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Links between Embodiment and Perceived Brightness in Orchestral Music

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Abstract

We present the initial findings of an empirical study investigating links between embodiment and the perception of brightness in music. We ask if the embodied experience of musical contour – as expansion and contraction, brightening and darkening – can be observed when individuals move expressively to music. In a pilot study, five adult individuals expressed their perception of brightness by moving to 2 tonal orchestral excerpts – one by Maurice Ravel depicting a sunrise, and another by Arnold Schoenberg depicting a sunset. Participants' movements were recorded using an optical motion capture system. A novel movement feature measuring bodily expansion and contraction was correlated with acoustic features computed from the musical excerpts. Generally, interpretive motions were closely related to acoustic features. We consider the preliminary findings within the context of kinaesthesia and its possible relation to embodied responses to music.

Introduction

For centuries, composers of Western orchestral music have created luminous depictions so compelling that they can be spontaneously experienced by listeners as if music has become light (Touizrar, 2021). For example, the opening sequence in Stanley Kubrick's film 2001: A Space Odyssey, set to the 'sunrise' of composer Richard Strauss' prelude to *Also Sprach Zarathustra*, vividly captures the resonance between multimodal stimulus and affective response in a familiar iconic intermedial statement. However, depictions of 'sonic luminosity' have received limited attention from musicologists who, rather importantly, have not adequately addressed the obvious and perplexing question: how can music be heard as depicting light? We might be tempted to explain the phenomenon simply as a species of auditory synaesthesia (Cytowic, 2002). After all, the music conjures analogies to color (Tarasti, 2001). Indeed, the sensation of auditory brightness is familiar to listeners of orchestral music, and timbre is often characterized in terms of brightness (Wallmark, 2019), a characteristic of sound that has been closely scrutinized by perceptual scientists (Saitis & Siedenburg, 2020). Although no previous work links perceived brightness to the perception and bodily sensation of movement, recent advances in motion-capture technology allow for greater insight into the ways embodied experiences of music can manifest as motion – a feature of experience that can be both *perceived* and *felt* in terms of kinaesthesia (sensory experience derived from bodily tension or movement) and expressed as *action* (Popova & Rączaszek-Leonard, 2020).

Embodied music cognition is a framework that views body movement and gestures as fundamental to understanding how music is perceived by a listener (Leman et al., 2018). Recent work in musicology underscores the importance of embodied cognition, including the relationship between musical gestures and conceptions of shape (Godøy, 2019). The embodied framework has fueled studies examining rhythmic entrainment (Kozak, 2019) and intersubjectivity in group performance (Himberg & Thompson, 2011), the embodiment of metrical hierarchies (Toiviainen et al., 2010), and relationships between musical structure and expressive bodily gestures during a performance (Thompson & Luck, 2012). An embodiment has also been linked, at least provisionally, with synaesthesia as both synthesize sensory data across modalities to form an integrated experience (Briscoe, 2019).

Associations between music and music-induced movement are often investigated by computing movement features derived from motion capture data and comparing them to acoustic features derived from audio signals. Much of the extant research focuses on sensorimotor synchronization, aiming to uncover relationships between body movement and metrical hierarchy or other rhythmic structures present within an audio signal (Toiviainen & Carlson, 2022; Toiviainen et al., 2010). These studies report that a typical dancer can synchronize to complex metrical hierarchies, and through movement and gestures, embody rhythmic characteristics across musical genres.

A greater challenge presents itself when we aim to study correspondences between corporeal behavior and musical meaning or signification. Such correspondences likely exceed rhythm on its own, especially in cases of higher-order metaphors or programmatic ideas that take shape over longer periods of time (e.g., gradual changes in spectral characteristics that help to convey ideas of brightening and darkening). One proprioceptive characteristic of the human body that has been observed to have a strong correspondence with higher-order responses to music, such as the perception of emotion, is the expansion and contraction of the body (Camurri et al., 2003; Glowinski et al., 2011).

Expanding on previous work, this project focuses on kinaesthetic relationships with programmatic music, or put another way, expressed musical relationships with seemingly metaphorical concepts the composer wishes to conjure. For the current study, we investigated how musical signification might be parsed through corporeal reactions to orchestral works that employ auditory brightness as a formal compositional strategy to evoke changes in light (e.g., a sunrise or sunset).

Aims

Our paper presents the initial findings of an empirical study investigating the links between embodiment and the sensation of luminosity in music. We ask if the embodied experience of musical contour – as expansion and contraction, brightening and darkening – can be observed when individuals move spontaneously to music. The analysis quantifies relationships between the dynamic postural changes of dancers and acoustic features derived from programmatic orchestral music that purports to depict either a sunrise or a sunset.

Methods

Participants. In a pilot study, 5 adult individuals (convenience sample; 3 females, 2 males; median age = 33) were invited to move freely and expressively to music evoking changes in brightness. Four of the 5 had studied music formally at the university and/or conservatory level. The fifth participant was not a trained musician, although did have extensive dance and aerobics training.

Musical stimulus. Two orchestral music excerpts were selected for the tasks. These excerpts had been previously studied for their evocation of light (Touizrar, 2020) – a tonal orchestral piece by Maurice Ravel (*Daphnis et Chloé, Prelude to Part 3: Lever du jour*) depicting a sunrise, and a tonal orchestral piece by Arnold Schoenberg (*Gurre-Lieder, Pt. 1: Orchestervorspiel*) depicting a sunset.

Pre-task procedure. The data collection consisted of 2 tasks. The first was a training aimed at acclimatizing the participants to the setting and to the music. Participants manipulated a hand-held device secured to both ends of a table with a rubber resistance band normally used for exercise. In a seated position and while listening to the orchestral pieces, participants provided a continuous rating of perceived brightness by moving the device towards their bodies to indicate low brightness, and away from their bodies to indicate high brightness. The movement of the device was tracked using motion capture (see below). We do not report the results of the pre-task here. However, preliminary analyses show that the device's movements were related to the music's variation in brightness and amplitude.

Main task procedure. The participants' movements were captured using a Qualisys motion capture system consisting of 12 infrared cameras. Twenty-eight reflective markers were attached to the major joints of the participants' bodies. The recordings were carried out individually. The participants were asked to move freely while listening to the 2 orchestral pieces. The instructions were: *As you listen, please indicate your sense of changing brightness by moving your body freely. Match the level of perceived brightness using your whole body. Try to at every moment use your body to interpret and express the contour of brightness-darkness that you hear in the music. How you interpret increased brightness and darkness is up to you. You may react to the music with tense or loose movements and use as much space as you wish. As before, there is no standard definition for what constitutes bright or dark, it is up to you to decide.*

Motion capture data pre-processing. The Qualisys system recorded the markers' three-dimensional positions at a rate of 120 Hz. Pre-processing was carried out using MATLAB and the Motion Capture Toolbox (Toiviainen & Burger, 2013). The initial 28 marker set was reduced to 20, eliminating some redundant markers or creating new synthetic markers located at the midpoint between 2 original markers. This marker reduction process approximates a similar method employed by Burger et al. (2013).

Movement feature. The sum of all distances among markers was used to accurately quantify postural expansion and contraction (Mendoza, 2023). This Expansion/Contraction feature measure quantifies the extent to which the markers are spread in space. It was preferred over measures previously implemented: the sum of distances from every marker to the centroid (Dahl & Visi, 2018; Fenza et al., 2005), the area of the minimum bounding rectangle (Burger & Toiviainen, 2013; Camurri et al., 2003), and the convex hull (Ajili et al., 2019; Hachimura et al., 2005; Hartmann et al., 2022). It must be noted that to be used with marker-based motion capture, the minimum rectangle needs to be expanded to 3 dimensions (i.e., a cuboid). Figure 1 and Table 1 show a comparison between these measures using markers projected onto a plane. Only the sum of all distances correctly represents the postural expansion and contraction.

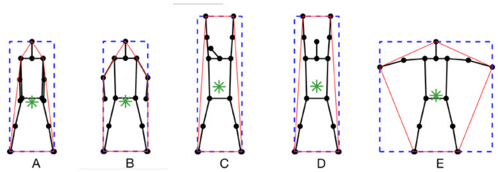

Figure 1. Example postures ordered from less to more expanded (more to less contracted), left to right. The centroid is indicated with a green asterisk, the minimum bounding rectangle is shown with a blue segmented line, and the convex hull with a red solid line.

Table 1. Rescaled measurements of the examples in Figure 1.

	A	B	C	D	E
Sum of all distances	1	1.2	1.74	1.75	2
Sum of distances to centroid	1	1.05	1.97	2	1.57
Bounding rectangle	1	1	1.15	1.15	2
Convex hull	1	1.17	1.34	1.34	2

Acoustic features. The acoustic features were selected for their presumed association with musical characteristics participants might attend to when hearing the pieces: root mean square (for perceived loudness), spectral centroid (for perceived brightness), spectral flux (for perceived timbral changes), and zero-cross (for perceived noisiness). All acoustic features were calculated using the MIRToolbox in MATLAB (Lartillot & Toiviainen, 2007). To achieve time-varying curves of equal frames to the motion capture data, the calculations were carried out using frame decomposition.

Results

Individual Differences

We first looked at the amount of movement produced while listening to the orchestral excerpts. Figure 2 plots the variation in movement across each participant by summing 3 movement quantity features: 1) the global movement, which is the summed displacement of all markers combined, and the 2) feet and 3) hand movements, which are derived by calculating the amount of movement (expressed as metres per second) in relation to the body's hip centrum. The figure also demonstrates that individuals moved in similar amounts across both excerpts, implying that the music being heard, its structure and its changing dynamics, did not greatly influence an individual's quantity of motion.

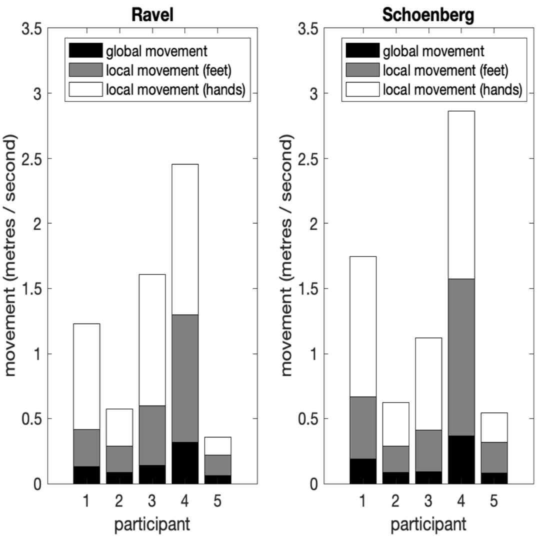

Figure 2. Stacked-bar charts depicting individual differences. Individuals moved in similar amounts across both pieces and movement profiles persist regardless of the music. Global movement refers to displacement (m/sec) within capture space. Local movement refers to feet and hand movement in relation to hip centrum.

Correlation Analysis Between Movement and Acoustic Features

We examined relationships between the expansion and contraction movement feature (averaged across participants) and acoustic features using Pearson's correlation. As the time series were autocorrelated, significance testing was carried out by first calculating the effective degrees of freedom (Pyper & Peterman, 1998). Significant correlations were found in both pieces.

The highest correlated feature for the Ravel stimulus was zero-cross, $r(30) = .73$, $p < .001$, followed by spectral centroid, $r(32) = .65$, $p < .001$, with root mean square, $r(28) = .49$, $p < .001$, and spectral flux, $r(28) = .49$, $p < .001$, yielding similar results. For the Schoenberg piece, zero-cross was also the highest correlated feature, $r(49) = .54$, $p < .001$, followed by spectral flux, $r(30) = .22$, $p < .05$, root mean square, $r(22) = .43$, $p < .001$, and, showing no significance, spectral centroid, $r(54) = -.2$, n.s.

As zero-cross represents a degree of noisiness within a signal (sounds with rich, enharmonic spectrums cross the zero line at higher rates), it might be said that participants were attending to changes in harmonic development, using expanding postures to depict denser spectral/timbral complexes. Figure 3 shows the Expansion/Contraction movement feature (averaged across the 5 participants) overlaid to the selected acoustic features. The top plot shows that in the Ravel the progression of the zero-cross feature follows a similar trajectory as the Expansion/Contraction feature. Changes in the root mean square correspond to the Expansion/Contraction curve at various points, such as right before the 300 second mark (the climax of the piece). The lower plot shows the features for the Schoenberg piece. Because the features fluctuate more, a relationship between movement and acoustic features is more difficult to track with the naked eye. However, as the piece represents a gradual reduction in brightness (meant to depict a sunset), a steady attenuation can be seen within all features from the 250 second mark onwards.

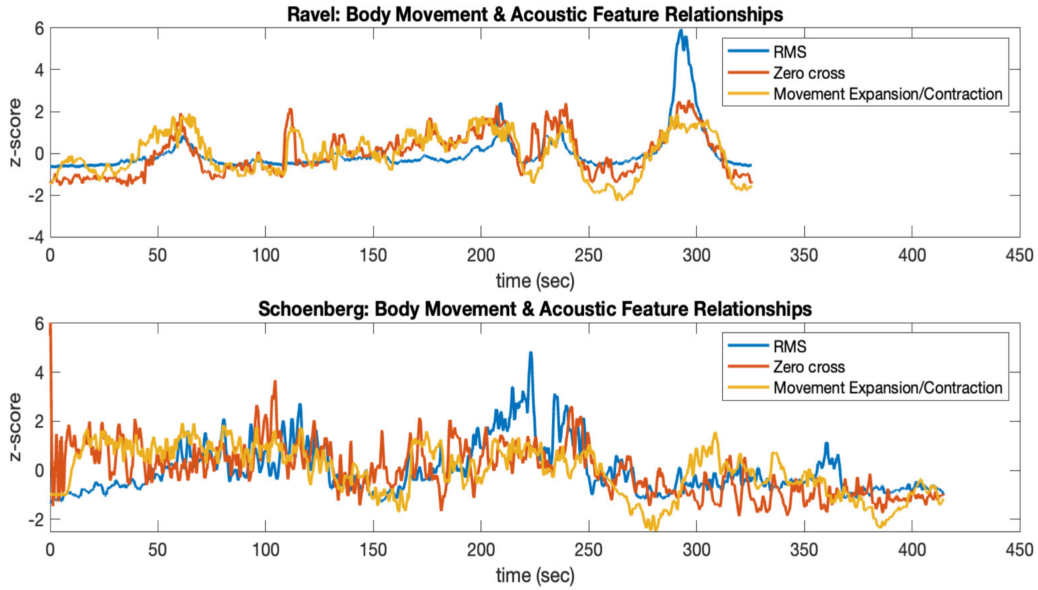

Figure 3. The Movement Expansion/Contraction feature (averaged across five participants) plotted to show temporal relationships with selected Acoustic features computed from the audio signal. All values have been *z*-scored for comparison.

Discussion

In this paper, we presented the findings of a pilot study that examined relationships between embodiment and the perception of brightness across time in orchestral music. To this end, five participants moved freely to 2 musical excerpts (between 5 and 7 minutes in duration) while their movements were recorded using motion-capture technology. To examine the participants' movements to the music, a novel movement feature was developed to measure full body Expansion/Contraction across time. This feature, which measures all possible distances within the marker set, was found to capture full body expansion more accurately than previously suggested methods. The feature was correlated with acoustic features computed from the audio signal (spectral centroid, flux, and zero-cross), demonstrating a link between embodied cognition and the perception of brightness over time.

For the Ravel piece, the feature correlated highly with zero-cross, a measure of signal noise. Perceptually, this means that sections of the piece containing increasing auditory roughness (e.g., dissonant frequencies at higher volume levels) may have compelled participants to expand their bodies. For the Schoenberg piece, relationships between movement and audio were less pronounced. However, there was a consensus toward less expansion near the end of the piece, which conforms with the composer's creative goal to depict a sunset.

In general, we found preliminary evidence for a contoured form of embodied experience in response to the musical stimulus that can be inferred from the correlation between interpretive motion and acoustic features. A growing body of evidence points compellingly to the conclusion that the "active tracing of sound features as shapes is integral to the perception and cognition of music" (Godøy, 2019, p. 238). However, the experience of shape unfolding as a continuous embodied process across large timescales remains a theoretical hypothesis (Godøy, 2019, pp. 244–246). Touizrar (2020) proposed that under certain conditions, the large-scale musical form can be understood as a contoured experience where the cognition of formal shape over time is paralleled by continuous build-up or reduction of brightness – especially with a great degree of attenuation that can be achieved by a symphony orchestra. Yet, how and under what conditions this form of cognition takes place remains to be fully understood. A good deal of further research is required.

Conclusions

Preliminary evidence for embodied contours experienced in response to a musical stimulus can be inferred from the correlation between interpretive motion and acoustic features. Kinaesthesia and its relation to experiences of art (Gallagher, 2011; Stuart, 2008), and to music (Ho, 2021; Kozak, 2019) provides a fruitful framework for further empirical study of musical form as an embodied and sympathetic phenomenon. The preliminary findings of the present study contribute to this endeavor in two important ways. First, we demonstrate that contoured experiences of musical form seem plausible, and furthermore, that they likely involve a dynamic and intermodal sense of self-movement. Secondly and more specifically, this study suggests a curious and hitherto unexplored relationship between proprioception and auditory perception as an aesthetic experience of perceived brightness in music, raising interesting questions about the nature of crossmodal perception viz. embodiment. We plan to undertake a follow-up study on a larger scale that will include professional dancers who are tasked to prepare a choreography in response to the 2 works discussed in the present study.

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