Standstill to the ‘beat’: Differences in involuntary movement responses to simple and complex rhythms

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ABSTRACT

Previous studies have shown that movement-inducing properties of music largely depend on the rhythmic complexity of the stimuli. However, little is known about how simple isochronous beat patterns differ from more complex rhythmic structures in their effect on body movement. In this paper we study spontaneous movement of 98 participants instructed to stand as still as possible for 7 minutes while listening to silence and randomised sound excerpts: isochronous drumbeats and complex drum patterns, each at three different tempi (90, 120, 140 BPM). The participants' head movement was recorded with an optical motion capture system. We found that on average participants moved more during the sound stimuli than in silence, which confirms the results from our previous studies. Moreover, the stimulus with complex drum patterns elicited more movement when compared to the isochronous drum beats. Across different tempi, the participants moved most at 120 BPM for the average of both types of stimuli. For the isochronous drumbeats, however, their movement was highest at 140 BPM. These results can contribute to our understanding of the interplay between rhythmic complexity, tempo and music-induced movement.

CCS CONCEPTS

• **Applied computing** → *Sound and music computing*; **Psychology**.

KEYWORDS

Music, Rhythm, Movement, Motion Capture, Groove

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Figure 1: A group of participants ready to stand still. Each participant wears a motion capture marker on top of their head. A reference marker placed on a tripod can be seen in between the participants. Two speakers in front of the participants were used for sound playback.

1 INTRODUCTION

Music and movement are so deeply connected that they can be considered an ‘ancient marriage’ [22]. Not only is body movement required to produce music (unless the process is fully moved to the digital realm), but also listening to music can create an *urge* to move [11]. Recent studies have shown that music can increase body movement even when people try to stand still [8, 9, 13]. These findings not only confirm the common belief that ‘music moves us’, but also show that movement to music can be involuntary. Moreover, previous studies have shown that particularly music with clear rhythmic patterns, such as electronic dance music (EDM), has movement-inducing properties [8]. This is in line with several other studies that have shown that rhythmic features have a particularly strong influence on body movement [4, 5, 31], and on the feeling of groove, i.e., an urge to move [11, 17, 21, 30].

Several studies indicate that an optimal rhythmic complexity, which is neither too simple nor too unpredictable, is crucial for inducing the sensation of wanting to move [17, 23, 30, 31]. However, a study in which actual movement was measured showed

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that free movement of hands and torso is fairly similar in terms of acceleration and synchronisation for rhythms of low and medium complexity [31]. Still, the lowest possible level of rhythmic complexity, such as in simple isochronous beats of a metronome—i.e., sequences of beats occurring at equal time intervals—should have a smaller movement-inducing effect than regular music. Contrary to this assumption, Zentner and Eerola [33] found that infants spontaneously moved to isochronous drum beats as much as they did to rhythmic music, and more than to rhythmic speech.

Studies on adults have shown mixed results when comparing movement to music and isochronous streams of sounds (most often, sounds of synthetic or acoustic metronomes). Both types of stimuli are often used as cues in research on motor rehabilitation, but typically either music or metronome stimuli are used without comparison [1, 20]. Studies on healthy populations have shown that music, compared to metronome cues, increases stride length and walking speed [25, 32]. On the other hand, it has also been found that metronome cues work better than music when people try to synchronise their steps to the beat while walking [15]. Thus, there seems to be little consensus on the effects of music and metronome-like sounds on body movement in the literature.

The use of metronomes for comparing the impact of simple rhythms with more complex rhythmic stimuli might result in biases. Metronome sounds are usually relatively high in pitch, whereas music used in movement studies usually contains a wider frequency range. Some studies indicate that low-frequency sound can increase the intensity of movement, as well as the quality of the synchronisation with the beat [3, 24, 28]. In the case of simple auditory rhythms, it has been shown that using a low-pitched metronome sound (100 Hz) results in higher movement intensity and better synchronisation with sound compared to that of a metronome with a higher pitch (1600 Hz) [29]. This can be explained by the superior time perception for lower musical pitch [10]. Moreover, the functioning of the vestibular system in the inner ear is particularly sensitive to stimulation with low-frequency sound, and is associated with sensations of body movement [26, 27]. Therefore, it seems more appropriate to use low-frequency sounds, such as the sound of a bass drum, when comparing the effects of simple isochronous rhythms with those of more complex rhythmic stimuli or music [33]. Natural drum sounds often have timbral and dynamical qualities that make them perceptually more similar to music than a plain metronome. Moreover, drums are often associated with body movement. In some cultures it is common to dance to the sound of drums alone, such as to the Japanese taiko [26]. To our knowledge, this type of music has not been used so far in studies on body movement.

Finally, there is evidence suggesting that the tempo of musical stimuli is crucial for inducing movement. Studies on groove showed that the optimal tempo for eliciting sensation of wanting to move is within the range 100–120 BPM [6, 11]. However, other studies suggest that tempo plays little role in the feeling of groove [17]. The preferred tempo for movement can depend on the type of movement. For dancing, on average people prefer a tempo around 125–130 BPM [19], while for walking, a tempo of 110–120 BPM is preferred [25]. Some researchers point out that the natural walking tempo, which on average is around 120 BPM [16], is similar to the tempo of dance and music. An evolutionary explanation of this can be that bipedalism contributed to the development of various rhythmic behaviours and organisation of sensory-motor circuits in the brain [14, 26]. One could speculate that tempi in the range 110–130 BPM should have particularly strong movement-inducing properties. However, the role of rhythmic tempo on inducing body movement when standing is still unknown.

In the present study, we examine the impact of complex drum patterns and isochronous drumbeats (in three different tempi) on involuntary movement responses to music, in a task where participants are asked to stand as still as possible. Based on knowledge from the literature, we hypothesise that:

(1) there will be more involuntary movement in the sound condition (both isochronous and complex drum patterns) than in the silence condition,
(2) the complex drum patterns will induce more involuntary movement than the isochronous drumbeats,
(3) the stimuli at 120 BPM will induce more involuntary movement than the stimuli at 90 BPM and 140 BPM, for both isochronous and complex drum patterns.

2 METHODS

2.1 Participants

The experiment took place during the University of Oslo "Open Day" in March 2019, advertised as "The Nordic Championship of Standstill". The participants included students and staff from the University, but also other interested people from the larger Oslo area. A prize of 1000 NOK was offered to the participant with the lowest captured motion. Participation was open to everyone, but those who met the exclusion criteria were excluded from the analysis: age under 18 years old, participation in earlier editions of the experiment, hearing loss or balance disorder. The final dataset used for the analysis consisted of 98 participants (41 female, 57 male, average age: 24.6 years, SD: 8.8 years).

The participants were asked to report on the hours per week spent on listening to music (15.9 hours, SD: 14.5), creating music (3.9 hours, SD: 9.2), dancing (1.9 hours, SD: 2.3), and exercising physically (4.2 hours, SD: 3.8). All participants gave their informed consent prior to the experiment, and they were allowed to withdraw from the study at any point in time.

2.2 Motion capture

An eight-camera optical, marker-based, infrared motion capture system (Optitrack Flex 100) was used to track the instantaneous 3D position of a reflective marker placed on the top of each participant's head at a sampling rate of 120 Hz. It has previously been shown that the spatial noise level of such motion capture system is considerably lower than that of human head sway during standstill [2, 12]. Position data was recorded and pre-processed in OptiTrack Motive, and further analysis was done in Python and SPSS Statistics.

2.3 Sound stimuli

The six sound stimuli consisted of three isochronous drumbeats (Isochronous) and three custom-made complex drum patterns (Complex).[1] Each set was played at different tempi (90, 120, 140 BPM).

[1]The stimuli are openly available under DOI: http://doi.org/10.5281/zenodo.3970991

The spectrograms in Figure 2 show the differences in tempo and overall density of the six tracks.

All stimuli were produced with samples from an openly available database of acoustic drum recordings.[2] Each of the three isochronous drumbeat tracks was based on a single drum sample, looped over 30 seconds. We ended up using a different drum sample for each of the three tracks to ensure that the timbral qualities of the drum sounds were preserved. This was decided on after initial testing with time stretching and pitch shifting of the samples, which resulted in audible artefacts. Since the original samples were slightly different between tempi, the final isochronous tracks ended up with some pitch and timbre differences, as can be seen in the chromagrams in Figure 4. It should also be noted that most of these samples are recorded from bass drums, thus they have a fairly low fundamental frequency and a long attack time (see the close-up of the waveform in Figure 3). We deliberately wanted such a rich and full bass drum sound for the isochronous drumbeats, instead of a sharper high-frequency metronome-like sound.

As for the complex drum patterns, these were produced based on short two-bar sequences of different types of drums in various tempi from the same database as mentioned above. The aim was to create drum patterns with a certain level of timbral and rhythmic complexity, rather than synthetic, highly controlled arrangements of isolated drum sounds. Again, we experimented with time stretching and pitch shifting recordings at different tempi, which ended up sounding unnatural. Thus, there are differences between the produced tracks because of the differences in samples used. The final tracks have qualities similar to those of the Japanese taiko drum playing, with rhythmic patterns that are neither too simple nor too complex. The different pitches of the drums and the richness of their timbres can easily be seen in the chromagrams in Figure 4.

The stimuli were played to the participants at a comfortably loud volume using two Genelec 8020 loudspeakers mounted on a rig between the ceiling and the wall facing the participants (see Figure 1). The distance between the speakers and the heads of the participants in the first row was approximately 1.5 meters. The speakers were mounted in such way that none of the participants stood directly in front of a speaker.

2.4 Procedure

The participants were recorded in groups of 4–8 people at a time. The uneven group distribution was caused by the availability of people throughout the day of the experiment. The distribution of participants in the laboratory was standardised across trials, with marks on the floor indicating the positions where people could stand. After choosing one of the marked spots on the floor, participants signed the consent forms and were instrumented with a single motion capture marker on top of their heads. Next, they were introduced to the study, and asked to stand as still as possible during the seven-minute long recording session, being free to choose their own standing posture. All participants faced in the same direction (see Figure 1).

During the recording session, the participants were exposed to silence and sound in alternating order. Each trial began and ended with 45 seconds of silence, with alternating segments of 30 seconds of sound (approximately, as the samples were cut to the bar) and 30 seconds of silence in between. Thus, a complete sequence consisted of: Silence, Stimuli1, Silence, Stimuli2, Silence, Stimuli3, Silence,

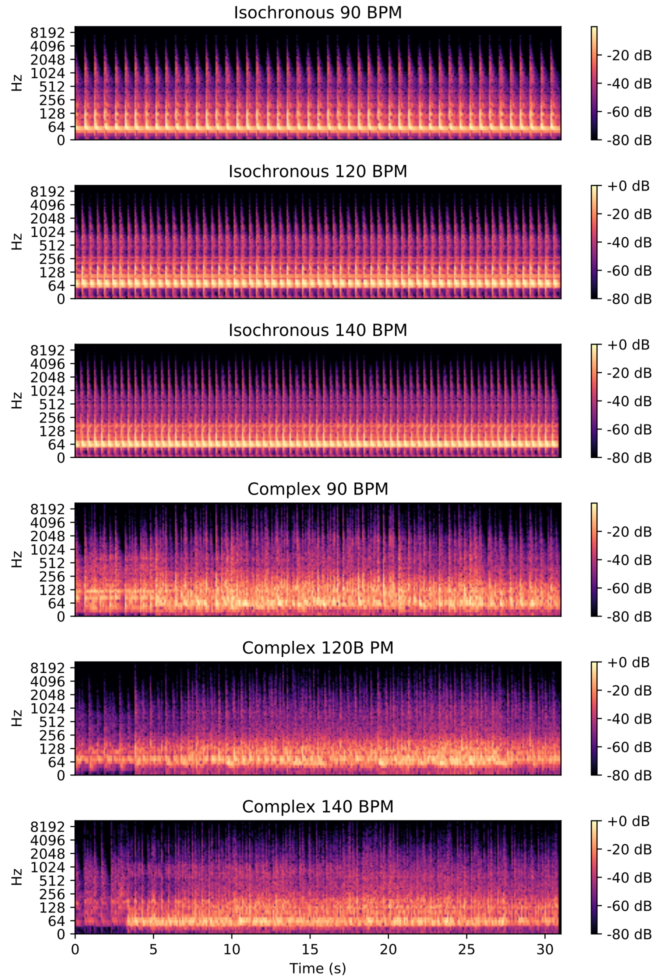

Figure 2: Spectrograms of each of the six sound stimuli, showing the differences in tempo and rhythmic complexity between the tracks.

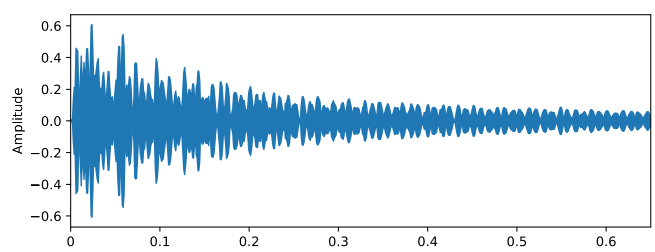

Figure 3: A closer look at the waveform of one of the drum sounds used in the isochronous pattern reveals some of the richness of this bass drum sound.

[2] https://www.musicradar.com/news/sampleradar-260-free-tribal-adventures-samples

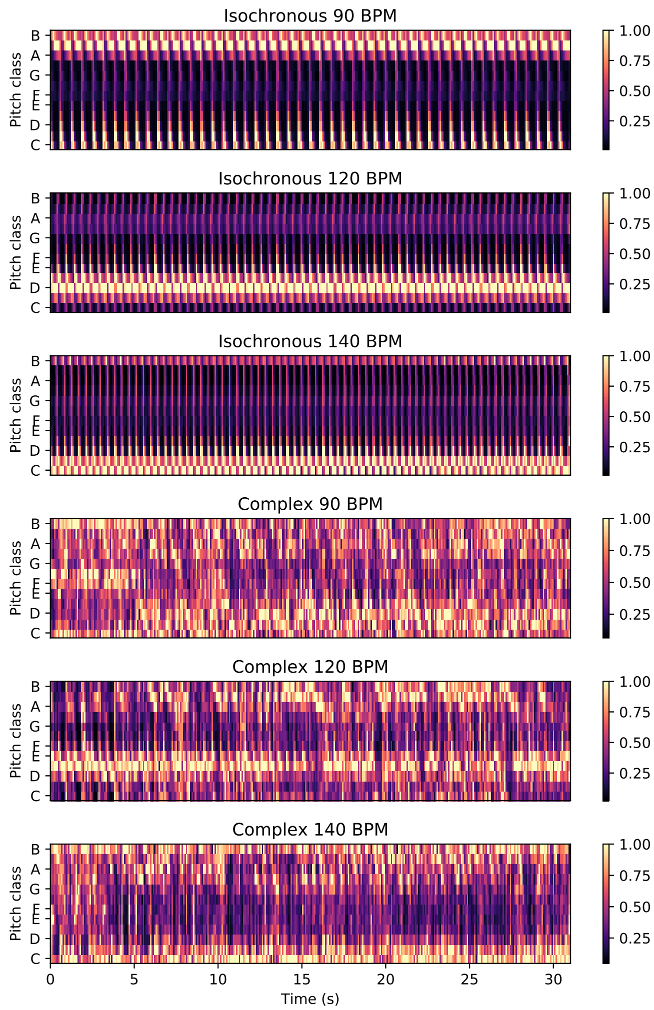

Figure 4: Chromagrams of the six stimuli reveal some pitch differences in the tuning of the drums. Since different samples were used (without pitch shifting), they have different pitches. The calculation is done using the `librosa.feature.chroma_cqt` function from Librosa [18], with a hop size of 512 samples.

Stimuli4, Silence, Stimuli5, Silence, Stimuli6, and Silence. The six sound stimuli were played in random order for each trial.

After the experiment, participants were asked to fill in a short set of questionnaires, which are not a subject of analysis in the present paper. The whole experiment session for each group lasted for approximately 30 minutes.

2.5 Analysis

As in our previous studies, the head sway of each participant was measured as the quantity of motion (QoM) of their respective reflective marker. This was computed as the first derivative of the position time series:

$$QoM = \frac{1}{T} \sum_{n=2}^{N} \parallel p(n) - p(n-1) \parallel$$

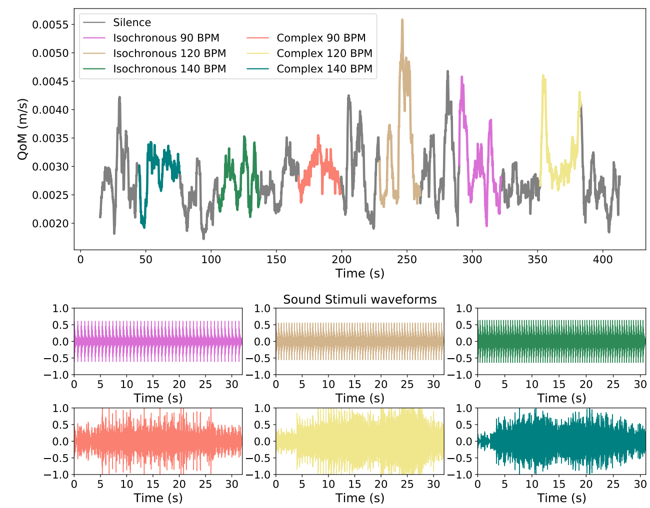

Figure 5: Waveforms of the auditory stimuli (bottom) and segmented QoM time series (top) showing the complete experiment data from one participant.

where p is the 3D position of a marker, N is the total number of samples and T is the total duration of the recording. Instantaneous QoM was obtained for each participant for the whole trial and subsequently segmented by stimulus for further analysis (see Figure 5). Thus, the complete data set consisted of 1274 QoM time series (116 participants x 13 segments). The position data of one marker attached to a tripod located at the centre of the capture volume was used to control for sound-induced and other types of artifacts in the motion data.

Mean QoM values were compared between conditions (sound stimuli and silence) using a paired-sample t-test, while a two-way repeated measures analysis of variance (ANOVA) was used to measure the effects of type of stimulus (isochronous and complex patterns) and tempo (BPM) on QoM. Analyses of the audio tracks were done with Librosa [18].

3 RESULTS

The head sway paths from a representative trial for one subject (Figure 6) show that people do, indeed, move continuously while trying stand still, yet at a very small scale. The influence of condition (silence vs sound stimuli) on QoM was assessed by computing the average QoM for segments of silence and segments of sound stimuli. The average QoM for the sound condition was 9.39 mm/s (SD = 2.64 mm/s), while the average QoM for the silence condition was 8.70 mm/s (SD = 2.71 mm/s). A paired-samples t-test revealed that these differences were statistically significant ($t(97) = 9.45$, $p < 0.001$). The differences were also significant when comparing the silence segments with the Complex stimuli ($t(97) = 11.26$, $p < 0.001$) and with Isochronous stimuli ($t(97) = 4.67$, $p < 0.001$) separately.

Mean and standard deviation values for QoM to each of the sound stimuli are displayed in Table 1. A two-way ANOVA revealed that there was a significant main effect of the type of sound stimulus on the participants' quantity of motion, which was higher to the Complex stimuli ($F(1,97) = 22.08$, $p > .001$, $\eta_p^2 = .185$). The main

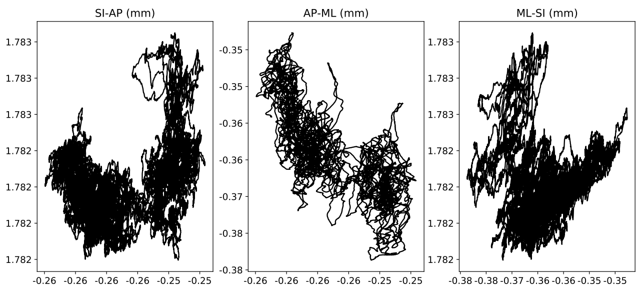

Figure 6: Example head movement exhibited by one participant for a complete trial (7 minutes) in the superior-inferior (SI), anterior-posterior (AP), and medial-lateral (ML) directions.

Table 1: Means and standard deviations of quantity of motion for all stimuli, and for the sound and silence conditions.

Track	Tempo (BPM)	Mean QoM (mm/s)	SD QoM (mm/s)
Isochronous	90	8.74	2.72
Isochronous	120	9.24	2.70
Isochronous	140	9.46	3.15
Complex	90	9.06	2.67
Complex	120	10.50	3.27
Complex	140	9.32	2.73
Sound	—	9.39	2.64
Silence	—	8.70	2.71

effect of tempo on QoM was also significant (F(2,194) = 31.66, p > .001, η_p^2 = .246). Highest QoM was observed to the sound stimuli at 120 BPM. Furthermore, there was a significant interaction between the type of stimulus and tempo (F(2,194) = 13.91, p > .001, η_p^2 = .125). For the Complex stimuli, the largest movement was at 120 BPM, while for the Isochronous stimuli the largest movement was observed at 140 BPM. Figure 7 displays the interactions between the type of stimulus and tempo, with respect to QoM.

4 DISCUSSION

The results show that both the complex drum patterns and the isochronous drumbeats appear to have movement-inducing properties. Compared to the silence condition, participants moved more to both types of sound stimuli. This is in line with our previous findings, which showed more involuntary movement to rhythmic music than silence [8, 9, 13]. It also corroborates findings that both isochronous drumbeats and rhythmic music induce spontaneous movement responses in infants [33].

When comparing the two types of sound stimuli, we found that the complex drum patterns induced more involuntary movement than the isochronous drumbeats. Previous studies suggest that rhythmic patterns should not be too simple, but also not too complex, in order to induce feelings of wanting to move to music [17, 23, 30]. Our findings fit well into this narrative. However, in another study [31], free movement of hands and torso did not differ

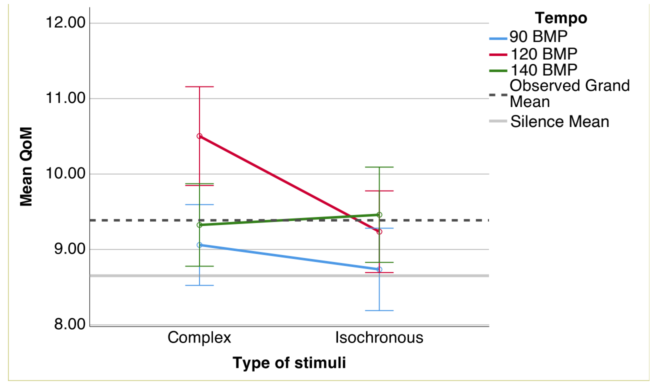

Figure 7: Interactions between the type of stimulus and tempo, with respect to quantity of motion. Error bars represent the 95% confidence interval (CI).

when performed to stimuli of low and medium rhythmic complexity. These findings seem to oppose our results, but it should be noted that this and the present study examined different types of movement behaviour (free movement versus involuntary movement during standstill), and used different types of rhythmic stimuli. In particular, the low-complexity stimuli used by Witek et al. [31] included a weak degree of syncopation, while our low-complexity stimuli was an isochronous beat pattern. Furthermore, some previous studies showed that music, compared to metronomes, has a stronger impact on walking [25, 32], while others produced the opposite result [15]. Our present findings indicate that, at least for spontaneous movement responses to sound, more complex rhythmic stimuli have more movement-inducing properties than simple isochronous beats.

For both types of sound stimuli, tempo appears to have a significant impact on the level of movement. We observed significantly more movement to the average of both sound stimuli at 120 BPM than at 90 BPM or 140 BPM. This fits well with studies indicating that we are particularly sensitive to rhythms at around 120 BPM, because it matches the natural tempo of human locomotion, which shaped the evolution of sensory-motor circuits in the brain [14, 26]. It also to some extent aligns with studies on the influence of tempo on the feeling of groove [6, 11] and preferred tempo for dance [19]. However, when investigating each of the two types of sound stimuli separately, 120 BPM was the most movement-inducing tempo only for the complex drum patterns, whereas for the isochronous drumbeats, it was 140 BPM. This result is surprising, and goes against our hypothesis. One reason for this finding could be that the very fast, repetitive stimuli had a discomforting or disorienting effect, which led to more fidgeting and more head movement. Another explanation could be that the participants involuntarily moved their head to the beats, and given that at 140 BPM tempo there are more beats per minute than in 90 or 120 BPM, there was also more head movement. However, that was not the case for the complex drum patterns. Perhaps the differences between the impact of tempo between the two stimuli types are due to the design of the stimuli between different tempi? In the case of the isochronous drumbeats, it may be that the drum sound used to produce the 120 BPM stimulus had more movement-inducing properties than the sounds used in the 90 BPM and 140 BPM stimuli. It is also possible that among the complex drum patterns, the 120 BPM stimulus was unintentionally produced in a way that gave a stronger urge to move than the stimuli at the two other tempi. When producing the complex stimuli, the use of syncopation and other sound features related to rhythmic complexity was not thoroughly controlled. All stimuli were designed by ear, without following a systematic pattern that would be identical for the three tracks.

This brings us to the issue that can be considered both a limitation and an advantage of this study. Our goal was to include stimuli that felt ecological to the participants, something that they could have heard in everyday life. For this reason, we employed prerecorded sounds of real drums. We tried to produce the drum stimuli in a way that would resemble music played by Japanese taiko drummers. Such music is associated with large, dynamic movements of the body, and is performed with a dance-like choreography. According to the motor-mimetic theory, we spontaneously associate the sounds we hear with the movement they resulted from [7]. Our aim was to try to induce movement in the participants with these naturalistic sounds associated with drum playing. Moreover, the drum sounds used in the stimuli had a more complex timbre as well as more low-frequency content. This was intentional, as previous research suggests that low-frequency sounds stimulate the vestibular system [26, 27], and increase the urge to move and the intensity of actual movement [3, 24, 28, 29]. However, the fact that we used drums of different frequencies when designing the stimuli (and particularly the isochronous drumbeats stimuli, in which only one drum was playing at a time), can be seen as a limitation. Our rationale was to pick drum samples that sounded well, and that would not bore the participants. It was beyond the scope of this paper to record our own, controlled drum samples, but this could be one approach to overcome such a limitation in future studies.

Last but not least, the potential influence of the group setting on body movement was not examined in this study, which can be seen as a limitation. It is possible that there were certain collective dynamics within groups of participants that influenced how much they moved. For example, the level of motivation to win the competition exhibited by a fellow participant could have influenced the attitude of the other people in the group towards the standstill task. At the same time, individuals can differ in terms of how easily they are affected by feelings and attitudes of others, for example depending on their level of empathy trait. It is also possible that seeing another person moving could have influenced the movement of a participant. Thus, it could be argued that the participants in the second row were able to see the participants standing in front of them, but not vice versa. In future studies, it would be interesting to take into account shared and individual experiences of movement that could influence the actual movement, and to experiment with the positioning of participants within the recording space.

5 CONCLUSIONS

In this study we compared the effects of simple isochronous drumbeats and complex drum patterns, produced with naturalistic drum sounds, on involuntary movement responses to music. We observed more head movement to both types of stimuli than in silence, as well as more movement to the complex drum patterns than to the isochronous drumbeats. These results fit well with previous findings about the movement-inducing properties of music. They also correspond with some previous findings on higher influence of music on body movement compared to simple isochronous rhythms, although there is little consensus on that topic in the literature. Furthermore, we showed that participants on average moved most to the music stimuli at 120 BPM. This supports the hypothesis of a particular 'resonating' frequency of spontaneous human body movement. However, contrary to our expectation, we found that the 140 BPM drumbeats were most movement-inducing among the isochronous beats. It would be interesting to study the effects of tempo differences between simple and complex rhythmic patterns on spontaneous body movement further in follow-up studies.

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