and weaker spatio-kinetic associations in children, as compared to adults.

The present study continues previous investigations of Eitan's group, but differs from them in two important ways. First, while our previous experiments explored music-motion associations through *verbal* responses, the effects of musical parameters on listeners' *actual movements* have not been systematically examined. Here, we seek to extend the exploration of music-motion associations through observation of actual bodily movement responses to music, allowing listeners to respond directly to the music itself, bypassing the mediation of verbal response. Such approach is particularly pertinent for children, as child development theories acknowledge that "the very young child communicates through movement long before his vocabulary develops" (Zimmerman, 1981, p.50). Thus, children as young as age three reveal an understanding of musical tempo and dynamics, and express it in their locomotive movements, i.e. running and walking (Moog, 1968/1976; Sims, 1988; McDonald & Simons, 1989; Metz, 1988). Energetic movements are a response to loud sounds, while movements showing low energy levels are typically a response to softer sounds (Gorali-Turel, 1997; Gluschankof, 2005). 4th grade subjects in a study by Andrews & Diehl (1967) evidenced changes in their overt movements in response to short musical excerpts which contained a change in duration or loudness. Importantly, however, changes in pitch were not reflected in the children's physical movement responses.

The possibility of understanding children's music perception through analyses of bodily movement responses to music is implied by diverse approaches to auditory and music perception. It is found in the paradigm of embodied music cognition (Leman, 2008), by which the human body is seen as a natural mediator between subjective experience and physical reality, as well in ecological approaches to music perception and cognition, emphasizing the role of bodily interaction with the environment (Clarke, 2005). The link between music perception and movement is also supported by studies of the role of mirror neurons, indicating that the auditory modality can access the motor system (Kohler et al., 2002).

Beside the investigation of actual movement responses, a second major distinction of this study involves the stimuli we presently use. Our previous studies of music and motion used systematically-constructed music-like stimuli, enabling controlled manipulation of musical parameters, though at the expense of ecological validity. The present study uses both controlled stimuli and segments from actual Western music compositions of the 18th to 20th centuries, featuring musical changes (e.g., crescendo and diminuendo, pitch rise and fall) analogous to those in the controlled stimuli. We thus aim at a greater ecological validity, gauging listeners' movement responses to "real" music, and comparing these responses to their responses to controlled (though musically impoverished) stimuli.

II. AIMS AND HYPOTHESES

The present study investigates whether music parameters are significantly associated with specific motion dimensions, by examining children's motion to musical stimuli in which changes in specific parameters are salient. Based on previous results (particularly Eitan & Granot, 2006; Eitan & Tubul, 2007) we hypothesize that:

A. the distribution of movement categories and movement directions would significantly differ for musical stimuli activating different musical parameters, such that

1. Verticality would be the prominent movement dimension for stimuli presenting pitch changes.
2. Speed change would be the prominent movement dimension for stimuli presenting tempo changes.
3. Stimuli presenting loudness changes would be associated with changes in multiple motion dimensions.

B. The directions of change in musical parameters would be associated with those in movement parameters, such that 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, and musical abatements – with shrinking movements (downward, backward, enclosing) and with movements decreasing in speed and muscular energy.

C. The effects hypothesized above (hypotheses A, B) would be stronger for 8 years old children, as compared to 5 years olds. Effects concerning pitch change would be significant only for the older children.

D. Effects would be similar for synthetic stimuli and actual music.

III. METHOD

A. Participants

106 elementary school children participated in the experiment. They included 60 children aged 8 (25 females, 35 males), 3rd grade students in an elementary school in the Tel Aviv area (Israel); 29 of these children (15 females, 14 males) have studied and played a musical instrument for at least 1 year. A second group included 46 children, aged 5 (23 females, 23 males), pupils in a preschool in the Tel Aviv area (Israel). Participants were mostly from a middle socio-economic background. None have had known hearing, learning or motor deficiencies.

B. Stimuli

The stimuli comprised of 9 musical excerpts involving bidirectional changes in pitch, loudness and tempo. Four of the stimuli were synthetically constructed, while 5 were taken from commercial recordings of standard classical repertory.

Four *synthetic stimuli* were created with Sibelius 1.2 software, using its "grand piano" sound, and recorded onto a CD. Each stimulus presented an "increase" and a "decrease" in a specific musical parameter (pitch rise–pitch fall, crescendo–diminuendo, accelerando-ritardando). Two stimuli consisted of a chromatic pitch change, rising from C4 to F#5 and falling back (SP1) or vice verse - falling from F#5 to C4 and rising back (SP2). All sounds in the above stimuli were equidurational (330 ms), except for the terminal notes of the ascending and descending phases, which were elongated. A third stimulus (SL) consisted of a series of repeated tones (C4), rising and falling in loudness from approximately 60 to 80 dB-A and back. Again, all sounds were equidurational (330 ms), except for the terminal notes of the crescendo and diminuendo phases, which were elongated. The fourth synthetic stimulus (ST) consisted of repeated tones (C4) decreasing and then increasing in duration in the range of 1200 to 300 ms.

Five *musical excerpts* from Western compositions were used, ranging in duration from 14 to 20 seconds. Each excerpt demonstrated a salient, continuous bi-directional 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 E-flat for clarinet and Orchestra (m. 75 ff), 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's Hungarian Dance no. 7 arranged for violin and piano, mm. 1-8, presented changes in tempo (accelerando followed by ritardando). All 5 segments were excerpted from commercial music CDs. Table 1 summarizes features of 9 stimuli.

Table 1. Features of the musical stimuli

Stimulus code	Parameter	Directions	Source
SP1	Pitch	rise-fall	Synthetic
SP2	Pitch	fall-rise	Synthetic
MP1	Pitch	rise-fall	Excerpt
MP2	Pitch	fall-rise	Excerpt
MP3	Pitch	rise-fall	Excerpt
SL	Loudness	crescendo-diminuendo	Synthetic
ML	Loudness	crescendo-diminuendo	Excerpt
ST	Tempo	accelerando-ritardando	Synthetic
MT	Tempo	accelerando-ritardando	Excerpt

C. Experimental procedure

After an introductory group meeting between the researcher and the children, each subject participated in 2 individual sessions. 5 stimuli, in random order, were presented in each session. The experiment took place in the school's music room and the activities area of the kindergarten, environments familiar to the children.

Participants were instructed as follows:

> "You will hear a short bit of music. 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 before children moved to it. Children were allowed to perform the movement again if they wished. 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.

Table 2. An example of referees' data coding form

Referee: Participant no.: Name: Track:

		Phase 1	Phase 2
	Movement start time (ss:ms):	02:400	10:000
Vertical	up		xx*
	down	x**	
	up/down***		
Horizontal (Direction)	right		xx
	left		
	right/left		
Horizontal (Shape)	spreading		
	enclosing		
	spreading/enclosing		
Sagittal	forward		
	backward		
	forward/backward		
Muscular Energy	increasing		
	decreasing		
	increasing/decreasing	x	
Speed	accelerating		
	decelerating		
	accelerating/decelerating		
another change between phases			

***xx**: The category/direction is present during the entire phase
****x**: The category/direction is present during a part of the phase
*****up/down, right/left, etc.**: Dimension (e.g., vertical motion) is clearly present, but without dominance of one direction over the other (e.g., constantly moving up and down).

D. 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, 1974; Moore & Yamamoto, 1988). After 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 6 bi-polar categories: [1]

- *Directions*:
  (1) Vertical (up/down)
  (2) Horizontal (left/right)
  (3) Sagittal (forward/backward).
- *Shape:* (4) spreading/enclosing
- (5) Muscular energy (increasing/decreasing)
- (6) speed (accelerating/decelerating).

Three referees, graduate students trained in LMA, watched (in random order) each participant's videotaped movements without sound, and independently encoded these movements

[1] . LMA employs a distinct vocabulary for Shape qualities in the 3 spatial dimensions: spreading/enclosing for the horizontal dimension (which we use), as well as rising/sinking and advancing/retreating, for the vertical and sagittal dimensions, respectively. 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.

according to the above categories. Referees were ignorant of the aims and hypotheses of the experiment. They were asked to observe whether there is a salient visible change in the child's movement and record (using Adobe Première Pro CS3 video editing software, version 3.2.0**)** the point in time in which this change occurred. They then marked on a form (See Table 2) all the movement categories and directions present before (phase 1) and after (phase 2) the change point.

IV. RESULTS

A. Musical parameters and movement dimensions.

To examine whether the motion dimensions activated by participants are associated with specific musical parameters, we compared the frequency of the 6 motion dimensions activated in different musical stimuli. Table 3 presents the number and percentage of participants who activated each of the 6 movement dimensions for each stimulus (musical segment), with the most frequent movement dimension for each segment highlighted. As the table indicates, verticality was consistently the most frequent movement dimension for stimuli activating pitch change, verticality and muscular energy were associated most frequently with stimuli activating loudness change, and speed was the most frequent movement dimension for stimuli activating tempo change.

To examine whether participants' choices of motion dimensions are indeed significantly related to the musical parameters activated, we calculated, for each participant, the average use of each movement dimension for each group of musical stimuli activating a the same parameter (e.g., the 5 stimuli MP1, MP2, MP3, SP1 and SP2, all activating pitch change), and performed a Friedman test for each movement dimension, comparing participants' average scores for the three musical parameters used (pitch, loudness, and tempo). The analyses indicate that the frequency of use of all movement dimensions but one is very significantly affected by the musical parameters activated. Thus, motion in the vertical dimension is applied more often in relation to pitch changes, as compared to loudness and tempo changes ($p<.00001$). Changes in movement's speed are applied mostly, as expected, by tempo changes, and least by pitch changes ($p<.00001$). Changes in muscular energy ($p<.00001$) are affected by tempo (most frequently), as well as by loudness, and least by pitch. Horizontal direction (right-left) is applied less frequently in relation to loudness changes, as compared to pitch or tempo changes ($p<.0001$). Sagittal motion (forward-backwards) is applied more in reaction to tempo changes than to either pitch or loudness ($p<.001$). Only the movement dimension of shape (spreading/enclosing) was not differentially affected by musical parameters.

Table 3. Number and percentage of participants applying each movement dimension in each of the musical segments.

***Abbreviations for musical stimuli*: 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. *Abbreviations for movement dimensions:* Vrt=Verticality; HD=Horizontal Direction (right/left); Shp=Shape (spreading/enclosing); Sag=Sagittal (forward/ backward); ME=Muscular Energy; Spd=Speed.**

The most frequent dimensions for each stimulus (yellow) and for each musical parameter (red) are highlighted.

	Vrt	HD	Shp	Sag	ME	Spd
SP1 rise-fall	70 *66.0%*	24 *22.6%*	6 *5.7%*	27 *25.5%*	12 *11.3%*	15 *14.2%*
SP2 fall-rise	67 *63.2%*	31 *29.2%*	11 *10.4%*	28 *25.5%*	10 *9.4%*	16 *15.1%*
MP1 rise-fall	78 *73.6%*	43 *40.6%*	26 *24.5%*	28 *26.4%*	50 *47.1%*	19 *17.9%*
MP2 fall-rise	87 *82.1%*	44 *41.5%*	27 *25.4%*	31 *29.2%*	54 *50.9%*	36 *34.0%*
MP3 rise-fall	90 *84.9%*	51 *48.1%*	34 *32.1%*	34 *32.1%*	80 *75.5%*	24 *22.6%*
Pitch Average	**77.6 *73.2%***	**38.6 *36.4%***	**20.8 *19.6%***	**29.6 *27.9%***	**41.2 *38.9%***	**22 *20.8%***
SL	61 *57.5%*	*22 20.7%*	*21 19.8%*	*33 31.1%*	*40 37.8%*	*29 27.3%*
ML	54 *50.9%*	20 *18.9%*	19 *18%*	35 *33.0%*	90 *84.9%*	43 *40.6%*
Loudness Average	**57.5 *54.2%***	**21 *19.8%***	**20 *18.9%***	**34 *32.1%***	***65 61.3%***	**36 *34.0%***
ST	46 *43.4%*	29 *27.4%*	21 *19.8%*	43 *40.6%*	94 *88.7%*	95 *89.6%*
MT	52 *49.1%*	57 *53.8%*	26 *24.5%*	53 *50.0%*	64 *60.4%*	90 *84.9%*
Tempo Average	**49 *46.2%***	**43 *40.6%***	**23.5 *22.1%***	**48 *45.3%***	**79 *74.5%***	**92.5 *87.3%***

Table 4. Summary results of Chi-square analyses comparing the distribution of movement dimensions for each pair of stimuli. * p<.05; **p<.001 ***p<.0001 (following Bonferroni corrections). For stimuli codes see caption to Table 1 above.

	SP2	MP1	MP2	MP3	SL	ML	ST	MT
SP1	-	*	*	***	*	***	***	***
SP2		-	-	***	*	***	***	***
MP1			-	-	-	***	***	***
MP2				-	-	***	***	***
MP3					-	**	***	***
SL						-	***	***
ML							-	-
ST								-

Complementarily, a series of chi-square analyses compared the distribution of movement dimensions in each pair of musical stimuli. Table 4 summarizes the results of these analyses, following Bonferroni corrections for multiple tests. As the table indicates, the distributions of movement dimensions in stimuli activating pitch (CP, MP) differed very significantly from those of stimuli activating tempo (CT, MT) in all 10 pairwise comparisons ($p<.0001$ for all comparisons, following Bonferroni corrections), and from stimuli activating loudness (CL, ML) in 7 of 10 comparisons. Stimuli activating loudness and tempo differed in 2 of 4 comparisons. In contrast, most distributions of movement dimensions in stimuli activating the same musical parameters were not significantly different. There was no significant difference between either tempo or loudness stimuli pairs; 6 of the 10 comparisons between pitch-change stimuli did not reveal a significant difference in the distribution of movement dimensions as well. Note that the 4 significantly different distributions between stimuli pairs involved comparisons of synthetic and "real" music in the pitch-change excerpts.

Demographic variables: age, gender, and musical training. A series of chi-square analysis compared, for each stimulus, the distribution of movement dimensions in different age groups (5 vs. 8 years old), between males and females, and (for 8 years old only) between children who have played an instrument and those who have not. Except for one comparison (5 vs. 8 years old children, stimulus MP2, horizontal direction, p<.005), no significant difference was found concerning any of the demographic variables.

B. Relationships between the directions of musical and movement changes

As Table 2 exemplified, referees marked, for each movement dimension, which "direction" of that dimension (e.g., ascending or descending motion, increase or decrease in speed), if any, was salient in each movement phase. Movement phases were concurrent with phases of musical activity, featuring a specific "direction" in a musical parameter (e.g., pitch rise or fall, crescendo or diminuendo, accelerando or ritardando). Hence, this information may suggest whether directions of change in music and movements correlate (e.g., whether pitch rise is associated with bodily ascent, rather than descent).

To examine whether the directions of change in musical parameters are significantly associated with the change directions of movement dimensions we first coded each movement dimension, except lateral motion, as either +1 (ascent, spreading, motion forward, increase in muscular energy, acceleration of speed) or -1 (descent, enclosing, motion backwards, decrease in muscular energy, deceleration of speed); ratings of different referees (for each participant/phase/movement dimension) were averaged. Then, the average rating for phase 1 (for each participant, in each movement dimension) was subtracted from that of phase 2. Wilcoxon tests determined, for each movement dimension in each stimulus, whether these rating differences deviate significantly from 0, significant deviations from 0 indicating that the poles of a musical parameter tend to associate with the poles of a movement dimension. For instance, Table 5 demonstrates that the mean difference between phases of stimulus SP1 (a synthetic stimulus comprising pitch rise followed by pitch fall) for the verticality (Vert.) dimension is -0.812, which is highly significant (the maximum difference possible in our coding is 2). This indicates that the 2nd (pitch descent) phase of this stimulus is more strongly related to descending movements than the 1st (pitch ascent) phase.

Table 5 demonstrates highly significant relationships between the "directions" of change in pitch, loudness and tempo and those in three movement dimensions – verticality, speed, and muscular energy. **Pitch** ascent and descent are associated with bodily ascent and descent, respectively. Importantly, this relationship is observed only when pitch rise precedes pitch fall (stimuli SP1, MP1, MP3). When the order is reversed (fall followed by rise. Stimuli SP2, MP2), no significant difference between phases with regard to the direction of vertical movement is observed. Note that these order-related differences do not affect the use of the verticality dimension of movement per se – as Table 3 has shown, this dimension is prominent in all pitch stimuli – but the *directional* association of music and motion. In the actual music excerpts (MP), pitch ascent and descent were, in addition to bodily ascent and descent, also associated with acceleration and deceleration and with increase and decrease in muscular energy, respectively, probably since these excerpts also featured some activity in musical parameters other than pitch. **Loudness** increase and decrease are strongly associated with the directions of change in several movement dimensions – pitch ascent and descent, speed acceleration and deceleration, and increase and decrease in muscular energy, respectively. There is also a tendency to associate crescendo, more than diminuendo, with forward motion. Acceleration and deceleration of musical **tempo** are associated with acceleration and deceleration of movement speed, and with increase and decrease in muscular energy, but not with spatial ascent and descent.

Table 5. Mean differences, in 4 movement dimensions (verticality, speed, sagittal, and muscular energy), between scores for movement phases 1 and 2 of each musical stimulus, and p values of Wilcoxon tests examining whether these differences significantly differ from 0. Results remaining significant following Bonferroni correction are highlighted.

		Vert.	Speed	Sagittal	Energy
SP1 rise-fall	p (Wilcox.)	***0.000***	0.478	0.958	0.407
	mean dif.	***-0.812***	-0.15	0.000	-0.250
SP2 fall-rise	p (Wilcox.)	0.795	1.000	0.246	0.608
	mean dif.	-0.052	0.031	-0.298	-0.150
MP1 rise-fall	p (Wilcox.)	***0.000***	0.564	0.843	0.882
	mean dif.	***-0.793***	-0.132	-0.042	0.017
MP2 fall-rise	p (Wilcox.)	0.030	***0.000***	0.892	***0.000***
	mean dif.	0.217	***-0.68***	0.020	***-0.927***
MP3 rise-fall	p (Wilcox.)	***0.000***	***0.000***	0.582	***0.000***
	mean dif.	***-0.830***	***-0.77***	0.091	***-0.901***
SL cresc.-dim	p (Wilcox.)	***0.000***	***0.000***	0.059	***0.000***
	mean dif.	***-0.661***	***-0.90***	-0.379	***-1.000***
ML cresc.-dim	p (Wilcox.)	***0.001***	***0.000***	0.002	***0.000***
	mean dif.	***-0.519***	***-1.24***	-0.500	***-1.585***
ST accel.-rit.	p (Wilcox.)	0.015	***0.000***	0.307	***0.000***
	mean dif.	-0.257	***-1.75***	-0.074	***-1.495***
MT accel.-rit.	p (Wilcox.)	0.007	***0.000***	0.008	***0.000***
	mean dif.	-0.301	***-1.21***	-0.148	***-1.135***

Demographic variables: age, gender, and musical training. We calculated phase differences (as described above) separately for each age group (5 vs. 8 years old), for males and females, and (among 8 years olds) for children playing and instrument vs. those who do not. While in most cases these demographic variables do not emerge as significant, age differences elicit interesting differences with regard to vertical movement dimension (see Table 6). While phase differences for verticality were significant for 8 years old in 3 of the pitch-change stimuli (those presenting pitch ascent followed by descent) and in both loudness stimuli, there was no comparable significant differences for 5 year olds. This suggests 8 years old children consistently relate pitch ascent and descent, as well as crescendo and diminuendo, respectively, to bodily ascent and descent, while 5 years olds do not. This age-related difference is particularly noteworthy given that the frequency of use of the vertical movement dimension per se did not significantly vary with age: while 5 years old children, just like 8 years olds, associated motion in the vertical dimension with pitch change, only the older children consistently associated the *directions* of change in these movement and musical dimensions.

Table 6. Mean differences between scores for the 1st and 2nd phase of each stimulus for the vertical movement dimension, calculated for 5 and 8 years olds. Significant phase differences for each age group are marked by asterisks (* p<.05; ***p<.0001, following Bonferroni corrections).

	Mean phase dif. (5)	Mean phase dif. (8)	p (Wilcoxon) age comparison
SP1 (rise-fall)	-0.374	-1.122***	0.009
SP2 (fall-rise)	0.247	-0.230	0.179
MP1 (rise-fall)	-0.477	-0.980***	0.038
MP2 (fall-rise)	0.162	0.255	0.729
MP3 (rise-fall)	-0.406	-1.076***	0.003
SL(cresc.-dim.)	-0.253	-0.985***	0.001*
ML(cresc.-dim.)	-0.076	-0.823*	0.009
ST (acc.-rit.)	-0.100	-0.444	0.201
MT (acc.-rit.)	-0.127	-0.419	0.127

Synthetic stimuli vs. musical excerpts. To examine whether synthetic and "real" music stimuli differ in their effect on the direction of movement, we calculated for each participant the mean score in each phase of each stimulus, for each movement dimension. Scores of the pitch-change stimuli were averaged for the 2 synthetic stimuli (SP1, SP2) and for the 3 musical excerpts (MP1, MP2, MP3). Using paired Wilcoxon tests, we compared, for each of the three musical parameters of pitch, loudness and tempo, the mean scores for synthetic and "real" music. Significant differences between synthetic and "real" stimuli were found only for the ascending phases of the pitch-change stimuli (p<.01, following Bonferroni corrections), with regard to the movement dimensions of verticality, speed and muscular energy. In all these three dimensions, mean scores were significantly higher for the musical excerpts, indicating that these excerpts elicited stronger ascending motion, faster movement, and increased muscular energy, as compared to the synthetic stimuli. Descending pitch-change phases did not present any significant differences between synthetic and actual music excerpts. No significant differences were found between synthetic and "real" stimuli presenting loudness and tempo changes, except a difference in the horizontal dimension (p<.001) between the accelerating phases of synthetic and "real" stimuli presenting tempo change.

V. CONCLUSIONS

A. Main findings

In this study, we investigated whether children's movement to music reveals consistent relationships between movement dimensions (the three spatial directions, changes in muscular energy, speed and shape) and changes in the musical parameters of pitch ("ascent" and "descent"), loudness (crescendo and diminuendo), and tempo (accelerando or ritardando).

We raised four hypotheses (see "Aims and Hypotheses" section above). **Hypothesis A**, which suggested that musical parameters would differentially affect children's choice of movement dimensions, was strongly corroborated (see Results, sub-section A, and Tables 3, 4). The use of 5 of the 6 movement dimensions examined (motion in the vertical, sagittal, and horizontal planes, as well as changes in muscular energy and speed) was significantly affected by the musical parameters activated, such that each musical parameter was characterized by a different profile of movement dimensions. Changes in pitch ("ascent" or "descent") elicited mostly movement in the vertical plane, and relatively little activity in other dimensions; changes in musical tempo elicited mostly changes in speed and muscular energy, and also activated the sagittal (forward-backward) dimension more frequently than pitch or loudness; changes in loudness emphasized movement in the vertical plane as well as changes in muscular energy, and tended to attenuate (relatively to other musical parameters) movement in the horizontal plane,.

Hypothesis B suggested associations between increase and decrease (or intensification and abatement) in musical and movement dimensions, respectively, such that increasing or intensifying musical changes -- crescendi, accelerandi, or pitch ascents -- would be associated with increasing or intensifying movement dimensions (rise, forward motion, opening movement, and increases in muscular energy and speed), and musical decreases or abatements (diminuendi, ritardandi, pitch descents) would be associated with decreasing or abating movements. This hypothesis was also clearly corroborated: highly significant correspondences between directions of change in music and movement were revealed for 8 of the 9 musical stimuli, while no stimulus presented any discrepancies between the directions of change in musical and movement dimensions (see Results, sub-section B, and Table 5). 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, and changes in loudness presented a one-to-many relationship, eliciting significant correspondences between increase and decrease in loudness and those in 4 movement dimensions (vertical, sagittal, speed and muscular energy).

Importantly, correspondences between pitch directions and directions in the vertical plane were presented only when pitch rise preceded pitch fall. When a fall-rise pitch pattern is presented, no such correspondence can be discerned (though movement in the vertical plane is as dominant in fall-rise stimuli as it is in rise-fall). We shall discuss the significance of this finding below.

Hypothesis C suggested that the music-movement relationships proposed in hypotheses A and B would be stronger for older children (8 years olds, as compared to 5 years olds). This hypothesis was only partially corroborated: while there was no age effect on the choices of movement dimensions (hypothesis A), age did affect the choice of movement *directions* (hypothesis B), particularly concerning movements in the vertical place. Thus, while children of both ages similarly associated pitch direction (as well as loudness change) with movement in the vertical plane, the association of pitch rise and fall (as well as loudness increase and decrease), with bodily rise and fall, respectively, was found only for the older group.

Hypothesis D suggested that the effects of changes in musical parameters on children's movement responses would be similar for synthetic music stimuli and actual musical excerpts. This hypothesis was partly corroborated. Notably, only the effect of pitch change on movement, rather than those of changes in loudness or tempo, was influenced by the actual/synthetic variable. When pitch change was the predominant musical parameter, "real" music activated several movement dimensions (verticality, speed, and muscular energy) more robustly than synthetic stimuli. These differences may be attributed to the interference of musical parameters other than pitch in the "real" musical excerpts, or to a generally stronger impact of these ecological excerpts, as compared to the impoverished synthetic stimuli. The fact that such effects were only discerned for pitch-change stimuli suggests that the motional effects of this dimension are more susceptible to interference of other musical parameters than those of changes in loudness or tempo.

B. Movement responses versus verbal responses: comparison with previous studies

Two previous studies by our group have examined the relationships of dynamic musical parameters and movement dimensions through verbal responses (reports of music-induced motion imagery): Eitan & Granot (2006), examining adult participants, and Eitan & Tubul (2007), examining 6 and 11 years old children (as compared to 5 and 8 in the present experiment). Here, we'll briefly compare results of the latter experiment with the present results.

Music-motion analogies suggested by children's verbal responses in Eitan and Tubul's study are strikingly similar to those presented, in this study, through actual bodily movement. This similarity suggests that children's associations of musical and motion dimensions are not mere verbal conventions, but rather reflect specific auditory-motor mappings, present at a relatively early age. In both experiments, loudness change elicited the strongest and most diverse relationship with movement, affecting movement in the vertical and sagittal planes (or distance, its equivalent in the verbal imagery experiment), as well as changes in energy and speed. Pitch direction, in both experiments, affected vertical motion (and in the verbal experiment, energy as well), while tempo affected speed and energy.

In their emphasis on loudness, rather than pitch, results in both Eitan & Tubul's study and the present one differ from those of Eitan & Granot (2006), which examined adult participants, in which pitch direction, rather than loudness change, elicited highly significant responses in most dimensions. Indeed, for children the tendency to relate crescendo and diminuendo, respectively, with bodily rise and fall was sometimes stronger (in both verbal and actual movement experiments) than that exhibited for pitch rise and fall. These results suggest that for children loudness change elicits more consistent and robust movement responses than either tempo change or pitch direction, while consistent associations of pitch direction with the dimensions and directions of movement develop relatively late.

In both the present experiment and the verbal experiments, musical "increase" (pitch ascent, crescendo, accelerando) tended to correspond with growing or intensifying movements (spatial rise, speeding, increasing muscular energy, forward motion), and musical "decrease" with shrinking or abating movements, often creating one-to-many music-motion relationships (see also item C below).

Both verbal and movement tasks presented some discrepancies between children of different ages, concerning the association of change directions in musical parameters (pitch rise and fall, increase and decrease in loudness and tempo) with those in movement dimensions. In the verbal experiment, older (11 y.o) children significantly related loudness changes to the dimensions of speed, distance and verticality, while younger (6 y.o) children did not. In the present experiment, the most conspicuous age-related differences concern the relationships of both pitch and loudness to the vertical plane of motion (pitch rise, crescendo→upward motion; pitch fall, diminuendo→ downward motion), which were more consistent for older children (see Table 6).

Note, however, that these two experiments examined children of different ages (5 and 8 in the present experiment, 6 and 11 in Eitan and Tubul's). The above differences may thus be related to task (verbal vs. movement), the different age groups in the two experiments, or both. To compare verbal and movement responses more directly, the present study included a verbal task analogous to the movement tasks, using the same stimuli and examining the same participants. This task is not reported here, since results are currently (May 2009) being analyzed; we hope to present the comparison of verbal and movement tasks at our ESCOM 2009 presentation.

C. Growth and decay in music and motion

The dynamic 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 may be similarly conceived: increase vs. decrease in muscular energy, speeding up vs. slowing down, rise vs. fall, opening vs. enclosing, and forward vs. backwards.

Our results indicate, beyond specific analogies between musical and movement dimensions, a tendency to relate musical and motional increase and decrease, sometime through mapping of a single pair of dimensions (pitch direction and verticality), but often through a one-to-many relationship, in which increase and decrease in a musical parameter are mapped into increase and decrease in several dimensions of motion (e.g., crescendo and diminuendo, respectively, are related to rise and fall, speeding up and slowing down, increase and decrease in muscular energy, and more or less forward motion).

These findings, and similar results in verbal tasks (Eitan & Granot, 2006; Eitan & Tubul, 2007), support the notion that cross-dimensional mappings involving auditory perception, and in particular analogies between music and movement, are based in part on general bi-polar "quantitative" analogies, mapping "more" and "less", or "increase" and "decrease" in different domains (see Eitan, 2007; Eitan & Granot, 2007; Marks, 2004; Stevens, 1975, for surveys of relevant empirical research). Results also lend further empirical support to a longstanding tradition in music theory and analysis, proposing that intensity contours, expressed analogously in different parameters, significantly contribute to shaping musical structure and expression (e.g., Berry, 1976; Hopkins, 1990; Kurth, 1991; Rink, 1999).

Movement responses to rise-fall and fall-rise stimuli. Of particular relevance to notions of growth and decay in music and motion are results for two of our stimuli (SP2, MP2), in which pitch fall preceded pitch rise, as compared to results in the other pitch-change stimuli (SP1, MP1, MP3), in which pitch rise preceded pitch fall. As noted, stimuli presenting pitch rises followed by falls tended to engender comparable rise-fall movements. Stimuli presenting pitch falls followed by rises, however, were *not* associated with fall-rise movement. Though the latter stimuli engendered as much movement in the vertical plane as pitch rise-pitch fall stimuli, the directions of this movement (up or down in the vertical plane) were not associated with the directions of pitch change ("up" or "down" in pitch).

This discrepancy suggests that, beyond the impact of the musical stimuli, a tendency towards a bipolar movement shape in which rise precedes fall might have affected results. Thus, incongruence of this movement tendency with the effect of pitch rise and fall have possibly annulled effects, resulting in vertical movements whose directions did not significantly associated with the directions of pitch change.

A natural tendency of the human body to grow first and then shrink has been suggested by Kestenberg (1967, cited in Kestenberg, Amighi et al. 1999), who argued that this process of alternations between growing and shrinking of body shape ("**bipolar shape flow")** is closely related to respiration. The body grows when air is inhaled and shrinks when air is exhaled. Similar processes of growing and shrinking form the basis for the functioning of the heart and other body organs (Kestenberg Amighi et al., 1999, p.111). Music scholars (e.g., Agawu, 1982; Zuckerkandl, 1956; Cohen, 1971; Cohen & Granot, 1995; Cohen & Wagner, 2000), have also suggested that a "convex curve" shape (Cohen 1971) serves as a natural process in music, expressed in multiple parameters. The above results tentatively suggest that such bipolar shapes affect both movement and music and their interaction. Obviously, much further experimentation is needed to support this hypothesis. For a start, repeating our tasks (as well as comparable verbal tasks) with "reversed" stimuli in loudness and tempo (diminuendo followed by crescendo, ritardando followed by accelerando) may indicate whether the interaction suggested here for pitch also affects the relationships of movement with other musical parameters.

D. The development of the pitch-verticality association: a two-stage process?

While there was no age effect on the choices of movement dimensions, age did affect the choice of motion *directions* within movement dimensions. Thus, children of both ages similarly associated pitch and verticality, but only older children associated pitch rise and fall, respectively, as well as crescendo and diminuendo, with bodily rise and fall.

There is a general agreement amongst researchers that pitch discrimination improves in later childhood, but there is still a controversy about the levels of discriminations that are attained at different ages. In studies investigating the ability of 6 years old children to detect tonal direction in short tonal patterns , very few of the subjects were able to verbalize the concepts of "up" and "down" (Hair, 1977; Zimmerman & Sechrest, 1970). In Eitan & Tubul (2007), children aged 11, but not 6 years olds, related crescendo and diminuendo to spatial rise and fall (though, surprisingly, there was no age difference concerning the relationship of pitch and verticality) These results may reflect a more general developmental trait, recurring in Piagetian studies of cognitive abilities: young children vary widely in their use and interpretation of terms like "more" and "less", and "higher" and "lower". Another factor that might add to this difficulty could be that metaphors like "up" and "down" for pitch confuse children descriptions because they don't reflect any acoustic feature of the stimuli, but rather stem from more abstract analogies of quantity and intensity level.

This study allowed children to respond directly to the music itself, bypassing verbal mediation. This notwithstanding, 5 years old did not demonstrate a statistically significant match between pitch rise and ascending movement, or pitch fall and descending movement, as the 8 years olds did. Yet, importantly, 5 years olds did encode changes in pitch by moving in the vertical dimension, just like 8 years olds. This suggests a graded developmental process, in which overall relationships of auditory and movement dimensions develop earlier than the associations of "directions" within each pair of bipolar auditory-motion dimensions. The present study, of course, gives this hypothesis only limited support, and much further investigation into this intriguing developmental issue is called for.

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