Proceedings of the 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music, July 23-28, 2012, Thessaloniki, Greece
Cambouropoulos E., Tsougras C., Mavromatis P., Pastiadis K. (Editors)

Music Moves Us: Beat-Related Musical Features Influence Regularity of Music-Induced Movement

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ABSTRACT

Listening to music makes us move in various ways. Several factors can affect the characteristics of these movements, including individual factors, musical features, or perceived emotional content of music. Music is based on regular and repetitive temporal patterns that give rise to a percept of pulse. From these basic metrical structures more complex temporal structures emerge, such as rhythm. It has been suggested that certain rhythmic features can induce movement in humans. Rhythmic structures vary in their degree of complexity and regularity, and one could expect that this variation influences movement patterns – for instance, when moving to rhythmically more complex music, the movements may also be more irregular. To investigating this relationship, sixty participants were presented with 30 musical stimuli representing different genres of popular music. All stimuli were 30 seconds long, non-vocal, and differed in their rhythmic complexity. Optical motion capture was used to record participants' movements. Two movement features were extracted from the data: Spatial Regularity and Temporal Regularity. Additionally, 12 beat-related musical features were extracted from the music stimuli. A subsequent correlational analysis revealed that beat-related musical features influenced the regularity of music-induced movement. In particular, a clear pulse and high percussiveness resulted in small spatial variation of participants' movements, whereas an unclear pulse and low percussiveness led to greater spatial variation of their movements. Additionally, temporal regularity was positively correlated to flux in the low frequencies (e.g., kick drum, bass guitar) and pulse clarity, suggesting that strong rhythmic components and a clear pulse encourage temporal regularity.

I. INTRODUCTION

Music makes us move. When we listen to music, we often move our body along with the music in a spontaneous fashion. Keller and Rieger (2009), for example, stated that simply listening to music can induce movement, and in a self-report study conducted by Lesaffre et al. (2008), most participants reported moving when listening to music. In general, people tend to move to music in an organized way, for example by mimicking instrumentalists' gestures or rhythmically synchronizing with the pulse of the music by tapping their foot, nodding their head, or moving their whole body in various manners (Leman & Godøy, 2010). Moreover, Leman (2007) suggests, "Spontaneous movements [to music] may be closely related to predictions of local bursts of energy in the musical audio stream, in particular to the beat and the rhythm patterns". Such utilization of the body is the core concept of embodied cognition, which claims that the body is involved in or even required for cognitive processes (e.g., Lakoff & Johnson, 1980/1999, or Varela, Thompson, & Rosch, 1991). Human cognition is thus highly influenced by the interaction between mind/brain, sensorimotor capabilities, body, and environment. Following this, we can approach music (or musical involvement) by linking our perception of it to our body movement (Leman, 2007). One could postulate that our bodily movements reflect, imitate, help to parse, or support the understanding of the content of music. Leman suggests that corporeal articulations could be influenced by three (co-existing) components or concepts: "Synchronization", "Embodied Attuning", and "Empathy", which differ in the degree of musical involvement and the kind of action-perception couplings. "Synchronization" forms the fundamental component, as synchronizing to a beat is easy and spontaneous. The beat serves as the basic musical element, from which more complex structures emerge. Leman furthermore suggests the term 'inductive resonance', which refers to more active control, imitation, and prediction of movements to display beat-related features in the music (the opposite of passively tapping to a beat) as the first step in engaging with the music. The second component, "Embodied Attuning", concerns the linkage of body movement to musical features more complex than the basic beat, such as melody, harmony, rhythm, tonality, or timbre. Following this idea, movement could be used to reflect, imitate, and navigate within the musical structure in order to understand it. Finally, "Empathy" is seen as the component that links musical features to expressivity and emotions. In other words, the listener feels and identifies with the emotions expressed in the music and imitates and reflects them by using body movement.

A large body of research has been conducted on listeners' abilities to synchronize to musical (or beat) stimuli through finger or foot tapping (for a review see Repp, 2005). However, less research has been conducted on music-induced whole-body movement. Zentner and Eerola (2010), nevertheless, investigated infants' ability to bodily synchronize with musical stimuli, finding that infants showed more rhythmic movement to music and metrical stimuli than to speech suggesting a predisposition for rhythmic movement to music and other metrical regular sounds. Eerola, Luck, and Toiviainen (2006) studied toddlers' corporeal synchronization to music, finding three main periodic movement types being at times synchronized with pulse of the music. Toiviainen, Luck, and Thompson (2010) investigated how music-induced movement exhibited pulsations on different metrical levels, and showed that eigenmovements of different body parts were synchronized with different metric levels of the stimulus. Luck, Saarikallio, Burger, Thompson, and Toiviainen (2010) studied the influence of individual factors such as personality traits and preference on musically induced movements of laypersons' dancing, finding several relationships between personality traits and movement characteristics. Furthermore, music-intrinsic features, such as beat strength and pulse clarity (Burger, Thompson, Saarikallio, Luck, & Toiviainen, 2010; Van Dyck et al., 2010) and emotional characteristics in music (Burger, Saarikallio, Luck, Thompson, & Toiviainen, 2012) have been found to influence music-induced movement in general.

Rhythmic music is based on beats, which can be physically characterized as distinct energy bursts in time. If such beats occur as regular and repetitive temporal patterns, they give rise to a percept of pulse. Beat and pulse structures can be regarded as the basic metrical structure in music from which more complex temporal structures, such as rhythm, emerge. It has been suggested that certain rhythmic features, such as event density or beat salience, have an effect on inducing movement in humans (Madison, Gouyon, Ullén, & Hörnström, 2011). Rhythmic structures can vary in their degree of regularity, which, combined with the notion of movement as imitating and reflecting musical structure, could lead to the assumption that the degree of irregularity of beat and rhythmic structures in music has an influence on the regularity of the resulting movement patterns; for instance, when moving to rhythmically more irregular music, the movements may also be more irregular.

This study investigates relationships between beat- and rhythm-related musical features, such as pulse clarity, spectral fluctuation, and note attack characteristics on one hand, and movement features characterizing regularity on the other. Two movement features were selected that relate to different aspects of regularity. *Spatial Regularity* is based on intrinsic dimensionality – in particular, the higher the dimensionality, the more irregular the movement. *Temporal Regularity* relates to regular/periodic movement on different metrical levels. These two features were computationally extracted from movement data acquired using a high-resolution optical motion tracking system. We predicted that these features would be influenced by the beat and rhythmic structure of the music. In particular, we expected that a clear pulse and strong beat would encourage participants to move in a regular fashion.

II. METHOD

A. Participants

A total of 60 participants took part in the experiment (43 females; average age = 24; SD of age = 3.3). Six participants had received formal music education, while four participants had a formal background in dance tuition. Participation was rewarded with a movie ticket.

B. Stimuli

Participants were presented with 30 randomly ordered musical stimuli of different popular music genres including Techno, Pop, Rock, Latin, Funk, and Jazz. All stimuli were 30 seconds long, non-vocal, and in 4/4 time, but differed in their rhythmic complexity, pulse clarity, and tempo.

C. Apparatus

Participants' movements were recorded using an eight-camera optical motion capture system (Qualisys ProReflex) tracking, at a frame rate of 120 Hz, the three-dimensional positions of 28 reflective markers attached to each participant. The locations of the markers can be seen in Figure 1a and can be described as follows (L = left, R = right, F = front, B = back): 1: LF head; 2: RF head; 3: LB head; 4: RB head; 5: L shoulder; 6: R shoulder; 7: sternum; 8: spine (T5); 9: LF hip; 10: RF hip; 11: LB hip; 12: RB hip; 13: L elbow; 14: R elbow; 15: L wrist/radius; 16: L wrist/ulna; 17: R wrist/radius; 18: R wrist/ulna; 19: L middle finger; 20: R middle finger; 21: L knee; 22: R knee; 23: L ankle; 24: R ankle; 25: L heel; 26: R heel; 27: L big toe; 28: R big toe. The musical stimuli were played back via a pair of Genelec 8030A loudspeakers using a Max/MSP patch running on an Apple computer.

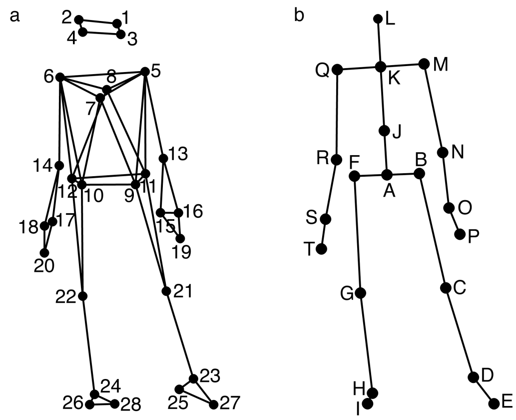

Figure 1. (a) Anterior view of the location of the markers attached to the participants' bodies; (b) Anterior view of the locations of the secondary markers/joints used in the analysis.

D. Procedure

Participants were recorded individually and were asked to move to the presented stimuli in a way that felt natural. Additionally, they were encouraged to dance if they wanted to, but were requested to remain in the center of the capture space indicated by a 115 x 200 cm carpet.

E. Movement Feature Extraction

In order to extract various kinematic features, the MATLAB Motion Capture (MoCap) Toolbox (Toiviainen & Burger, 2011) was used to first trim the data to the duration of each stimulus and, following this, to derive a set of 20 secondary markers – subsequently referred to as joints – from the original 28 markers. The locations of these 20 joints are depicted in Figure 1b. The locations of joints C, D, E, G, H, I, M, N, P, Q, R, and T are identical to the locations of one of the original markers, while the locations of the remaining joints were obtained by averaging the locations of two or more markers. Subsequently, the data were transformed into a local coordinate system, in which joint A was located at the origin, and segment BF had zero azimuth. Two regularity-related movement features, Spatial Regularity and Temporal Regularity, were then extracted from these data.

1) Spatial Regularity. This feature was based on the intrinsic dimensionality of the movement according to the Maximum Likelihood Estimator (Levina & Bickel, 2004). The intrinsic dimensionality of a high-dimensional data set describes how many variables are needed to represent the set without significant information loss. Thus, the more intrinsic dimensions needed to explain the movement, the more irregular and complex the movement is. A graphical description based on Principal Component Analysis to obtain the signal's dimensions is displayed in Figure 2.

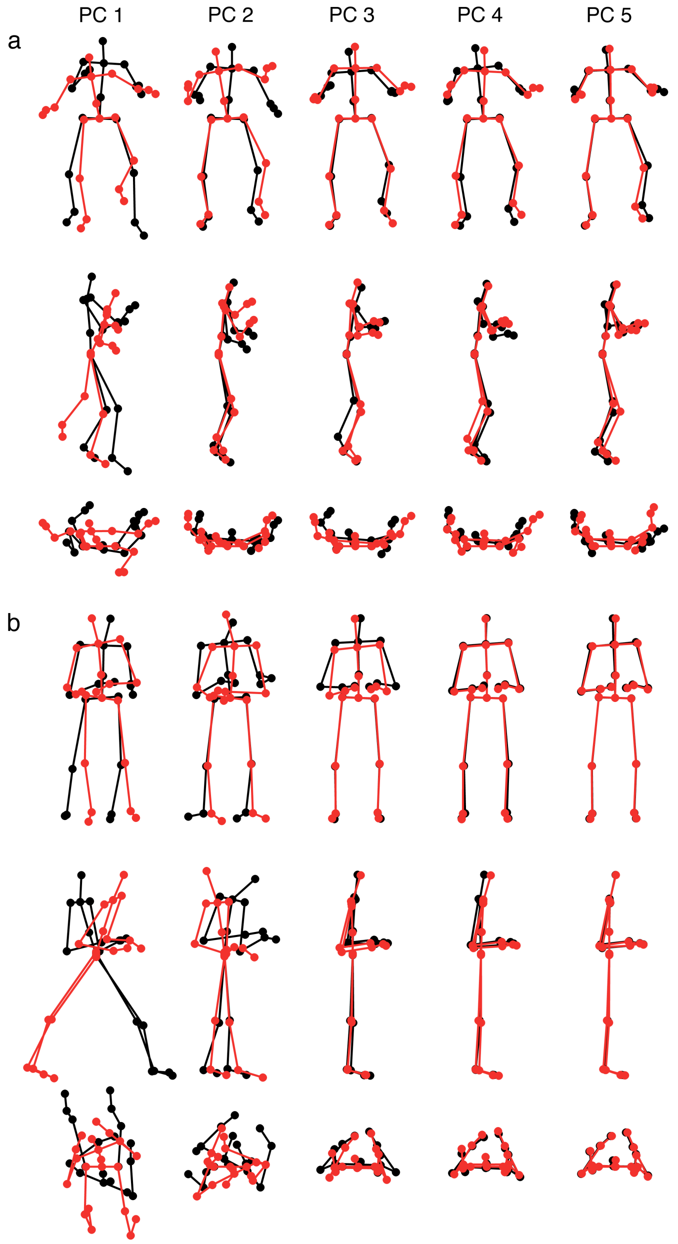

Figure 2. Intrinsic dimensionality of movement illustrated by displaying the projections of the first five Principal Components of (a) high-dimensional movement and (b) low-dimensional movement. The extreme deflections of the projections are plotted from the front, from the side, and from the top. (a) High intrinsic dimensionality, manifested as significant movement in all five PC projections; (b) Low intrinsic dimensionality, manifested as significant movement in only the lower PC projections.

2) Temporal Regularity. This feature relates to the presence of regular movement on different metrical levels simultaneously, calculated by filtering the position data (all joints) using 80 bandpass filters in a frequency range between 0 and 4 Hz with each filter having a bandwidth of 0.1 Hz and an overlap of 0.05 Hz with the adjacent filters. For each of the 80 channels, the temporal average of kinetic energy was estimated using body-segment modeling (see Toiviainen et al., 2010) and then merged into a spectral representation. Following this, each spectrum was autocorrelated, and the vertical differences of the autocorrelation function summed. The higher this sum, the more regular movement there was on different metrical levels. The procedure is depicted in Figure 3.

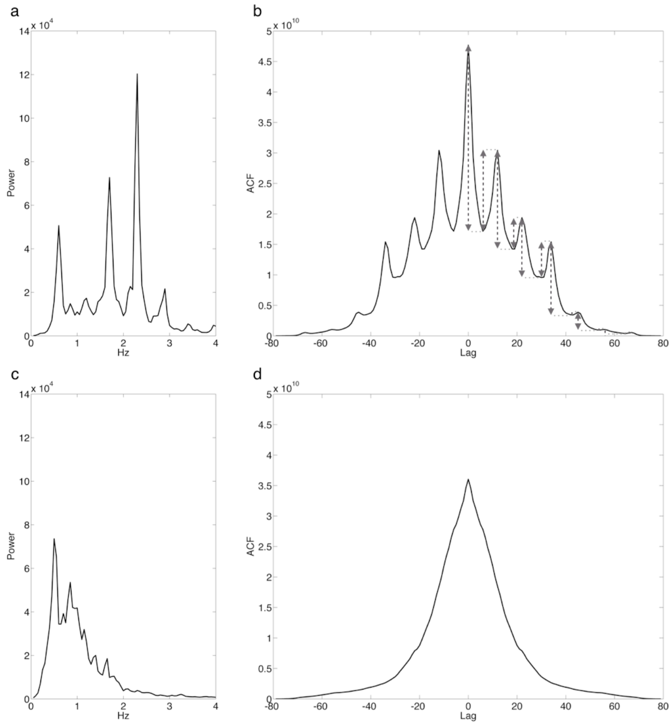

Figure 3. High vs. low metrical regularity: High metrical regularity indicated by several high, clear, and regular peaks in both the kinetic energy spectrum (a) and the corresponding autocorrelation function (b). The peaks correspond to the metrical levels existing in the underlying stimuli. In contrast, low metrical regularity indicated by an irregular kinetic energy spectrum (c) and a flat autocorrelation spectrum (d).

Subsequently, the values of each variable were averaged across participants for each stimulus presentation. This yielded a total of two statistical movement features for each of the 30 stimuli.

F. Musical Feature Extraction

In addition to the movement features, 12 beat- and rhythm-related features were extracted from the music stimuli using the MATLAB MIRToolbox (Lartillot & Toiviainen, 2007), resulting in one averaged value per stimulus:

1) Pulse Clarity. This feature indicates the strength of rhythmic periodicities and pulses in the signal, estimated by the relative Shannon entropy of the fluctuation spectrum (Pampalk, Rauber, & Merkl, 2002). Entropy is a measure of the degree of peakiness of the spectrum.

2) Percussiveness. This feature is defined as the average value of the slope of the amplitude envelope at the note onsets. The steeper the slope, the more percussive the sound.

3) Sub-band Fluxes (10 features). These features indicate the extend to which the spectrum changes over time. The stimulus is divided into 10 frequency bands, each band containing one octave in the range of 0 to 22050 Hz. The Sub-Band Flux is then calculated for each of these ten bands separately by calculating the average of the Euclidean distances of the spectra for each two consecutive frames of the signal (Alluri & Toiviainen, 2010). Two spectrograms of sub-band no. 2 (50-100 Hz) are displayed in Figure 4 to show the difference between high and low sub-band flux.

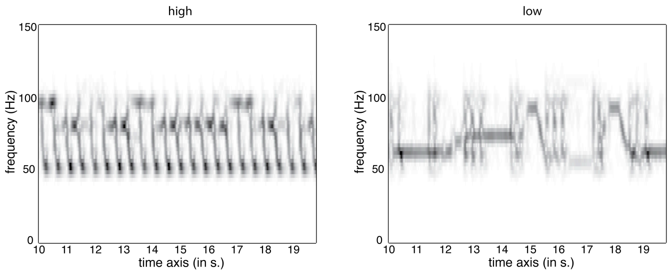

Figure 4. Sub-band spectrograms (sec. 10 to 20) of the two stimuli with the highest (left) and lowest (right) value for Spectral Flux of Sub-Band No. 2. The darker the area the more energy is present in the stimulus at that time and frequency. Thus, the left stimulus contains more temporal change in the frequency range between 50 and 100 Hz than the right one.

III. RESULTS

In order to investigate influences of beat-related musical features on regularity-related aspects of music-induced movement, we correlated the two movement features with the 12 musical features. The results are displayed in Table 1.

Table 1: Results of the correlation between the regularity-related movement features and the beat-related musical features.

	Spatial Reg.	Temporal Reg.
Pulse Clarity	**.50****	**.57*****
Percussiveness	**.48****	**.50****
Sub-band No. 1 Flux	.01	**.63*****
Sub-band No. 2 Flux	.08	**.72*****
Sub-band No. 3 Flux	.11	**.64*****
Sub-band No. 4 Flux	.10	.37
Sub-band No. 5 Flux	.02	.35
Sub-band No. 6 Flux	.14	.38
Sub-band No. 7 Flux	.06	.24
Sub-band No. 8 Flux	.09	.39
Sub-band No. 9 Flux	.39	**.47****
Sub-band No. 10 Flux	.18	-.01

**$p < .01$, ***$p < .001$

We found that both Regularity features correlated significantly with Pulse Clarity (Spatial Regularity: $r(30)=.50$, $p<.01$, Temporal Regularity: $r(30)=.57$, $p<.001$) and Percussiveness (Spatial Regularity: $r(30)=.48$, $p<.01$, Temporal Regularity: $r(30)=.50$, $p<.01$). Temporal Regularity also correlated significantly with Spectral Flux of the first three sub-bands (0-50 Hz: $r(30)=.63$, $p<.001$ / 50-100 Hz: $r(30)=.72$, $p<.001$ / 100-200 Hz: $r(30)=.64$, $p<.001$) and the 9th sub-band (6400-12800 Hz) ($r(30)=.47$, $p<.01$). Thus, high pulse clarity and percussiveness in the music were related to movements of low intrinsic dimensionality suggesting that there is small spatial variation indicating low-dimensional movement. Stimuli with unclear pulse and low percussiveness, on the other hand, were connected to greater spatial variation indicating higher dimensional movement. Furthermore, high pulse clarity, strong spectral flux in the frequency ranges below 200 Hz and between 6400 and 12800 Hz, and high percussiveness resulted in temporally regular movements suggesting that participants moved periodically in relation to several metrical levels if the spectral flux of the low and high frequency bands, percussiveness, and pulse clarity were high. If these musical features were weakly present in the stimuli, participants moved less periodically to different metrical levels.

IV. DISCUSSION

The results of this study suggest that beat-related musical features influence the regularity of music-induced movement. Changes in both Pulse Clarity and Percussiveness were found to affect both Spatial and Temporal Regularity. Clear pulse and high percussiveness resulted in movements of low intrinsic dimensionality, suggesting that there is little spatial variation in the movements. Thus, low-dimensional movements were used to reflect the characteristics of the music. Stimuli with an unclear pulse and low percussiveness on the other hand seemed to encourage people to use more spatial variation and thus high-dimensional movement. The participants might have used such high-dimensional movements to parse and understand the unclear beat of the music, as if they were searching for the beat.

Additionally, Temporal Regularity was related to Flux in the low and high frequencies, Percussiveness, and Pulse Clarity, suggesting that participants moved periodically in relation to several metrical levels if the stimuli contained such musical characteristics. If these musical features were weakly present, participants moved less periodically in relation to different metrical levels. Strong flux of the low frequency bands was mostly related to presence of the kick drum and bass guitar, whereas flux of the high frequency band was mostly associated with the presence of hi-hat or cymbals, since such instruments are dominant in the respective frequency regions. Thus, our results suggest that a strong and regularly fluctuating rhythm section encouraged the participants to move in a temporally regular fashion with motions periodic to different metrical levels, whereas more complex, irregular rhythmic structures resulted in temporally less regular movement.

The results could provide support for notions of embodied music cognition (Leman, 2007). Both regularity features can be related to actively controlling, imitating, and predicting the music regarding beat-related features (‘inductive resonance’) and for movement-based ‘navigation’ within the music as a behavior rather used with higher-level musical structures, such as rhythmic components (‘embodied attuning’). Following the concept of ‘inductive resonance’, if the music has a clearly perceivable and strong beat, it might have a “resonating” effect that results in temporally and spatially regular movements, imitating the clear beat structure. However, if the music has a less clear beat structure, the more fuzzy/blurry resonance of such music rather induces temporally and spatially irregular movement, as if the participants were searching for the beat. Moreover, the results could serve as an example for the concept of ‘embodied attuning’ – movement-based navigation through the rhythmic structures of the stimuli. It could be suggested that participants attune to strong spectral fluctuation in low and high frequency ranges by imitating it with temporally regular movement periodic to different metrical levels, whereas participants attune to less salient rhythmic structures with temporally less regular movement not being periodic to the different metrical levels. Participants might have used such movements to navigate through the music and to parse and understand the rhythmic/musical structure better.

V. CONCLUSION

This study offers insights into how beat-related musical features influence regularity aspects of music-induced movement. Two regularity features, Temporal and Spatial Regularity, were found to correlate significantly with pulse clarity, percussiveness, and spectral flux of low and high frequency ranges. The results can be linked to the framework of embodied music cognition, as both regularity features can be related to actively controlling, imitating, and predicting the beat- and rhythm-related features in music, and for movement-based parsing and understanding of such structures.

Our aim was to carry out an ecological study, as far as this was possible with an optical motion capture system and a laboratory situation. To this end, we chose real music stimuli (pre-existing pop songs), accepting that they were less controlled, very diverse, and more difficult to analyze, as computational analysis of complex stimuli is not yet as sufficiently developed as for simpler, i.e., monophonic, stimuli. However, this approach made it possible to present the participants with music that they were potentially familiar with, and that is played in dance clubs. One could assume that this kind of music would make them move more, and do so in a more natural fashion than more artificial stimuli.

Future analysis approaches arise from the results of this study that will give more detailed insights into temporal behavior in music-induced movement. Such approaches will cover rhythm, periodicity, and synchronization related aspects, such as synchronization to different metrical levels, as well as analyses of the body parts that exhibit periodic movements on different metrical levels.

Moreover, future work could include perceptual tests to evaluate and validate both movement and musical features. Perceptual experiments could be conducted, in which participants are asked to rate the movements presented as point-light videos regarding regularity aspects, for example the conveyance of periodicity and beat.

ACKNOWLEDGMENT

We thank Mikko Leimu for help and technical assistance during the motion capture data collection. This study was funded by the Academy of Finland (projects 118616, 125710, 136358).

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