sempre:
Society for Education, Music and Psychology Research

MUSIC & SCIENCE

Research Article

Music & Science
Volume 3: 1–16

DOI: 10.1177/2059204320974216
journals.sagepub.com/home/mns
SAGE

Who Moves to Music? Empathic Concern Predicts Spontaneous Movement Responses to Rhythm and Music

Agata Zelechowska[1,2], Victor E. Gonzalez Sanchez[1,2], Bruno Laeng[1,3], Jonna K. Vuoskoski[1,2,3] and Alexander Refsum Jensenius[1,2]

Abstract

Moving to music is a universal human phenomenon, and previous studies have shown that people move to music even when they try to stand still. However, are there individual differences when it comes to how much people spontaneously respond to music with body movement? This article reports on a motion capture study in which 34 participants were asked to stand in a neutral position while listening to short excerpts of rhythmic stimuli and electronic dance music. We explore whether personality and empathy measures, as well as different aspects of music-related behaviour and preferences, can predict the amount of spontaneous movement of the participants. Individual differences were measured using a set of questionnaires: Big Five Inventory, Interpersonal Reactivity Index, and Barcelona Music Reward Questionnaire. Liking ratings for the stimuli were also collected. The regression analyses show that Empathic Concern is a significant predictor of the observed spontaneous movement. We also found a relationship between empathy and the participants' self-reported tendency to move to music.

Keywords

EDM, empathy, individual differences, motion capture, music-induced movement, rhythm, spontaneous movement

Submission date: 23 December 2019; Acceptance date: 26 October 2020

Introduction

Moving to music is a phenomenon observed in all known human cultures (Sievers et al. 2013), spontaneously appearing as early as in infancy (Zentner & Eerola, 2010). Spontaneous movement to music can come in many forms, such as feeling the urge to dance, tapping a foot, or adjusting the tempo of walking. We have been particularly interested in spontaneous movement happening when people try to stand still (Jensenius et al., 2017; Gonzalez Sanchez et al., 2018, 2019). The measured motion of the head during still standing is typically less than 10 millimetres per second, what we refer to as *micromotion*. This level of micromotion appears to be fairly similar across people of different ages, heights, genders, and musical backgrounds. But we have been curious to understand more about whether there are individual differences between people that can explain the extent to which they will spontaneously respond to music with body movement? This question is based on studies suggesting that peoples' individual traits are associated with the quantitative and qualitative properties of their movement to music (Bamford & Davidson, 2017; Carlson et al., 2016; Luck et al., 2009, 2010). In this article, our aim is to answer the question: which individual characteristics make people more likely to move to music?

[1] RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion, University of Oslo, Oslo, Norway
[2] Department of Musicology, University of Oslo, Oslo, Norway
[3] Department of Psychology, University of Oslo, Oslo, Norway

Corresponding author:
Agata Zelechowska, RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion, Postboks 1133, Blindern, 0318 Oslo, Norway.
Email: agata.zelechowska@imv.uio.no

Spontaneous Movement Responses to Music

Bodily responses to music can be divided into two main categories: *physiological* and *physical* (Hodges, 2009). Physiological responses manifest through various bodily phenomena, such as changes in skin conductivity, muscular tension, heart rate, respiration, body temperature, and pupil diameter. Physical responses, on the other hand, are related to movement of the body. A number of studies have dealt with body movement as a specific activity connected to experiencing music (Godøy & Leman, 2010; Gritten & King, 2006, 2011). There are fewer studies that have investigated spontaneous—that is, unplanned, resulting from an impulse—motor responses to music. It is common to say that music 'moves us', which suggests that movement to music is an outcome of an external 'force', as opposed to a conscious decision to move. The underlying mechanisms that cause such an urge to move, however, are not yet fully understood.

It has been shown that music, as well as simple auditory rhythms, influence human posture by altering body sway and encouraging spontaneous motor synchronisation to the rhythmical structure (Coste et al., 2018; Ross et al., 2016). In our own studies on involuntary body movement, we have shown that music with a clear rhythmic structure significantly increases the amount of head movement (Jensenius et al., 2017; Gonzalez Sanchez et al., 2018, 2019). This was found in motion capture studies in which people were asked to stand as still as possible while listening to alternating music excerpts and silence. Other researchers have shown that subtle body movement, such as head nodding, can appear spontaneously while engaging in different music-related tasks even when participants are not given any instructions regarding movement (Kilchenmann & Senn, 2015), or where the focus is on a different body part (Hurley et al., 2014). Other studies have highlighted the role of body movement in interpreting rhythmic structures (Phillips-Silver & Trainor, 2005, 2007, 2008; Su & Pöppel, 2012). Thus, there is ample evidence that body movement is crucial for the processing of rhythm and music.

The concept of 'groove' in music is often explained in relation to body movement, rhythm, and pleasure (Câmara & Danielsen, 2018). Studies on groove typically focus on musical features, such as the level of syncopation (Witek et al., 2014, 2017) or microtiming (Davies et al., 2013; Skaansar et al., 2019), that make music feel 'danceable' and inspiring to move. However, groove can also be viewed as a psychological construct of a subjective sensorimotor response to music (Skaansar et al., 2019). Such response can be in the form of *wanting* to move (Janata et al., 2012; Madison, 2006), feeling an *impulse* to move (Senn et al., 2019), getting an *urge* to move (Senn et al., 2018), or that music *makes* one move (Madison, 2006). Some researchers specifically use the term 'groove response' to refer to such experiences (Janata et al., 2012; Senn et al., 2018, 2019). Experimental research on groove is largely based on paradigms that measure people's self-reported desire to move, and not the actual body movement, although there are some exceptions (Hurley et al., 2014; Witek et al., 2017). Although the main focus is still on the properties of music, there are now indications that individual differences may be equally, or perhaps even more, important in explaining groove responses to music (Senn et al., 2018, 2019). We will describe some of these and other relevant findings in the following section.

Individual Differences in Bodily Responses and Movement to Music

Previous studies have identified a number of participant characteristics that are relevant for various types of bodily responses to music (Gingras et al., 2015; Laeng et al., 2016; McCrae, 2007; Nusbaum & Silvia, 2011), as well as for different features of spontaneous dance (Burger et al., 2013; Luck et al., 2010, 2014). In the present study, we focus on a selection of previously reported personality variables, hypothesising that they might be related not only to various aspects of movement to music, but also to the tendency to engage in such movement spontaneously.

Personality

In the psychology literature, personality traits are typically classified according to a five-factor model that includes Openness to Experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism (John et al., 2008). To our knowledge, only a few studies have examined the relationship between such personality traits and physiological responses to music. These studies have shown that people with high Openness to Experience are more prone to aesthetic chills (McCrae, 2007; Nusbaum & Silvia, 2011). In terms of body movement, Luck et al. (2009, 2010, 2014) analysed motion capture recordings of free dance to music and found that different movement patterns can be associated with different personality traits. They found that Openness and Agreeableness were associated with smooth movement, and that Extraversion and Conscientiousness correlated with higher movement speed (Luck et al., 2009), although for Conscientiousness the results only approached significance. In a later study, Luck et al. (2010) observed particularly strong connections between Extraversion and Neuroticism and specific movement patterns. They found that Extraversion was linked to fast movement of the head, hands, and centre of mass, as well as an overall higher amount and energy of global and local body movement. In one of the studies, Neuroticism was associated with lower levels of global and local movement (Luck et al., 2009), while both of the previously mentioned studies found that Neuroticism was related to jerky and accelerated movement (Luck et al., 2009, 2010). More recently, Carlson et al. (2016) showed that low

Conscientiousness and high Extraversion are associated with responsiveness to small tempo changes in dance.

Empathy

Empathy can be defined as an individual's 'responsivity to the other' (Davis, 1980). While it is typically associated with sharing emotions of the other person, it also can modify interactions between people at a physical level. It has been previously shown that empathy increases the so-called 'chameleon effect', referring to people non-consciously mimicking motor behaviours of their interaction partners (Chartrand & Bargh, 1999). This responsivity to another person's bodily actions may be connected to the mirror neuron system (MNS) in the motor cortex, which is activated both when we observe (see or hear) an action and when we execute it (Gallese & Goldman, 1998; Keysers et al., 2003; Kohler et al., 2002). In music perception studies, it has been shown that simply listening to rhythmic sounds activates regions of the brain responsible for planning and execution of movement (Grahn & Brett, 2007). Based on findings about MNS and motor areas of the brain involved in processing music, Overy and Molnar-Szakacs (2009) developed the model of shared affective motion experience (SAME), which emphasises the role of simulated motor actions in the perception and cognition of musical sounds. It is similar to the motor-mimetic hypothesis by Godøy (2003), who argues that (musical) sounds are experienced through motor resonance. Launay (2015) has developed this further into a model explaining how we sense agency in music through such motor-mimetic principles, and that this, in turn, results in a social experience.

Following such ideas about relationships between music and movement, Bamford and Davidson (2017) explored the relationship between empathy and certain aspects of movement to music. They found that participants who scored high in empathy adapted their movement faster to tempo changes in the presented music stimuli. The high-empathy participants also reported that they enjoyed dancing more often than participants with low empathy scores. Recently, Novembre et al. (2019) examined the effect of a particular component of empathy—empathic perspective taking—on interpersonal coordination in a music-making task that required synchronising streams of sounds. They found that participants who scored high in this dimension were better at predicting the actions of their leading partner. They also found that pairs of people with high empathic perspective taking scores were more accurate at synchronising their actions. These findings contradict the results of Carlson et al. (2016), who found no correlation between empathic perspective taking and responsiveness to tempo in dance; however, the two studies employed different experimental paradigms. In later research, Carlson et al. (2018) measured overall trait empathy instead of empathic perspective taking, and found a positive relationship between empathy and responsiveness to the movement of the partner in dance. Thus, while there is some evidence supporting a potential relationship between empathy and the urge to move to music, more research needs to be done to draw definite conclusions.

Music Preferences

Some musical features appear to be similarly appreciated between people. For example, the preferred tempo for dance is typically in the range of 120 to 130 bpm (Moelants, 2003). Other aspects of music, such as genre, instrumentation, or the content of low frequencies, can be a matter of personal taste. It has recently been found that both preference for, and familiarity with, the music stimuli positively affects participants' experience of groove (Senn et al., 2018, 2019). In fact, these extra-musical parameters predicted the groove experience better than any of the music-related features. In terms of actual body movement, Luck et al. (2014) found that a preference for the music stimuli had a U-shape relationship with the amount of observed movement. Furthermore, Gingras et al. (2015) and Laeng et al. (2016) found that participants' liking for the music excerpts modulated pupillary responses to these excerpts. Another study of spontaneous physiological responses to music showed that listening to preferred music can reduce anxiety levels by lowering the mean arterial blood pressure and heart rate (Walworth, 2003).

Music-Related Behaviour

Musical expertise is a variable that is often investigated in studies on groove and bodily responses to music. It has been shown that professional musicians associate groove with different genres from those selected by amateur musicians and non-musicians (Senn et al., 2018). Professional musicians are also more sensitive to musical features associated with groove, such as syncopation (Senn et al., 2019; Witek et al., 2017) and microtiming (Kilchenmann & Senn, 2015). Furthermore, it has been found that musical training modulates the effect of groove-evoking music on the motor system (Stupacher et al., 2013), as well as the individual's ability to synchronise to groovy music (Hurley et al., 2014; Skaansar et al., 2019). It is, however, worth considering how responsive people are to music regardless of musical training, and to find out which aspects of their musical experience they find rewarding and pleasurable.

The Barcelona Music Reward Questionnaire (BMRQ) is a self-report measure specifically developed for addressing different music-related reward experiences (Mas-Herrero et al., 2013). The questionnaire decomposes musical reward into five factors: Musical Seeking, Emotion Evocation, Mood Regulation, Social Reward, and Sensory-Motor. The last variable is particularly relevant for our present research, since it comprises questions that directly address the general feeling of wanting to move to music. The authors of the questionnaire observed that Sensory-

Table 1. An overview of the music stimuli used in the study.

Artist	Song title / Label / Year	Seconds	Tempo (bpm)
Beat track	Custom-made	45 s	120
André Bratten	Trommer Og Bass / Correspondant / 2014	0:00–0:45	120
Pysh feat. Poludnice	Sadom (Original Mix) / Mono.Noise / 2017	0:28–1:13	123
Neelix	Cherokee (Extended Mix) / Kontor Records / 2017	1:07–1:52	138
Neelix	Cherokee (Extended Mix) / Kontor Records / 2017	4:32–5:17	138

Motor scores correlate positively with the personality trait Openness to Experience. However, since their analyses did not include other personality dimensions, there is no information on possible correlations with Conscientiousness, Extraversion, Agreeableness, or Neuroticism.

Research Questions and Hypotheses

The data set used in this article is the same as used in a previous article (Zelechowska et al., 2020). That article focused on observable differences in body movement between two different listening scenarios: presenting the sound stimuli using either headphones or speakers. There, we found that there are, indeed, differences, and that listening to music on headphones leads to significantly higher quantity of motion on average. A secondary result was that there are different experiences, preferences, and habits associated with the use of these two playback methods, largely varying between the participants. Here, the main goal is to explore the individual characteristics of the participants, and see whether these characteristics can explain the amount of spontaneous movement to music.

As mentioned previously, the prior literature on relationships between individual traits (such as empathy or personality) and movement to music is both scattered and scarce. Yet, there appears to be some evidence pointing towards a connection between such traits and movement to music. We hypothesise that the amount of spontaneous body movement to music can be explained by some of the following variable groups: personality traits (Luck et al., 2009, 2010; McCrae, 2007; Nusbaum & Silvia, 2011), empathy scores (Bamford & Davidson, 2017), types of rewards drawn from music (Mas-Herrero et al., 2013), and preference for the experimental stimuli (Gingras et al., 2015). Given the many open questions, this study is necessarily exploratory in nature. The literature summarised here employed research paradigms and research questions significantly different from ours, typically investigating dynamic body movement or other types of bodily behaviour. Thus, we do not set up a directional hypothesis for each variable.

Methods

Participants

The participants for this study were recruited from the community around the University of Oslo. Exclusion criteria included hearing loss, neurological disorders, arthritis, orthopaedic conditions, recent injuries, or balance disorders. We also avoided participants in the Norwegian Championship of Standstill, which is a separate experiment paradigm that we have been running for some years (Jensenius et al., 2017; Gonzalez Sanchez et al., 2018, 2019). A total of 42 participants were recruited to the study. Owing to incomplete data collection, one case of misunderstood instructions, and one late report of a foot injury, five participants were excluded from further analysis. Three more participants were identified as outliers after initial computation of quantity of motion for all participants. Out of those three, one participant started dancing, one was fidgeting and stretching throughout the recordings, and one was continuously twitching their head. The final dataset included in the analyses therefore consisted of 34 participants (18 female, 16 male; mean age = 27 years, $SD = 5.5$ years). Of the total sample, 23 participants reported having some musical training, either professional or self-taught, out of which 18 still practised playing an instrument or singing. Participation in the study was rewarded with a 200 NOK (approx. 20 EUR) universal gift card. The study obtained ethical approval from the Norwegian Center for Research Data (NSD), with the project identification number 58546.

Music Stimuli

The music stimuli used in the experiment consisted of six excerpts: four EDM excerpts, one custom-made synthetic drum track, and one ‘beat’ track comprising a 120 bpm isochronous beat based on a synthetic bass drum sound. In our previous study on the same dataset, we were interested in comparing the six tracks for two different playback methods (Zelechowska et al., 2020). In this study, however, we are primarily interested in the responses to the four EDM excerpts. We have therefore chosen to exclude the synthetic drum track, and will only use the beat track as a reference track.

All the sound stimuli were approximately 45 seconds in duration (with small fade-ins and fade-outs for the EDM excerpts), were in quadruple metre, contained no lyrics, and had a tempo in the range of 120 to 138 bpm (see Table 1 for an overview, and Zelechowska et al. (2020) for more details). Waveform displays of the tracks can be seen in Figure 1. The displays are based on visualising the harmonic and rhythmic content in two different colours, using the sound separation

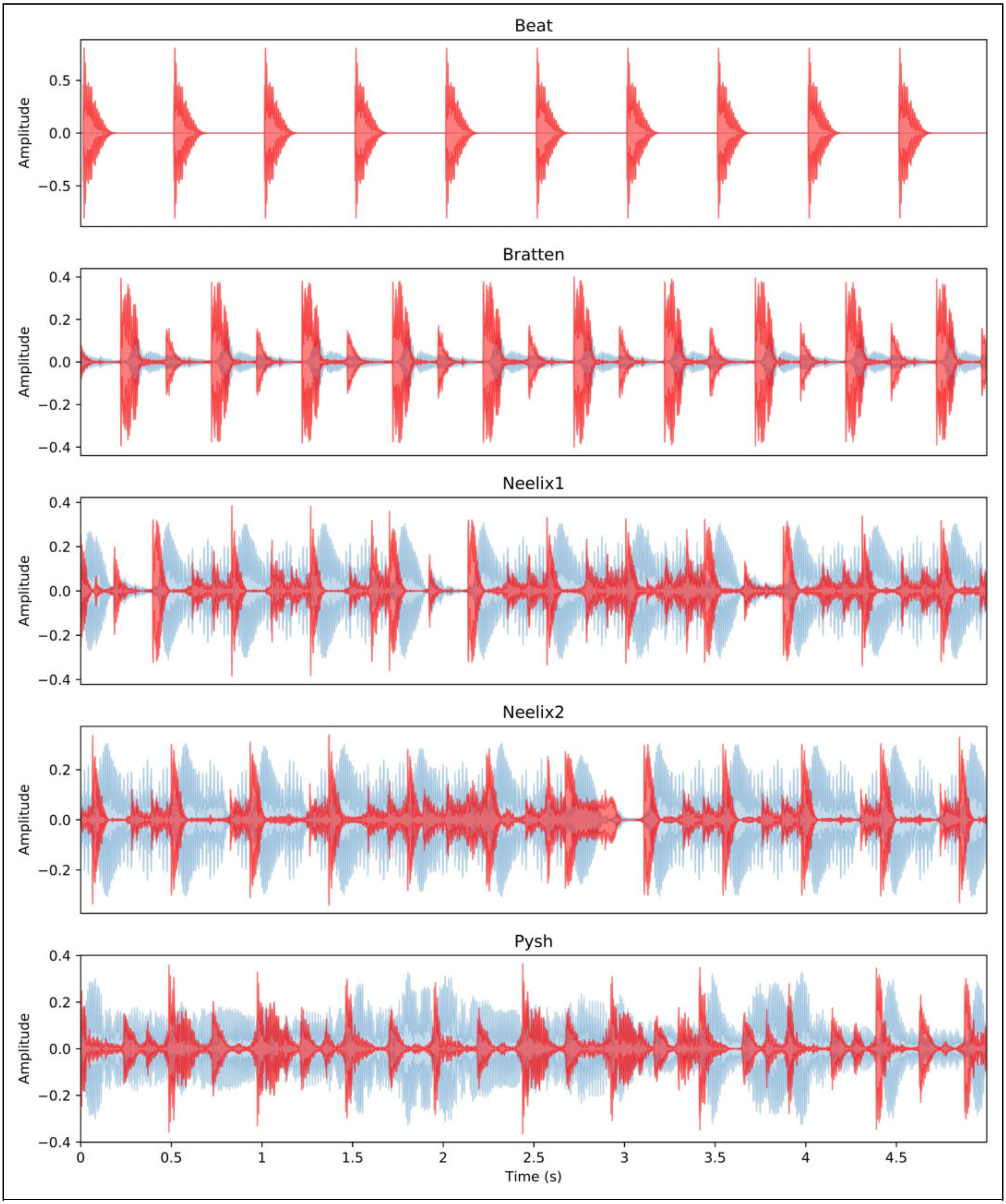

Figure 1. Waveform displays of 5 seconds of each of the five sound stimuli used in the analysis: the reference beat track (top) followed by the four EDM tracks: Bratten, Neelix1, Neelix2, and Pysh. The waveform has been split into two components: harmonic (grey) and rhythmic (pink), based on the method proposed by McFee et al. (2015).

algorithm of Fitzgerald (2010) and Driedger (2014) implemented in librosa for Python (McFee et al., 2015).

Each experiment consisted of two listening sessions. During each listening session (approx. 8 minutes), all stimuli were played in random order, alternating with 30-second segments of silence. Each session also started and ended with silence. The loudness across excerpts was normalised by ear by three of the authors during the pilot phase. This was to ensure that the tracks were perceptually similar. Since the question of playback method (headphones versus speakers) is not relevant for the analysis performed in this article, we have averaged the movement observed in the two listening sessions.

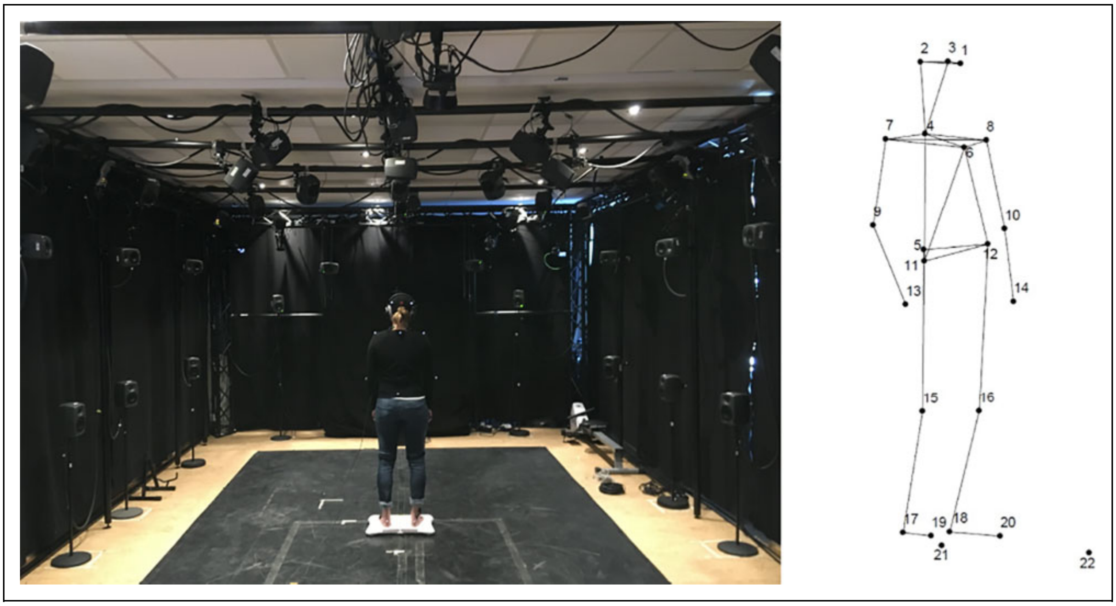

Figure 2. Left: Laboratory setup and one participant standing during the headphones condition. Written informed consent was obtained from the participant for publication of images. **Right**: Motion capture reconstructed markers and segments. The markers were located as follows (L, left; R, right; F, front; B, back): 1 – F head; 2 – RB head; 3 – LB head; 4 – B neck; 5 – sacrum; 6 – sternum; 7 – R shoulder; 8 – L shoulder; 9 – R elbow; 10 – L elbow; 11 – R hip; 12 – L hip; 13 – R wrist; 14 – L wrist; 15 – R knee; 16 – L knee; 17 – R heel; 18 – L heel; 19 – R toe; 20 – L toe; 21 – reference marker on the balance platform; 22 – reference marker on the floor.

Apparatus

A 12-camera infrared motion capture system from Qualisys (Oqus 300/500 cameras) was used to acquire the position data of 20 reflective markers attached to relevant anatomical landmarks on the subjects (Figure 2). The system was running at a 200 Hz sampling rate. A custom-made patch running in Max (Cycling '74) was used to play back the music stimuli in a randomised order. Uncompressed audio files were used for the experiment (.WAV files), played over an RME MADI-face Pro sound card. Synchronisation between the played audio files and the recorded motion capture data was achieved by sending a trigger signal from the motion capture system to the patch running the sound playback.

All subjects completed two listening sessions during the experiment, one with headphones and one with speakers. The headphones sessions were carried out with the sound stimuli presented through a pair of Beyerdynamic DT 770 PRO 80 Ohm headphones. The headphones were carefully placed on the participant's head, and the headband was adjusted as necessary. The speaker sessions were performed with a pair of Genelec 8020 loudspeakers and a Genelec 7050 sub-woofer. Each speaker was mounted on a stand at the height of 165 cm. The distance between the participant and each speaker was 315 cm, and the distance between the speakers was 290 cm. The sub-woofer was placed on the floor equidistant between the speakers, 245 cm away from the participant. The sound levels of both playback systems were high, but not uncomfortable. This meant a level of around 72 dB for speakers, and around 74 dB for headphones. The difference of 2 dB compensated for the lack of crosstalk when listening on headphones (McMullin, 2017). A short sound check was performed prior to the headphones session to determine that the headphones volume was, indeed, loud but not uncomfortable. A total of eight subjects asked for the volume to be lowered (to either 72 dB or 68 dB).

Movement Measures

The subjects wore a motion capture suit with 20 reflective markers placed on selected anatomical landmarks (Figure 2). The whole body movement was measured by calculating the average position of all 20 markers for each sample and differentiating the position data to obtain the norm of the velocity vector. Post-processing of the motion capture data was performed in Qualisys Track Manager (QTM) and the further analysis was performed in Matlab using the MoCap Toolbox (Burger & Toiviainen, 2013). The data from each listening session was then split into two segments: (1) EDM (the average of the four EDM tracks) and (2) beat track. The average movement velocity was computed for both these segments. The data from the two types of listening sessions (headphones and speakers) were averaged to simplify the analysis.

Self-Report Measures

The participants were asked to fill in a set of questionnaires during the break between listening sessions and at the end of the experiment. The following sections describe the different questionnaires used.

Personality. The Big Five Inventory (BFI; John et al., 2008) was used to evaluate the personality dimensions of the participants: *Extraversion*, *Agreeableness*, *Openness*, *Conscientiousness*, and *Neuroticism*. The questionnaire comprises 44 statements (e.g., '*I see myself as someone who worries a lot*'), each attributed to one of the five dimensions, and the answers are given on a five-point scale ranging from '*Disagree strongly*' to '*Agree strongly*'.

Empathy. The Interpersonal Reactivity Index (IRI; Davis, 1980) was employed to assess participants' trait empathy. The IRI measures both the cognitive and the affective aspects of empathy, divided into four subscales: *Fantasy*, *Perspective Taking*, *Empathic Concern*, and *Personal Distress*. It comprises 28 items (e.g., '*I really get involved with the feelings of the characters in a novel*'), which are rated on a five-point scale ranging from '*Does not describe me well*' to '*Describes me very well*'.

Table 2. Means and standard deviation values for background variables. The answers to the three last questions were given on a five-point Likert scale (*Definitely not* to *Definitely yes* for "Liking to dance", *Poor* to *Excellent* for "Sense of rhythm" and *Clumsy* to *Excellent* for "Physical coordination").

Question		Mean	SD
Hours spent weekly on:	listening to music	14.90	11.55
	playing/producing/ composing music	4.02	8.30
	dancing (professional, at a party, etc.)	1.15	1.94
	exercising (other than dance)	4.85	5.40
Music training:	years	5.82	7.11
	weekly hours of practice	2.37	5.32
Liking to dance		3.68	1.27
Sense of rhythm		3.76	1.02
Physical coordination		3.53	0.75

Music Reward Experiences. The BMRQ (Mas-Herrero et al., 2013) was employed to determine which aspects of a music experience are most motivating for participants. The questionnaire comprises 20 items (e.g., '*When I hear a tune I like a lot I can't help tapping or moving to its beat*'), which are grouped into five dimensions: *Emotional Evocation*, *Sensory-Motor*, *Mood Regulation*, *Musical Seeking*, and *Social Reward*. The ratings are given on a five-point scale ranging from '*Completely disagree*' to '*Completely agree*'.

Stimulus Ratings. At the end of the experiment, short excerpts of each of the stimuli were replayed so that the subjects could evaluate their liking of each track on a seven-point scale ranging from '*Dislike strongly*' to '*Like strongly*'. None of the participants knew any of the songs used in the experiment, but some of them expressed general familiarity with the music genre.

Background Variables. A custom-made questionnaire was distributed at the end of the experiment, which included questions on age and gender, as well as on the number of hours spent weekly on listening to music, playing/producing/composing music, dancing, and doing physical exercise (other than dance). We also asked about liking to dance (from '*Definitely not*' to '*Definitely yes*'). At the end, there were some questions on musical training based on items from the Beat Alignment Test (BAT; Iversen & Patel, 2008). An overview of the distribution of scores can be found in Tables 2 and 3.

Procedure

The experiment took place in the fourMs Lab at the University of Oslo. The participants were invited to the laboratory individually and written informed consent was obtained prior to the experiment. During the preparation phase, the participants put on the motion capture suit and reflective markers were placed on selected points of their body (Figure 2). Additional data collection included EMG electrodes placed on each foot, forearm, and shoulder, a breathing chest sensor, and a balance platform. These extra

Table 3. Comparison of the average quantity of motion (QoM) and BMRQ Sensory-Motor score based on gender and musical training.

		Women			Men		
		Mean	SD	N	Mean	SD	N
QoM	EDM	7.64	1.35	18	7.29	1.29	16
	Beat	7.63	1.45	18	7.24	1.31	16
BMRQ Sensory-Motor		3.78	0.82	18	3.70	0.69	16
		Music training (>2 years)			Little or no music training (<2 years)		
		Mean	SD	N	Mean	SD	N
QoM	EDM	7.51	1.51	19	7.43	1.07	15
	Beat	7.46	1.68	19	7.43	0.93	15
BMRQ Sensory-Motor		3.86	0.74	19	3.58	0.76	15

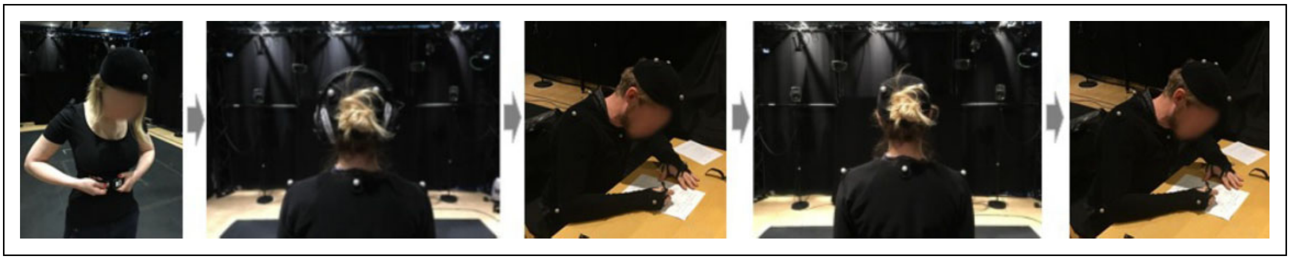

Figure 3. The different parts of the experiment (from left to right): preparation, first listening session, first set of questionnaires, second listening session, second set of questionnaires (written informed consent was obtained from the participants for publication of images in this article).

sensors were added as part of the ongoing methodological experimentation in the lab, and were not part of the original study design. Data from these sensors will therefore not be analysed in the current article.

The subjects were instructed to stand on the balance platform in a relaxed, comfortable position. They were asked to focus their gaze on a white cross placed on the wall in front of them (340 cm away from the platform). No specific instructions about moving to the music or trying to stand still were provided. The complete oral instruction can be found in the Appendix.

After completing the first recording session, the participants filled in the first part of the questionnaires: their subjective experience of the session, as well as the BFI and IRI questionnaires. Then, after completing the second listening session, they filled in the remaining set of questionnaires: experiences from the second session, BMRQ, and also some other questionnaires that are not covered in the present analysis. Figure 3 shows a summary of the different steps of the study. The experiment took about 1 hour and 15 minutes to complete.

Analysis

Pre-processing of motion capture data was performed in Qualisys Track Manager, and the data was exported to Matlab for further processing using the MoCap Toolbox (Burger & Toiviainen, 2013). The average *quantity of motion* (QoM) was calculated as the first derivative (the velocity) of the whole body position data. The norm of the velocity was then calculated from the three components of the velocity vector. The resulting value was averaged across samples in each stimuli. The end result is one average QoM value per person per stimuli. The analyses of the questionnaires, and their correlations with the QoM data, were performed using IBM SPSS Statistics 25.

In order to explore whether any of the individual difference variables significantly predict the amount of movement in response to the two types of stimuli (EDM and beat), two regression analyses were run. The regression approach was a combination of the sequential and stepwise methods, where predictors are first tested in theoretically informed blocks using the stepwise method, and then significant predictors are entered into a final model in a pre-determined order (Tabachnick et al., 2007). This approach mitigates some of the weaknesses of the simple stepwise method (namely, the limitation that the fit of variables is assessed based on other variables in the model) by enabling more predictors to be entered into the final model. The predictor variables were grouped into hierarchical blocks in terms of their level of specificity, starting with broad, stable personality traits (Block 1), followed by trait empathy (Block 2), kinds of musical reward (Block 3), and liking for the experimental stimuli (Block 4). Within each block, we tested for significant predictors using the stepwise method in SPSS. In essence, this method uses forward selection, but additionally each time a predictor is added to the model, a removal test is applied to the least useful predictor in the model. Probability of F was used as the stepping criterion, with $p<.05$ as the threshold of entry into the model, and $p>.10$ as the threshold for removal. Separate regression analyses were carried out for QoM in response to EDM and the plain beat stimulus. EDM carries with it a multitude of associations (to dancing, clubbing, etc.), so the simple beat track functioned as a more neutral control stimulus to test whether similar – or different – predictors explain the QoM in the two cases.

The dependent variable was the QoM in response to each stimulus type. The independent variables that were tested blockwise comprised:

- Block 1: Five subscales of BFI: Openness to Experience, Conscientiousness, Extraversion, Agreeableness, Neuroticism
- Block 2: Four subscales of IRI: Fantasy, Perspective Taking, Empathic Concern, Personal Distress
- Block 3: Five subscales of BMRQ: Emotion Evocation, Sensory-Motor, Mood Regulation, Musical Seeking, Social Reward
- Block 4: Averaged EDM Stimuli Liking for the four EDM fragments or Beat Stimuli Liking for the beat track, depending on the regression model.

An additional stepwise regression model was built, with the BMRQ Sensory-Motor subscale as the dependent variable. This was done to test whether the self-reported tendency to move to music (measured through the Sensory-Motor subscale from BMRQ) can be explained by trait empathy and/or personality traits. Similar to the previous two analyses, a combination of the stepwise and sequential approaches was used. Personality traits were tested in Block 1, while the subscales of trait empathy were tested in Block 2.

Finally, to test for potential differences between male and female participants, t-tests were performed for the average of the EDM and beat segments from the two listening sessions, as well as for the Sensory-Motor subscale of the BMRQ. Also, potential differences between musically trained and non-trained participants were explored through t-tests, in which musically trained participants were defined as those who had more than two years of musical training ($N = 19$).

Results

When it comes to QoM in response to EDM, in the blockwise regression analyses of significant predictors (using the stepwise method), only Empathic Concern (a subscale of trait empathy; Block 2) emerged as a significant predictor of average QoM in response to EDM (*Beta* = .384, $t = 2.35$, $p = .025$). Thus, only Empathic Concern was entered into the final regression model. The model explained 12.1% of the variance (adjusted R square; $F(1,32) = 5.526$, $p = .025$).

Similarly, QoM to the beat segment was explained only by Empathic Concern (*Beta* = .365, $t = 2.44$, $p = .021$), and the model explained 13% of the variance (adjusted R square; $F(1,32) = 5.936$, $p = .021$). The Spearman correlations between all independent and dependent variables are displayed in Table 4.

Since the stepwise-method is associated with an inflated likelihood of Type 1 errors (i.e., false positives), we also carried out two confirmatory regression analyses using the Enter-method to explore whether Empathic Concern remains a significant predictor of QoM when all possible predictors are included in the model. Although the resulting regression models themselves were non-significant due to the high number of non-significant predictors, these analyses revealed that Empathic Concern remained a significant predictor (*Beta* = .628, $t = 2.72$, $p = .014$ for EDM; *Beta* = .569, $t = 2.38$, $p = .028$ for beat) even when all the possible predictors were included in the model. Additionally, BMRQ Musical Seeking emerged as a significant, negative predictor in both analyses (*Beta* = -.584, $t = -2.50$, $p = .022$ for EDM; *Beta* = -.896, $t = -2.46$, $p = .024$ for beat). The coefficients for all variables in both models are shown in Table 5.

When it comes to the self-rated tendency to move to music, in a similar blockwise regression analysis of the significant predictors of the Sensory-Motor score from BMRQ, only Empathic Concern (Block 2) emerged as a significant predictor (*Beta* = .349, $t = 2.11$, $p = .043$). The model explained 12.2% of the variance (adjusted R square; $F(1,32) = 4.437$, $p = .043$).

A series of independent samples t-tests showed no significant differences between male and female participants, nor between musically trained and non-trained participants, in QoM or self-reported tendency to move (Table 3).

Discussion

The results of the regression analyses revealed that trait empathy, specifically the Empathic Concern scale, is a significant and moderate predictor of spontaneous movement to the stimuli. The Empathic Concern scale taps into feelings of compassion and sympathy experienced in response to the observed negative experiences of others (Davis, 1980). This empathy component has previously been linked to the enjoyment of sad and tender music (Taruffi & Koelsch, 2014; Vuoskoski et al., 2012), as well as to the intensity of music-induced emotions (Saarikallio et al., 2012; Vuoskoski & Eerola, 2012).

Our findings are in line with those of Bamford and Davidson (2017), who found that trait empathy was associated with more accurate synchronisation to musical rhythms. They postulated that empathy and rhythmic entrainment might rely on shared brain circuits, namely the human mirror neuron system, which has been hypothesised to play an important role in both music cognition and empathic processes (Gallese, 2001; Molnar-Szakacs & Overy, 2006; Overy & Molnar-Szakacs, 2009). Both empathy and rhythmic entrainment entail attuning to the actions and expressions of others, and involve motor resonance, either simulated or enacted (Keller et al., 2014; Preston & De Waal, 2002). Furthermore, experiencing both empathy and rhythmic entrainment has been associated with subsequent increases in social bonding and prosocial behaviour (Seyfarth & Cheney, 2013; Wiltermuth & Heath, 2009).

While the link between empathy and entrainment seems more straightforward in the context of interpersonal interaction and behavioural synchrony, it could also apply to spontaneous movement to music. Listening to music that evokes a clear sense of pulse involves a significant degree of auditory-motor resonance even in the absence of overt movement (Stupacher et al., 2013), and the areas of the brain that are involved in motor planning and execution are also engaged in beat processing (Grahn, 2012; Grahn & Brett, 2007). Thus, it could be argued that beat-induction is achieved through simulated motor action. Since trait empathy is associated with increased motor simulation when observing facial expressions (Pfeifer et al., 2008) or listening to action sounds (Gazzola et al., 2006), it is possible that high trait empathy also contributes to greater motor simulation in the context of beat processing. Indeed, in a study by Wallmark et al. (2018) both affective and cognitive forms of empathy modulated activity in

Table 4. Means, standard deviations, and Spearman correlations of the model variables.

Variable	M	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Body EDM	7.48	1.32																		
Body Beat	7.45	1.38	0.91**																	
BFI Extraversion	3.18	0.70	0.05	-0.01																
BFI Agreeableness	3.78	0.46	0.04	0.09	-0.09															
BFI Conscientiousness	3.67	0.59	-0.24	-0.20	0.26	-0.07														
BFI Neuroticism	2.79	0.75	0.07	0.03	-0.42*	0.20	-0.38*													
BFI Openness	4.03	0.43	0.02	-0.07	0.09	0.21	0.35*	0.09												
IRI Perspective Taking	2.76	0.65	0.15	0.09	-0.11	0.12	-0.12	0.11	0.01											
IRI Fantasy	2.30	0.71	0.18	0.27	-0.07	0.19	-0.19	0.26	-0.01	0.07										
IRI Empathic Concern	2.61	0.61	0.40*	0.34	0.11	0.14	0.08	0.36*	0.23	0.11	0.30									
IRI Personal Distress	1.54	0.67	0.02	0.08	-0.38*	0.12	-0.42*	0.61**	-0.16	0.12	0.25	0.07								
BMRQ Emotion Evocation	3.92	0.77	0.11	0.17	0.25	0.27	0.04	-0.02	0.10	0.20	0.43*	0.22	0.27							
BMRQ Sensory-Motor	3.74	0.75	0.23	0.27	0.16	-0.01	-0.15	0.02	-0.22	0.18	0.28	0.34	0.12	0.44**						
BMRQ Mood Regulation	4.08	0.69	0.22	0.31	0.07	0.50**	-0.19	0.21	-0.04	0.11	0.44**	0.18	0.42*	0.68**	0.48**					
BMRQ Musical Seeking	3.54	0.93	-0.11	-0.09	0.27	0.30	0.03	0.12	0.21	0.14	0.20	0.23	0.18	0.40*	0.26	0.58**				
BMRQ Social Reward	3.79	0.72	0.06	0.21	-0.03	0.39*	0.12	0.30	0.13	0.03	0.43*	0.34	0.29	0.45**	0.44**	0.54**	0.51**			
Stimuli liking EDM	4.60	0.94	0.18	0.28	-0.02	0.22	-0.18	0.24	-0.15	0.11	0.16	-0.10	0.33	0.24	0.30	0.59**	0.27	0.24		
Stimuli liking Beat	2.03	1.17	0.11	0.02	0.21	0.10	-0.03	-0.13	0.15	-0.15	0.10	0.05	-0.13	0.17	0.22	0.20	0.20	0.05	0.20	

Notes: ** indicates significance at the $p<0.01$ level and * at the $p<0.05$ level.

Table 5. Standardised Beta coefficients for all variables from the regression analysis with Enter-method.

	EDM			Beat		
	Beta coefficients	t	Sig.	Beta coefficients	t	Sig.
(Constant)		1.593	0.129		1.354	0.192
IRI Perspective Taking	0.162	0.894	0.383	0.111	0.564	0.580
IRI Fantasy	-0.056	-0.274	0.787	-0.012	-0.055	0.957
IRI Empathic Concern	0.628	2.722	0.014	0.569	2.382	0.028
IRI Personal Distress	-0.031	-0.122	0.904	0.087	0.321	0.752
BMRQ Emotion Evocation	-0.087	-0.310	0.760	-0.058	-0.202	0.842
BMRQ Sensory-Motor	-0.162	-0.701	0.492	-0.212	-0.865	0.398
BMRQ Mood Regulation	0.598	1.549	0.139	0.635	1.734	0.100
BMRQ Musical Seeking	-0.584	-2.501	0.022	-0.602	-2.461	0.024
BMRQ Social Reward	-0.028	-0.110	0.914	0.096	0.346	0.733
BFI Extraversion	0.097	0.480	0.637	0.154	0.717	0.483
BFI Agreeableness	-0.194	-0.861	0.401	-0.079	-0.331	0.745
BFI Conscientiousness	-0.458	-2.067	0.053	-0.392	-1.671	0.112
BFI Neuroticism	-0.294	-1.151	0.265	-0.323	-1.178	0.254
BFI Openness to Experience	0.201	1.024	0.320	0.118	0.565	0.579
Stimuli liking (EDM/Beat)	0.230	1.060	0.303	-0.002	-0.008	0.993

sensorimotor and cognitive areas of the brain during listening to music and short musical sounds. The authors pointed out that musical sound is not an obvious social stimulus (compared with those typically used in studies on empathy), and yet it can elicit neural responses consistent with empathic processes. They suggest that studying musical experiences can provide a window into understanding social cognitive and affective processing. Similarly, Launay (2015) argues that listening to any musical sound is inevitably a social experience, and that musical engagement should be viewed as a form of social engagement.

Our results show that Empathic Concern predicts the amount of spontaneous movement not only in response to music, but also in response to the simple isochronous beat of the reference track. Compared to EDM, the simple isochronous beat is not as closely associated with genre-related behaviours, such as dancing and clubbing. This result can be interpreted with regard to the role of empathy in processing rhythmical sounds, or with regard to sound features that are associated with movement responses. It is important to note that the reference track was made with a synthetic bass drum sound, not a standard metronome click that is typically used for reference. We decided to use a bass drum sound, since it resembles the ‘flat four’ pattern found in EDM tracks. In fact, it is not uncommon for EDM tracks to use such a simple bass drum beat as part of the intro section. Therefore, one could argue that the bass drum beat used in the reference track was more ‘musical’ than a higher-pitched metronome sound would have been. It has been shown that low-frequency energy in a musical beat intensifies body movement to music (Bamford & Davidson, 2017; Burger et al., 2013, 2017; Van Dyck et al., 2010). Moreover, Zentner and Eerola (2010) showed that infants spontaneously respond with movement not only to music, but also to simple rhythmic stimuli. Some of their stimuli were similar to the beat track used in our study, and were designed with a similar goal of making them less abstract and less distant from music by using a drum-like sound instead of a metronome click. These results suggest that a regular pulse may be more important for driving spontaneous movement responses to music than the complexity of the rhythmic stimuli (including its timbral features, syncopation, microtiming, and so on). Future studies should look more systematically into the role of different rhythmic components in spontaneous movement responses.

Furthermore, Empathic Concern also emerged as the only significant predictor on the Sensory-Motor subscale of the BMRQ. This subscale comprises four questions:

- ‘I don’t like to dance, not even with music I like.’ (reverse score)
- ‘Music often makes me dance.’
- ‘I can’t help humming or singing along to music that I like.’
- ‘When I hear a tune I like a lot I can’t help tapping or moving to its beat.’

The consistent correlation between trait empathy and both the observed movement and the self-reported general tendency to move to music suggests that empathy may indeed be related to this behaviour in everyday life. This limits the possibility that highly empathic participants were just motivated to provide ‘satisfactory’ results. The fact that they were in a motion capture lab might have prompted them to think that the researchers were expecting to observe some movement, even though the instructions were kept intentionally unclear on whether movement was expected.

Based on knowledge from the literature, we hypothesised that the amount of movement could be predicted by the participants’ personality traits (Luck et al., 2009, 2010;

McCrae, 2007; Nusbaum & Silvia, 2011), and Sensory-Motor-oriented style of drawing reward from music (Mas-Herrero et al., 2013). None of these turned out to be significant in our analyses. This result is not conclusive, however, given the limitations of our study, the scarcity of previous literature on the role of individual differences in listeners' tendency to move to music, the varying paradigms used to study body movement in response to music, and the fact that most previous studies have targeted large-scale body movement. It is possible that traits such as Openness to Experience (McCrae, 2007; Nusbaum & Silvia, 2011) or Extraversion (Luck et al., 2009, 2010) are more related to other aspects of responsiveness to music than the particular one that we measured. Moreover, the relatively small sample in this experiment, when compared with the number of variables in the regression models, might have resulted in biases in giving or taking weight from specific variables. In the confirmatory regression analyses using the Enter-method, the BMRQ-subscale Musical Seeking emerged as another significant predictor of quantity of motion in response to both EDM and beat. However, the relationship between Musical Seeking and QoM was negative, meaning that the tendency to seek new music and music-related information was associated with less movement. Since Musical Seeking did not emerge as a significant predictor in the sequential stepwise regression analyses, and since the raw correlation between Musical Seeking and QoM was rather low, it may be that this variable only happened to explain a portion of the variance in QoM not explained by any of the other predictors.

Contrary to our prediction, the variables describing preference for experiment stimuli did not predict the amount of movement. The correlations between EDM stimuli liking and body movement were positive, but did not reach significance. This might, again, result from a small sample size and other limitations of the study. There are some studies suggesting that preference for the stimuli is important for ratings of groove (Senn et al., 2018, 2019) and the amount of movement during spontaneous dance (Luck et al., 2014). An alternative explanation would be that music does not need to be enjoyed to induce spontaneous movement responses. However, the enjoyment of music can modulate automatic physiological processes such as heart rate and blood pressure (Walworth, 2003), or pupillary responses to music (Gingras et al., 2015; Laeng et al., 2016). We believe that this topic is worth further investigation.

Surprisingly, musical training did not predict QoM in our study, nor the Sensory-Motor score of BMRQ. However, the self-reported measurement of musical training used in our study was fairly general, so other results could have been found with a more detailed breakdown of musical training. To conclude about the role of musical expertise on spontaneous body movement to music, a more thorough collection of data, and a larger sample of participants, is required.

Limitations

It is worth repeating that the present study is exploratory in nature and has several limitations. First, the sample size of the participants is relatively small. Given the high number of independent variables, as well as the relatively low significance values, the results need to be approached carefully and without arriving at definite conclusions. It should specifically be noted that the stepwise method used in the regression analyses is associated with an increased likelihood of Type I errors. However, we tried to mitigate this possibility by running confirmatory regression analyses using the Enter-method, with all potential predictors included in the model. Empathic Concern remained a significant predictor of QoM also with all other predictors included. Furthermore, Empathic Concern predicted the self-rated tendency to move to music, providing further support for a positive relationship between music-induced movement and empathic traits.

In this study, we have primarily looked at the *amount* of movement, measured as QoM from the motion capture data. While this measure tells something about how much people moved on average to the different stimuli, it does not allow us to conclude whether the observed movement is related to sensorimotor synchronisation with music and rhythm, or to other causes of movement, such as postural adjustments, intensified body sway, and so on. Future studies could aim at analysing the periodicity of the motion capture time series, and try to cross-correlate these to various continuous musical features, such as, rhythmic events, harmonic changes, melodic shapes, and spectral flux.

Another limitation of the present study is the potential effect of the laboratory context within which the study was carried out. As mentioned previously, both our study and that by Bamford and Davidson (2017) employed an open-ended instruction, in which participants were allowed to respond freely to the music stimuli. However, the laboratory setting afforded movement in different ways in these two studies. In our study, the participants were standing on a balance board with multiple sensors attached to their bodies. In the study by Bamford and Davidson (2017), on the other hand, participants were not restricted by any equipment, and were able to move freely in the recording space. These two experimental paradigms allowed for different types of analyses and observations, and are also prone to different types of biases. On the one hand, letting participants decide whether they want to move to music seems appropriate for studying *spontaneous* movement responses to music. On the other hand, some aspects of the study design will inevitably be noticed by the participants, and can lead to different, perhaps even opposing, interpretations of the task by the subjects. In our study, the participants' movement responses may have been driven by whether or not they assumed that movement is expected of them. We have previously run several other experiments that have been branded publicly as 'Norwegian

Championship of Standstill' (Jensenius et al., 2017; Gonzalez Sanchez et al., 2018, 2019). The current experiment was never branded in this way, and we explicitly excluded people that had participated in previous experiments. Still, it may be that knowledge about our previous experiments primed some participants to stand as still as possible.

Given that our current study was carried out in a highly controlled laboratory setting, it would be premature to extrapolate these data to reflect participants' general tendency to move to music. At the same time, the consistency between the results for the movement variables, and the self-reported tendency for music-induced movement (Sensory-Motor scale from BMRQ), suggests that this inference from lab-specific behaviour to a more general tendency is worthy of further investigation.

An alternative interpretation of our results could be that empathic people move more in general, independent of music. A comparison of spontaneous movement in silence and music could address this question. Unfortunately, in the present data, an analysis of movement in silence was not performed due to an unexpected bias in the data. Since we did not explain the role of the silence segments in between the music excerpts, some of our participants treated them as breaks, so they would occasionally adjust their posture, scratch their nose, and so on. Therefore, we decided not to use the silence fragments in the current analysis.

Yet another limitation of the current study is that it only deals with EDM tracks. This musical genre has some characteristics (steady beat, confined form, etc.) that make it difficult to generalise our findings to other types of music. Furthermore, only four EDM excerpts (from three different tracks) were included in the experiment. More systematic studies, comprising a larger collection of stimuli and a broader selection of musical genres, are needed to better understand spontaneous motor responses to music, and the musical features that drive such responses. It would also be interesting to examine movement patterns to different parts of an EDM track, such as done by Burger et al. (2017) and Solberg and Jensenius (2016).

Conclusions

The aim of this article has been to investigate the role of individual characteristics in people's spontaneous body movement responses to music. We explored whether personality traits, empathy, music-related behaviour, and liking for the experiment stimuli could predict the amount of spontaneous movement to four EDM tracks and to a simple, isochronous reference beat. We also tested whether the same variables could predict participants' self-reported tendency to move to music.

Even though there are many limitations of the experiment (as discussed previously), our results suggest that there is, indeed, a link between empathy and spontaneous movement responses to music. This is in line with previous research by Bamford and Davidson (2017). Among various other listener characteristics, empathy appeared to be the single significant predictor both for observed body movement and for a self-reported tendency to move to music. The results of this exploratory research suggest that there is a link between spontaneous sensorimotor synchronisation with auditory rhythms and the affective aspect of empathy.

The experimental paradigm and the results presented in this article should be seen as a preliminary investigation of the question: 'Who is likely to move to music?' There have been an increasing number of studies into different types of music-related body movement in recent years, but less attention has been devoted to individual differences. We hope that this study will encourage more researchers to explore this research question, and develop more paradigms for studying spontaneous body movement to music.

Author Note

Supplementary material is available on the MICRO project website: https://www.uio.no/ritmo/english/projects/micro/.

Action Editor

Andrew Goldman, Western University, Faculty of Music.

Peer Review

Emily Carlson, University of Jyväskylä, Department of Music, Art and Culture Studies.
Carlos Cornejo, Pontificia Universidad Católica de Chile, Escuela de Psicología.

Author Contributions

AZ researched literature and conceived the study. All authors contributed to study design. AZ was involved in gaining ethical approval and participant recruitment. AZ and VGS performed the collection of data. AZ, JV, VGS and ARJ performed data analyses. AZ wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Research Council of Norway through its Centres of Excellence scheme, project numbers 250698 and 262762.

ORCID iD

Agata Zelechowska https://orcid.org/0000-0002-0592-0717

References

Bamford, J. M. S., & Davidson, J. W. (2017). Trait empathy associated with agreeableness and rhythmic entrainment in a spontaneous movement to music task: Preliminary exploratory investigations. *Musicae Scientiae*, *23*(1), 5–24.

Burger, B., London, J., Thompson, M. R., & Toiviainen, P. (2017). Synchronization to metrical levels in music depends on low-frequency spectral components and tempo. *Psychological Research*, *82*(6), 1–17.

Burger, B., Thompson, M. R., Luck, G., Saarikallio, S., & Toiviainen, P. (2013). Influences of rhythm- and timbre-related musical features on characteristics of music-induced movement. *Frontiers in Psychology*, *4*(183), 183.

Burger, B., & Toiviainen, P. (2013). *Mocap toolbox: A Matlab toolbox for computational analysis of movement data*. Proceedings of the Sound and Music Computing Conference, Stockholm.

Câmara, G. S., & Danielsen, A. (2018). *Groove. The Oxford handbook of critical concepts in music theory*. Oxford University Press.

Carlson, E., Burger, B., London, J., Thompson, M. R., & Toiviainen, P. (2016). Conscientiousness and extraversion relate to responsiveness to tempo in dance. *Human Movement Science*, *49*, 315–325.

Carlson, E., Burger, B., & Toiviainen, P. (2018). Dance like someone is watching: A social relations model study of music-induced movement. *Music & Science*, *1*, 1–16.

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception–behavior link and social interaction. *Journal of Personality and Social Psychology*, *76*(6), 893.

Coste, A., Salesse, R. N., Gueugnon, M., Marin, L., & Bardy, B. G. (2018). Standing or swaying to the beat: Discrete auditory rhythms entrain stance and promote postural coordination stability. *Gait & Posture*, *59*, 28–34.

Davies, M., Madison, G., Silva, P., & Gouyon, F. (2013). The effect of microtiming deviations on the perception of groove in short rhythms. *Music Perception: An Interdisciplinary Journal*, *30*(5), 497–510.

Davis, M. H. (1980). A multidimensional approach to individual difference in empathy. *JSAS Catalog of Selected Documents in Psychology*, *10*(85).

Driedger, J. (2014). *Extending harmonic percussive separation of audio signals*. Proceedings of the International Society for Music Information Retrieval Conference, Taipei, Taiwan.

Fitzgerald, D. (2010). *Harmonic/percussive separation using median filtering*. Proceedings of the International Conference on Digital Audio Effects (p. $\tilde{7}$), Graz, Austria.

Gallese, V. (2001). The ‘shared manifold’ hypothesis. from mirror neurons to empathy. *Journal of Consciousness Studies*, *8*(5-6), 33–50.

Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, *2*(12), 493–501.

Gazzola, V., Aziz-Zadeh, L., & Keysers, C. (2006). Empathy and the somatotopic auditory mirror system in humans. *Current Biology*, *16*(18), 1824–1829.

Gingras, B., Marin, M. M., Puig-Waldmüller, E., & Fitch, W. (2015). The eye is listening: Music-induced arousal and individual differences predict pupillary responses. *Frontiers in Human Neuroscience*, *9*, 619.

Godøy, R. I. (2003). Motor-mimetic music cognition. *Leonardo*, *36*(4), 317–319.

Godøy, R. I., & Leman, M. (Eds.). (2010). *Musical gestures: Sound, movement, and meaning*. Routledge.

Gonzalez Sanchez, V. E., Zelechowska, A., & Jensenius, A. R. (2018). Correspondences between music and involuntary human micromotion during standstill. *Frontiers in Psychology*, *9*, 1382.

Gonzalez Sanchez, V., Zelechowska, A., & Jensenius, A. R. (2019). Analysis of the movement-inducing effects of music through the fractality of head sway during standstill. *Journal of motor behavior*, *52*(6), 734–749.

Grahn, J. A. (2012). Neural mechanisms of rhythm perception: Current findings and future perspectives. *Topics in Cognitive Science*, *4*(4), 585–606.

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. *Journal of Cognitive Neuroscience*, *19*(5), 893–906.

Gritten, A., & King, E. (Eds.). (2006). *Music and gesture*. Ashgate.

Gritten, A., & King, E. (Eds.). (2011). *New perspectives on music and gesture*. Hampshire: Ashgate.

Hodges, D. A. (2009). *Bodily responses to music* (pp. 121–130). Oxford University Press.

Hurley, B. K., Martens, P. A., & Janata, P. (2014). Spontaneous sensorimotor coupling with multipart music. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(4), 1679.

Iversen, J. R., & Patel, A. D. (2008). *The beat alignment test (bat): Surveying beat processing abilities in the general population*. Proceedings of the International Conference on Music Perception and Cognition, Sapporo, Japan.

Janata, P., Tomic, S. T., & Haberman, J. M. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General*, *141*(1), 54–75.

Jensenius, A. R., Zelechowska, A., & Gonzalez Sanchez, V. E. (2017). The musical influence on people’s micromotion when standing still in groups. In *Proceedings of the Sound and Music Computing Conference* (pp. 195–200). Stockholm.

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy: History, measurement, and conceptual issues. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), *Handbook of personality: Theory and research* (3rd ed., pp. 114–158). The Guilford Press.

Keller, P. E., Novembre, G., & Hove, M. J. (2014). Rhythm in joint action: Psychological and neurophysiological mechanisms for real-time interpersonal coordination. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1658), 20130394.

Keysers, C., Kohler, E., Umiltà, M. A., Nanetti, L., Fogassi, L., & Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Experimental Brain Research*, *153*(4), 628–636.

Kilchenmann, L., & Senn, O. (2015). Microtiming in swing and funk affects the body movement behavior of music expert listeners. *Frontiers in Psychology*, *6*, 1232.

Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). Hearing sounds, understanding actions: Action representation in mirror neurons. *Science*, *297*(5582), 846–848.

Laeng, B., Eidet, L. M., Sulutvedt, U., & Panksepp, J. (2016). Music chills: The eye pupil as a mirror to music's soul. *Consciousness and Cognition*, *44*, 161–178.

Launay, J. (2015). Musical sounds, motor resonance, and detectable agency. *Empirical Musicology Review*, *10*(1–2), 30–40.

Luck, G., Saarikallio, S., Burger, B., Thompson, M. R., & Toiviainen, P. (2010). Effects of the big five and musical genre on music-induced movement. *Journal of Research in Personality*, *44*(6), 714–720.

Luck, G., Saarikallio, S., Burger, B., Thompson, M. R., & Toiviainen, P. (2014). Emotion-driven encoding of music preference and personality in dance. *Musicae Scientiae*, *18*(3), 307–323.

Luck, G., Saarikallio, S., & Toiviainen, P. (2009). *Personality traits correlate with characteristics of music-induced movement*. Proceedings of the 7th Triennial Conference of the European Society for the Cognitive Sciences of Music, Jyväskylä, Finland.

Madison, G. (2006). Experiencing groove induced by music: Consistency and phenomenology. *Music Perception: An Interdisciplinary Journal*, *24*(2), 201–208.

Mas-Herrero, E., Marco-Pallares, J., Lorenzo-Seva, U., Zatorre, R. J., & Rodriguez-Fornells, A. (2013). Individual differences in music reward experiences. *Music Perception: An Interdisciplinary Journal*, *31*(2), 118–138.

McCrae, R. R. (2007). Aesthetic chills as a universal marker of openness to experience. *Motivation and Emotion*, *31*(1), 5–11.

McFee, B., Raffel, C., Liang, D., Ellis, D., McVicar, M., Battenberg, E., & Nieto, O. (2015). *Librosa: Audio and music signal analysis in python*. Proceedings of the International Python in Science Conference, Austin, Texas.

McMullin, E. (2017). *A study of listener bass and loudness preferences over loudspeakers and headphones*. Audio Engineering Society Convention 143, New York.

Moelants, D. (2003). *Dance music, movement and tempo preferences*. Proceedings of the 5th Triennial Conference of the European Society for the Cognitive Sciences of Music (pp. 649–652). Hanover.

Molnar-Szakacs, I., & Overy, K. (2006). Music and mirror neurons: From motion to'e'motion. *Social Cognitive and Affective Neuroscience*, *1*(3), 235–241.

Novembre, G., Mitsopoulos, Z., & Keller, P. E. (2019). Empathic perspective taking promotes interpersonal coordination through music. *Scientific Reports*, *9*(1), 12255.

Nusbaum, E. C., & Silvia, P. J. (2011). Shivers and timbres: Personality and the experience of chills from music. *Social Psychological and Personality Science*, *2*(2), 199–204.

Overy, K., & Molnar-Szakacs, I. (2009). Being together in time: Musical experience and the mirror neuron system. *Music Perception: An Interdisciplinary Journal*, *26*(5), 489–504.

Pfeifer, J. H., Iacoboni, M., Mazziotta, J. C., & Dapretto, M. (2008). Mirroring others' emotions relates to empathy and interpersonal competence in children. *Neuroimage*, *39*(4), 2076–2085.

Phillips-Silver, J., & Trainor, L. J. (2005). Feeling the beat: Movement influences infant rhythm perception. *Science*, *308*(5727), 1430–1430.

Phillips-Silver, J., & Trainor, L. J. (2007). Hearing what the body feels: Auditory encoding of rhythmic movement. *Cognition*, *105*(3), 533–546.

Phillips-Silver, J., & Trainor, L. J. (2008). Vestibular influence on auditory metrical interpretation. *Brain and Cognition*, *67*(1), 94–102.

Preston, S. D., & De Waal, F. B. (2002). Empathy: Its ultimate and proximate bases. *Behavioral and Brain Sciences*, *25*(1), 1–20.

Ross, J. M., Warlaumont, A. S., Abney, D. H., Rigoli, L. M., & Balasubramaniam, R. (2016). Influence of musical groove on postural sway. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(3), 308.

Saarikallio, S., Vuoskoski, J., & Luck, G. (2012). *Emotion perception in music is mediated by socio-emotional competence*. Proceedings of the 12th International Conference on Music Perception and Cognition, Thessaloniki.

Senn, O., Bechtold, T. A., Hoesl, F., & Kilchenmann, L. (2019). Taste and familiarity affect the experience of groove in popular music. *Musicae Scientiae*. Retrieved from https://journals.sagepub.com/doi/10.1177/1029864919839172

Senn, O., Kilchenmann, L., Bechtold, T., & Hoesl, F. (2018). Groove in drum patterns as a function of both rhythmic properties and listeners' attitudes. *PloS One*, *13*(6), e0199604.

Seyfarth, R. M., & Cheney, D. L. (2013). Affiliation, empathy, and the origins of theory of mind. *Proceedings of the National Academy of Sciences*, *110*(2), 10349–10356.

Sievers, B., Polansky, L., Casey, M., & Wheatley, T. (2013). Music and movement share a dynamic structure that supports universal expressions of emotion. *Proceedings of the National Academy of Sciences*, *110*(1), 70–75.

Skaansar, J. F., Laeng, B., & Danielsen, A. (2019). Microtiming and mental effort: Onset asynchronies in musical rhythm modulate pupil size. *Music Perception: An Interdisciplinary Journal*, *37*(2), 111–133.

Solberg, R. T., & Jensenius, A. R. (2016). Pleasurable and intersubjectively embodied experiences of electronic dance music. *Empirical Musicology Review*, *11*(3–4), 301–318.

Stupacher, J., Hove, M. J., Novembre, G., Schütz-Bosbach, S., & Keller, P. E. (2013). Musical groove modulates motor cortex excitability: A tms investigation. *Brain and Cognition*, *82*(2), 127–136.

Su, Y.-H., & Pöppel, E. (2012). Body movement enhances the extraction of temporal structures in auditory sequences. *Psychological Research*, *76*(3), 373–382.

Tabachnick, B. G., Fidell, L. S., & Ullman, J. B. (2007). *Using multivariate statistics* (Vol. 5). Boston: Pearson.

Taruffi, L., & Koelsch, S. (2014). The paradox of music-evoked sadness: An online survey. *PLoS One*, *9*(10), e110490.

Van Dyck, E., Moelants, D., Demey, M., Coussement, P., Deweppe, A., & Leman, M. (2010). *The impact of the bass drum on body movement in spontaneous dance*. Proceedings of the 11th International Conference in Music Perception and Cognition, pp. 429–434, Seattle, WA.

Vuoskoski, J. K., & Eerola, T. (2012). *Empathy contributes to the intensity of music-induced emotions*. Proceedings of the 12th International Conference on Music Perception and Cognition (pp. 1112–1113), Thessaloniki.

Vuoskoski, J. K., Thompson, W. F., McIlwain, D., & Eerola, T. (2012). Who enjoys listening to sad music and why? *Music Perception: An Interdisciplinary Journal*, *29*(3), 311–317.

Wallmark, Z., Deblieck, C., & Iacoboni, M. (2018). Neurophysiological effects of trait empathy in music listening. *Frontiers in Behavioral Neuroscience*, *12*, 66.

Walworth, D. D. (2003). The effect of preferred music genre selection versus preferred song selection on experimentally induced anxiety levels. *Journal of Music Therapy*, *40*(1), 2–14.

Wiltermuth, S. S., & Heath, C. (2009). Synchrony and cooperation. *Psychological Science*, *20*(1), 1–5.

Witek, M. A., Clarke, E. F., Wallentin, M., Kringelbach, M. L., & Vuust, P. (2014). Syncopation, body-movement and pleasure in groove music. *PloS One*, *9*(4), e94446.

Witek, M. A., Popescu, T., Clarke, E. F., Hansen, M., Konvalinka, I., Kringelbach, M. L., & Vuust, P. (2017). Syncopation affects free body-movement in musical groove. *Experimental Brain Research*, *235*(4), 995–1005.

Zelechowska, A., Gonzalez-Sanchez, V. E., Laeng, B., & Jensenius, A. R. (2020). Headphones or speakers? An exploratory study of their effects on spontaneous body movement to rhythmic music. *Frontiers in Psychology*, *11*.

Zentner, M., & Eerola, T. (2010). Rhythmic engagement with music in infancy. *Proceedings of the National Academy of Sciences*, *107*(13), 5768–5773.

Appendix

The oral instruction given to subjects before the experiment:

> Please stand on the force platform in a relaxed, comfortable position with your arms at the sides of your body. Try to remain in this neutral position during the experiment. Keep your eyes on the white cross on the wall. You will hear some rhythms and music, with periods of silence between them, and the experiment will last about 8 minutes. We will start with 30 seconds of silence. Are the instructions clear?