Syncopation affects free body-movement in musical groove

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Abstract

One of the most immediate and overt ways in which people respond to music is by moving their bodies to the beat. However, the extent to which the rhythmic complexity of groove – specifically its syncopation – contributes to how people spontaneously move to music is largely unexplored. Here we measured free movements in hand and torso while participants listened to drum-breaks with various degrees of syncopation. We found that drum-breaks with medium degrees of syncopation were associated with the same amount of acceleration and synchronisation as low degrees of syncopation. Participants who enjoyed dancing made more complex movements than those who didn't enjoy dancing. While for all participants, hand movements accelerated more and were more complex, torso movements were more synchronised to the beat. Overall, movements were mostly synchronised to the main beat and half-beat level, depending on the body-part. We demonstrate that while people do not move or synchronise much to rhythms with High syncopation when dancing spontaneously to music, the relationship between rhythmic complexity and synchronization is less linear than in simple finger-tapping studies.

Keywords: music, movement, rhythm, syncopation groove, synchronisation

Effects of syncopation on free body-movement in musical groove

The body is posited as the central site for cognitive processes, according to the embodied approach to perception (Clark 2008; Leman 2007; Varela et al. 1991). For music, it is hard to imagine a context more obvious than dance as an illustration of that claim: through body-movement, music is actively perceived and physically embodied in ways that correspond to the structure of the music. An important concept in music and dance is groove. It is defined as a musical quality associated with a pleasurable desire for body-movement (Janata et al. 2012; Madison 2006; Madison et al. 2011; Stupacher et al. 2013) and music that is associated with groove is thus a particularly suitable venue for the investigation of music-directed dance. In groove research, syncopation – a form of rhythmic complexity – has been shown to be an important predictor. While some studies have shown that there is an inverted U-shaped relationship between syncopation and ratings of pleasurable wanting to move (Sioros et al. 2014; Witek et al. 2014b), other studies show negative linear relationships between syncopation and synchronised finger-tapping (Fitch and Rosenfeld 2007; Ladinig et al. 2009; Song et al. 2013; Witek et al. 2014a). But what is the relationship between syncopation in groove and body-movement in dance? To what extent does syncopation affect how people move spontaneously to music? Here, we report on a study in which we used motion-capture to record free body-movement in response to rhythmic patterns with varying degrees of syncopation, measuring the acceleration, synchronisation, complexity and periodicity of body movements. Our main aim was to investigate the effects of a) syncopation in groove and b) musical background on these movement properties.

The progress in embodied music perception (Johnson and Larson 2003; Leman 2007; Zbikowski 2004) has been facilitated by the development of sophisticated motion-capture systems for measuring body-movements in space and time. Motion-capture research in music demonstrates that dancers map their body-movements to the structural (Leman and Naveda 2010), acoustic (Burger et al. 2013b) and emotional characteristics (Burger et al. 2013a; Saarikallio et al. 2013) of music. Some studies have specifically focused on rhythm and metre (Toiviainen et al. 2010), rhythm being broadly defined as a pattern of discrete durations organised into groups (Clarke 1999; Fraisse 1963; Fraisse 1982); while metre is understood as the temporal framework in relation to which rhythm is perceived (Jones 2009; Lerdahl and Jackendoff 1983; London 2012). Formally, metre is also organised hierarchically (Lerdahl and Jackendoff 1983; Longuet-Higgins and Lee 1984; Temperley 2010), with different periodicities corresponding to differing levels of metric salience. At the most fundamental level, metre perception requires beat perception, i.e. the temporal perception of events relative to a regular interval, or “beat” (Honing 2012). Evidence from motion-capture suggests that the most prominent metric periodicity, or beat, expressed in dance is the tactus (the main pulse, or main beat), and that different body-parts can embody different metrical beat levels, simultaneously (Toiviainen et al. 2010). Furthermore, a number of individual factors can affect the propensity towards and nature of music-directed dance, such as biomechanical properties (Todd et al. 2007), personality (Luck et al. 2010), genre preference (Van Dyck et al. 2010) and dance experience (Witek et al. 2014b).

Dance also involves sensorimotor synchronisation, which is the rhythmic coordination of perception and action allowing us to synchronise our movements to a beat. It relies fundamentally on mechanisms of prediction and adaptation (Konvalinka et al. 2010; Repp and Su 2013): in order to align one’s movements with a periodic external referent, one must be able to anticipate the referent’s temporal progression and continuously correct for movement errors. The most significant musical property to affect sensorimotor synchronisation is rhythmic complexity (Chen et al. 2008; Repp and Su 2013; Witek et al. 2014a). One of the most studied forms of rhythmic complexity in music is syncopation, which is defined as a rhythmic event that violates listeners’ metric expectations (Fitch and Rosenfeld 2007; Ladinig et al. 2009; Longuet-Higgins and Lee 1984; Margulis and Beatty 2008; Song et al. 2013; Temperley 2010; Witek et al. 2014a). Using a neural model of oscillations based on dynamic attending theory, Large et al. (Large et al. 2015) confirmed that it is possible to perceive a pulse frequency that is not acoustically present but only metrically implied in a rhythm (i.e. a syncopated rhythm). Furthermore, they found that the more spectral energy at the beat frequency, the less variable was the finger-tapping to the beat. Similar to this, Snyder and Krumhansl (Snyder and Krumhansl 2001) found that tapping to ragtime (i.e. a jazz piano style defined largely by its syncopatedness) was significantly affected by removing the left-hand part, which usually features a predictable alternating bass pattern. Without the regular beat of the left-hand part, tapping to the syncopated patterns of the right-hand part increased the tapping variability and asynchrony and caused more off-beat tapping. Consistent with these studies, a number of experiments have show a negative linear relationship between syncopation and synchronised finger-tapping (Fitch and Rosenfeld 2007; Ladinig et al. 2009; Song et al. 2013; Witek et al. 2014a): more syncopated rhythms challenge listeners’ metric predictions and thus reduce the capacity to synchronise. This effect is modulated by musical training, with musicians performing better than non-musicians (Palmer and Krumhansl 1990; Witek et al. 2014a).

Rhythmic complexity has been shown to be an important structural aspect of groove. In a previous experiment (Witek et al. 2014b) we have shown that medium degrees of syncopation elicit the most desire to move and the most pleasure while listening to drum-breaks, in particular for participants who enjoy dancing. This suggests that listeners prefer a balance between predictability and complexity in music and that there is an inverted U-shaped relationship between syncopation and the desire for body-movement (Sioros et al. 2014). This inverted U-shape – also called Wundt-curve (Wundt 1874) – between complexity and preference has previously been suggested to reflect aesthetic appreciation of art more broadly (Berlyne 1971). Finding this function in response to syncopation in groove, however, seems to contradict evidence regarding the relationship between syncopation and synchronised body-movement: tapping studies show a negative linear relationship between syncopation and synchronisation (Fitch and Rosenfeld 2007; Ladinig et al. 2009; Song et al. 2013; Witek et al. 2014a), while studies involving groove suggest an inverted U-shaped relationship between syncopation and desire for synchronised body-movement (Sioros et al. 2014; Witek et al. 2014b). While one study showed that the more a piece of music is perceived as having groove the more participants synchronise their finger-tapping to the beat (Janata et al. 2012), no study has until now specifically measured the synchronisation of free body-movements to syncopated music. While finger-tapping is an embodied activity, moving the core body (i.e. torso) is more embodied in the sense that it involves moving the whole body and affords a different affective experience.

The study reported here used motion-capture to investigate the relationship between three degrees of syncopation and free body-movements in the hands and torsos of participants with varying levels of musical training and who enjoyed dancing and listening to groove to differing extents. In light of earlier findings of an inverted U-shaped relationship between syncopation and wanting to move (Witek et al. 2014b), we hypothesised that participants would move more to drum-breaks with Medium syncopation, compared to Low and High. Since dancing to rhythmic music is generally synchronised, we tested the extent to which people synchronised to rhythms with different levels of syncopation and hypothesised that Medium syncopation would increase movement synchronisation. However, since there are no explicit instructions to synchronise when dancing spontaneously to music (this is only implied by the music's rhythmicity), we did not ask people to synchronise. As such, this is not primarily a synchronisation study, but a study of free body-movement which measures synchronisation alongside a number of other movement properties. One of these other properties was the spatial dimensionality of movements, which we measured to investigate whether syncopation affects the complexity of people's movements and whether there is a relationship between temporal synchronisation and spatial complexity in moving to groove. The possible effect of syncopation on the most prominent periodicities in movements was also investigated, on the basis that people might change the metrical level to which they synchronise according to the degree of syncopation in the drum-break. Since musicians demonstrate improved synchronisation with syncopated rhythms (Witek et al. 2014a), we hypothesised that participants with more musical training would be more synchronised than participants with less musical training. Finally, since our previous study (Witek et al. 2014b) found that dance experience influenced ratings of pleasure and wanting to move to groove, and since personality and genre preferences have been found to affect body-movements in dance (Luck et al. 2010; Van Dyck et al. 2010), we measured the effects of dancing experience and groove familiarity.

Method

Participants

Twenty-six right-handed Danish-speaking participants (7 females, 19 males) aged between 21 and 40 (Mean = 25.13, SD = 5.34) were recruited in Aarhus, Denmark, through adverts and opportunity sampling. Informed consent was obtained from all individual participants included in the study. Participants received a small payment for their participation. Before taking part in the motion-capture experiment, they participated in an unpublished fMRI study. One participant (a musician who enjoyed neither groove nor dancing) was excluded from the analysis, since his data showed that he barely moved during the experiment and he reported that he found the study highly unnatural and uncomfortable. Thus the final number of participants was 25.

Participants completed a demographics questionnaire about musical training, dance experience and groove familiarity, which showed that most participants enjoyed dancing and frequently danced to music, and liked and frequently listened to groove. All 25 participants' data were included in the analysis, regardless of their score on these measures. As expected, there were strong correlations between liking and frequency of listening to groove ($r = .642$, $p < .001$), and between liking and frequency of dancing ($r = .625$, $p < .001$). Thus, a principal component analysis (PCA) was run on each of these two group measures, and the resulting first principal components were used as measures of groove familiarity and dance experience. Participants were then defined as belonging to groups based on their position on the spectrum of groove familiarity and dance experience, i.e. whether they were below or above the mean. This yielded the following numbers in each category: groove-enjoyer $n = 12$; non-groove-enjoyer $n = 13$; dance-enjoyer $n = 12$; non-dance-enjoyer $n = 13$. It should be noted that the distribution of responses below and above the mean was not clearly discrete, i.e. there were some responses close to the mean. Therefore, these should not be thought of as strict categories but rather groups of participants with more or less experience with groove and dance. Importantly, groove familiarity did not correlate with dance experience (r = .243, p = .231), suggesting that these categories represented different attributes. The classification of musical training was categorical: Those with six or more years of musical training were categorised as musicians (n = 12), and those with five or fewer years of training were categorised as non-musicians (n = 13).

Stimuli

Participants heard 15 synthesised drum-breaks with varying degrees of syncopation programmed using a synthesised drum-kit in GarageBand 5.1 (Apple, Inc.). Degree of syncopation was coded according to a modified version of Longuet-Higgins and Lee’s (1984) syncopation index, which not only considered the notes’ metric positions but also the polyphonic context and instrumental configuration (see the corrected supporting information in (Witek et al. 2015; Witek et al. 2014b) for a detailed description of the index). We categorised the drum-breaks into three syncopation levels: Low, Medium and High (5 examples in each category). The drum-breaks were chosen from the larger pool of 50 funk drum-breaks used in a previous online survey (Witek et al. 2014b). They consisted of 16-second repeated 2-bar drum-kit patterns of bass-drum, snare-drum and hihat, at 120 bpm. The hihat was sounded on every semi-quaver. Degree of syncopation correlated marginally significantly with total number of onsets (r = -.498, p < .059). The appendix to this paper shows notational transcripts of the 15 drum-breaks used in the study, with Low, Medium and High Syncopation.

Apparatus

Participants’ body-movements were measured using the accelerometer data generated by the Wii remote controllers of the wireless motion-sensor videogame console Wii (Nintendo, Inc). One ‘Wiimote’ was strapped to the lower back (torso), and another held in the right hand. Previous research has found that movements in these body-parts are the most consistently entrained to the main pulse during spontaneous dance to music (Toiviainen et al. 2010). Acceleration in all three Euclidian dimensions (two horizontal, one vertical) was recorded simultaneously for both Wiimotes via WiiDataCapture 2.1 (Burger and Toiviainen 2013) on a MacBook laptop running OSX 10.4. Data were recorded with a sampling frequency of 100 samples per second. The drum-breaks were presented to participants over loudspeakers, and the order of presentation was counter-balanced and logged using Presentation (Neurobehavioral Systems, Inc.) on a Sony Vaio laptop.

Procedure

The room in which the motion-capture took place was large and mostly empty, apart from a table by one wall on which the laptops controlling the experiment and the speakers were placed, facing the centre of the room. A strip of tape was stuck to the floor 130 cm from the speakers, and participants were told not to move beyond the tape during the experiment, in order to keep the loudness level as stable as possible across participants. The loudness of the drum-breaks as projected from the speakers was held constant for all participants, and was measured at the tape location, using a DAWE D-1422C digital sound-level meter, with a 30–135 dB sound range. The mean loudness for the drum-breaks was 75 dB (SD = .97 dB).

The motion-capture recording was triggered by a one-second-long loud beep, and 16 seconds later the first drum-break was presented. In this way, the motion-capture recording was time-locked to the stimuli. During the first 16 seconds of silence, the experimenter left the room, thus leaving the participant to perform the motion-capture task completely alone. Participants were asked to *move freely* to the drum-breaks. Note that there were no explicit instructions to synchronise to the music. Each drum-break was heard twice during the course of the experiment, in randomised order. All drum-breaks were heard once before the repetitions were presented. The drum-breaks followed on from one another continuously, with no gap between them. This prevented any disruption to the regularity of the metre, which was continuous across drum-breaks, avoiding a loss of flow in body-movements. After the last drum-break, the experimenter entered the room and stopped the recording. Finally, subjects completed the demographics questionnaire.

Analysis

The first four seconds of the motion-capture data for each drum-break (i.e. corresponding to the first two bars of the drum-break) were excluded, to allow participants to adjust their movements to the new rhythmic pattern. Four properties of movement were extracted from the data: acceleration, synchronisation index, movement complexity and periodicity. Data were analysed using the MoCap Toolbox 1.4 (Burger and Toiviainen 2013) for MATLAB (Mathworks, Inc.) and PASW 19.0 (IBM, Inc.).

To address how much people moved to drum-breaks with different degrees of syncopation, we measured movement acceleration, defined by the mean acceleration in each trial, averaged over the three Euclidean dimensions (as normalised using the 'mcnorm' function in the MoCap toolbox) and the two repetitions of each drum-break.

To investigate whether participants synchronised to the drum-breaks and whether the synchronisation depended on the degree of syncopation, we calculated the synchronisation index (SI) between the movements and the main pulse of the drum-break, representing the variance of the relative phase (Konvalinka et al. 2010). The three dimensions of motion-capture data were first reduced using Principal Component Analysis (PCA). Subsequent processing and analyses were performed on the first principal component, since it involved the majority of movements' variance. In order to measure synchronisation we needed to focus on a single periodicity to compare between movements and music. Following Phillips-Silver et al. (2010), we filtered the data using Fast Fourier Transform (FFT) with a Gaussian kernel distribution centred on the frequency of the main pulse (i.e. main beat) of the stimuli (2 Hz, given the tempo of 120 bpm and a sampling frequency of 100 samples per second), including 10% of variability on either side of the centre frequency. The filtered data were then Hilbert-transformed, and instantaneous phase data were estimated. A variable representing the tactus in the stimulus (a single value at each sample representing the 2 Hz frequency, i.e. the main pulse) was also processed with the Hilbert transform. SIs were then calculated from the relative phase between the movement data and the tactus. The SI is based on the relative phase of the signals, and is output as a unitless value between 0 and 1, representing the absence of synchrony and perfect synchrony respectively (Skewes et al. 2015; Tognoli et al. 2007). The formula in equation (1) was used:

$$SI = \frac{1}{N}\left|\sum_{n=1}^{N} e^{i(\theta_1(t_n)-\theta_2(t_n))}\right| \qquad (1)$$

where N is the number of taps in each trial, and $\boldsymbol{\theta 1}$ and $\boldsymbol{\theta 2}$ are the respective phases of the movement signal and the tactus. All SIs were averaged across the two stimulus repetitions.

To investigate the relationship between complexity of movements and syncopation, we computed the dimensionality of the motion-capture data, following

Saarikallio et al. (2013). We used PCA on the mocap data to determine the cumulative variance of the principal components. According to Bennett (1969), there is an inverse relationship between the variance in interpoint distances within a hypersphere and the dimensionality of a hypersphere. Thus, in our analyses, a high proportion of cumulative variance represents low dimensionality, i.e. low complexity. Since the first two components of the hand and torso data contained on average about 80% and 86 % of the cumulative variance respectively, we used the cumulative variance of the second component (CumVarPC2) as our measure of dimensionality (i.e. the sum of the variances of the first and second components). Values were averaged across stimulus repetitions.

For acceleration, synchronisation and complexity we performed separate linear and quadratic regressions, using the individual syncopation values for each drum-break as the predictor and average acceleration and synchronisation as the output variables. For these measures, we also performed separate mixed-model 3x2x2x2x2 ANOVAs, with syncopation (Low, Medium and High) and body-part (hand, torso) as the within-subjects variables and musical training, groove familiarity and dance experience as between-subjects variables. Correlations between the measures were also calculated. Due to the large number of variables, we only report main effects and two-way interactions.

For the purpose of obtaining participants' movement periodicities, the maximum amplitude (i.e. the most prominent periodicity during dancing to each drum-break) was extracted, using the 'mcperiod' function (autocorrelation) in the MoCap toolbox. In order to do this, the Euclidean dimensions of the data were reduced with PCA. Since it did not make sense to average across the two repetitions (periodicities are not linear), we chose to use data from the first repetition only, unless no period was detected, in which case we used data from the second repetition. With this procedure, there were only two trials with no period across all participants (these were both in the hand). We then categorised the periods of each trial according to their nearest metric periodicity, with a 20% tolerance. If the period of a trial fell outside of this range, the trial was left empty, indicating that the most prominent periodicity for this trial was not metric. Then, metric periodicity trials were grouped into the three levels of syncopation (Low, Medium and High). It was found that movements were periodic at three metric levels, the quaver 8th note level, the 4th note (beat) level and the half-note level. Using SPSS, we thus performed a 2x3x3 repeated measures ANOVA, with body part (hand and torso), syncopation level (Low, Medium and High) and metric levels (8th, 4th and half note) as independent variables. To reduce the number of variables, we did not include any between-subjects variables in this analysis.

Results

For amount of movement, the regression showed a significant negative linear relationship between acceleration in the hand and syncopation $R^2 = .585$, $F(1,14) = 18.31$, $p < .001$. For the hip, there was a significant negative quadratic relationship between acceleration and syncopation $R^2 = .660$, $F(1,14) = 11.67$, $p = .002$. Table 1 reports the coefficients. In the mixed ANOVA, there were significant main effects of syncopation $F(2,34) = 22.60$, $p < .001$, $\eta^2_p = .571$, and body-part $F(1,17) = 123.37$, $p < .001$, $\eta^2_p = .879$, and an interaction between syncopation and body-part $F(2,34) = 8.23$, $p < .001$, $\eta^2_p = .326$. There were no effects of musical background. Bonferroni corrected tests for simple effects (Table 2) showed that movements in the hand accelerated more than in the torso, and that for both body-parts, movements accelerated more during Low and Medium syncopation, compared to High. There was no significant difference between Low and Medium. Figure 1 shows a) the means for the three levels in both body-parts, as well as the regressed acceleration responses for each participant and the average across participants in b) hand and c) torso.

The relationship between syncopation and synchronisation to the tactus, i.e. main beat of the drum-breaks, was according to our regression analysis negatively linear for the hand R^2 = .784, F(1,14) = 47.08, p < .001, and negatively quadratic for the torso R^2 = .824, F(1,14) = 28.11, p < .001. Coefficients are reported in Table 1. The mixed ANOVA showed main effects of body-part F(1,17) = 10.96, p = .004, η^2_p = .392, and syncopation F(2,34) = 52.77, p < .001, η^2_p = 756, and a significant interaction between syncopation and musical training F(2,34) = 4.91, p = .013, η^2_p = .224. Bonferroni corrected tests of simple effects showed that the torso had a higher SI than the hand (p = .004). Table 3 and Figure 2a show that syncopation affected the synchronisation of musicians and non-musicians similarly, with significant differences between Low and High, and between Medium and High, but not between Low and Medium. Musicians were also marginally significantly more synchronised during High syncopation compared to non-musicians. Figure 2b and 2c show the regression curves for individuals as well as averaged over all participants, for hand and torso respectively. Furthermore, there was a significant between-subjects effect of dance experience F(1,17 = 5.40, p = .033, η^2_p = .241, suggesting that non-dance-enjoyers (Mean = .742, SE = .026) were more synchronised than dance-enjoyers (Mean = .657, SE = .026. There were significant negative correlations between synchronisation and acceleration for hand r = -542, p = .006, and torso r = -.442, p = .027.

For movement complexity, we found no significant regression for the hand. However, for the torso, there was a significant negative quadratic effect of syncopation R^2 = .730, F(1,14) = 16.20, p < .001. See Table 1 for coefficients. There was no effect of syncopation on movement dimensionality in the mixed ANOVA, but a marginally significant effect of body-part $F(1,18) = 3.907$, $p = .065$, $\eta^2_p = .187$, suggesting a trend for hand movements to be more complex than torso movements. Furthermore, dance-enjoyers made more complex movements than non-dance-enjoyers, indicated by dance-enjoyers' lower CumVarPC2 (mean = .856, SE = .006) compared to non-dance-enjoyers (mean = .877, SE = .006) $F(1,17) = 6.86$, $p = .018$, $\eta^2_p = .287$. There were also strong positive correlations between SI and dimensionality (averaged across body-parts) for both musicians ($r = .991$, $p < .001$) and non-musicians ($r = .974$, $p < .001$), and for dance-enjoyers ($r = .987$, $p < .001$) and non-dance-enjoyers ($r = .982$, $p < .001$).

For periodicities, we found significant main effects for metric level $F(1,48) = 27.52$, $p < .001$, $\eta^2_p = .534$, and syncopation level $F(1,48) = 6.56$, $p = .003$, $\eta^2_p =.215$, and also significant interactions between body-part and metric level $F(2,48) = 18.49$, $p < .001$, $\eta^2_p =.435$ and between syncopation and metric level $F(4,96) = 3.26$, $p = .015$, $\eta^2_p = .120$. Bonferroni-corrected simple comparisons showed that there were significant differences between all metric levels in the hand (all $p < .05$), but only between the 8th and 4th note beat level and the 8th and half note level in the torso (p < .01). Figure 3a depicts the means and standard errors, which show that for the hand, the half-note level was the most prominent periodicity, followed by the 4th note beat level and the 8th note level respectively. For the torso, the beat level was the most prominent periodicity compared to the other periodicities, which were not significantly different. There were also significant differences between the hand and torso at every metric level (8th note $p = .029$, 4th note $p < .001$, half-note $p < .001$). The interaction between syncopation and metric level (Figure 3b) amounted mostly to differences within the syncopation levels, although there was also a significant difference between syncopation levels at the beat frequency, specifically participants' movements were more periodic during Medium syncopation compared to High syncopation (p = .022). Within each syncopation level, there were significant differences between the 8th and 4th note beat levels, and between the 8th and half-note levels (all $p < .001$), but not between the 4th and half-note levels.

Discussion

In this study, we found that participants move the least to drum patterns with High levels of syncopation. For the hand, there was a negative linear relationship between syncopation and acceleration, while for the torso, this negative relationship was U-shaped. However, when we compared Low and Medium syncopation for both body-parts, there were no significant differences. Medium syncopation, i.e. a balance between predictability and complexity, has previously been associated with the most wanting to move and the most pleasure in groove (Witek et al. 2014b). Thus, our data suggest that there is some correspondence between ratings of desire to move and actual body-movement in groove (people neither want to nor actually move much to High syncopation), but that intermediate complexity drum-breaks elicit as much movement as rhythmically simple drum-breaks.

A similar pattern was found for synchronisation. In the hand, the regression analyses showed a negative linear relationship, suggesting that the more syncopated the rhythm, the less synchronised the movements. In the torso, this negative relationship was U-shaped. As in movement acceleration, we found no differences between Low and Medium synchronisation for either body-part. Previous research has shown that when asked to synchronise to a rhythm, participants perform worse the more complex the rhythm is (Fitch and Rosenfeld 2007; Ladinig et al. 2009; Song et al. 2013; Witek et al. 2014a). Here, we did not ask participants to synchronise but to move freely, and it seems that the relationship between syncopation and spontaneous synchronisation, while not quite inversely U-shaped, is less clearly negatively linear. Thus, it may be that the desire to move and pleasure specific to groove interacts with the more general detrimental effect of syncopation on sensorimotor synchronisation. In other words, because Medium syncopation motivates body-movement in groove, it may be improving synchronisation; not enough to produce a full-blown inverted U-shaped effect, but by an amount that makes it indistinguishable from Low syncopation. This interpretation would be in accordance with Janata et al.'s study (2012), in which it was found that the more a piece of music was perceived as having groove, the more participants synchronised their tapping to the beat.

But why should intermediately syncopated rhythms invite synchronised behaviour? While the link between medium complexity and maximum pleasure in art has been addressed for several decades (Berlyne 1971) and rhythmic entrainment is increasingly being studied as a musical emotion induction mechanism (Trost and Vuilleumier 2013), it is less clear why intermediate levels of complexity would afford maximal synchronisation. When addressing the link between synchronisation and pleasure, prediction and dopamine are often mentioned, because of their role in both motor and reward functioning (Keitz et al. 2003). The idea is that the embodiment of successful temporal predictions afforded by synchronising to a beat stimulates the reward network in the brain and dopamine encodes these predictions. As for the link between intermediate complexity and sensorimotor synchronisation, it has been argued that syncopation, particularly at medium degrees, invites synchronised body-movements in groove because it opens up 'gaps' in the rhythmic structure that the body feels compelled to 'fill in' by moving to the beat (Witek in press). In other words, syncopation affords a situation in groove where dancers can use their own body-movements to emphasise the beat. This may explain why the participants in our study synchronised more to drum-breaks with medium syncopation than previous finger-tapping studies would predict. Rather than making it more difficult to synchronise, the particular complexity of syncopation in groove makes it more *motivating* to synchronise. In other words, the desire to move elicited by the syncopations counter-balances the difficulty of synchronising to syncopated rhythms.

There were few differences between musicians and non-musicians in our study. Both groups synchronised more to Low and Medium syncopation, compared to High syncopation. At High syncopation, musicians were marginally more synchronised than non-musicians, in accordance with previous research (Chen et al. 2008; Fitch and Rosenfeld 2007; Repp and Su 2013; Witek et al. 2014a). It is possible that with stricter criteria for our groups, this improvement for musicians would be more robust and that there would be significant differences in the other syncopation condisitons as well. There were also strong positive correlations between synchronisation and movement dimensionality for both musical training groups, suggesting that the more spatially complex are their movements, the less are they temporally synchronised. This was also the case for dance-enjoyers and non-dance-enjoyers. Furthermore, dance-enjoyers made significantly more complex movements and were marginally less synchronised compared to non-dance-enjoyers. While professional dancers may be better at synchronising when specifically asked to do so (Miura et al. 2013), our study suggests that when moving spontaneously to music, people who enjoy dancing are more concerned with making spatially complex movements, and this is at the expense of their overall temporal synchronisation. We found no effects of groove familiarity, suggesting that liking and frequently listening to groove does not affect the way people move to music.

There were a number of differences between the two body-parts whose movements we measured. We found that the hand accelerated more, i.e. it moved more than the torso. This can be explained by the greater spatial and temporal degrees of freedom for movement in the hand, due to its smaller size and weight, and greater mobility at the end of a limb. We also found that the torso was more synchronised than the hand. As noted by Toiviainen et al., (2010), the torso has a higher moment of inertia than the arm, due to its greater mass. We thus suggest that the torso is better suited to synchronising to the beat than the hand, while the hand is better suited to making complex non-beat related movements. This was suggested by the finding that hand movements were marginally more complex than torso movements.

The hand and torso also differed in how strongly they entrained to different metrical levels in the drum-breaks, although overall, movements were most strongly entrained to the beat, half-note and 8th note level, as expected (Toiviainen et al. 2010), and only occasionally to non-metric periodicities. For the hand, the half-note was the most prominent periodicity, followed by the beat level and the 8th note level in that order. In the torso, the beat-level was the most prominent periodicity, followed by the half-note and the 8th note, which were similarly prominent. There were also significant differences between the two body-parts at each metric level; the 8th note and beat levels were more prominent in the torso, while the half-note level was most prominent in the hand. Toiviainen et al. (2010) used biomechanical properties to explain different periodicity patterns found in the hand compared to the torso, proposing that body-parts with greater inertia necessarily have longer periodicities in movement. This is opposite to our finding that the torso, with much greater inertia, produced much more prevalent 8th note periodicities than the hand. Therefore, it may be that biomechanical aspects like inertia cannot fully explain the relationship between body-parts and metric periodicities. We suggest that it could be the movements in the legs that determined the metric levels embodied in the torsos of our participants. While we did not measure leg movements, they may have affected the spatio-temporal patterns in the torso. Specifically, we suspect that participants moved to the 8th note level in the legs, by e.g. bending the knees up and down to each 8th note, perhaps in alternating fashion between the right and left leg. This movement would be mirrored in the torso and may explain why we see relatively frequent 8th note periodicities in torso movements. Furthermore, our drum-breaks were instrumentally sparser than the stimuli used in Toiviainen et al.'s study (2010), who used a full-band 12-bar blues progression, and the difference in our findings may be due to the difference in stimuli.

Between the different levels of syncopation, there were few differences in movement periodicities, except that Medium syncopation was associated with more beat level periodicities than High syncopation. This is consistent with the finding that participants were more synchronised to Medium than to High syncopation.

To conclude, this study has shown that during free body-movement to music, syncopation relates to the amount of movement, degree of synchronisation, complexity and the prevalence of different periodicities in hand and torso movements in ways that interact with musical training and dance experience. Contrary to previous finger-tapping research, we found that, during free body-movement to music, the relationship between rhythmic complexity – here in the form of syncopation – and sensorimotor synchronisation is not clearly negatively linear, with no difference in synchronisation between low and medium degrees of syncopation. Our findings further contribute to an understanding of what it is about music that motivates spontaneous motor behaviour, and how musical structure shapes our body-movements. Our study emphasises that when moving freely to music, dancers do not just embody the music by synchronising to the beat but also respond by changing their movements' spatial complexity. As an instance of embodied cognition (Clark 2008; Leman 2007; Varela et al. 1991), we demonstrate how musical properties are spontaneously expressed in body-movement, and how musical dance involves the coordination of perceptual, cognitive and sensorimotor capacities.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Tables

		Hand		*Torso*	
Predictor		*B(β)*	*SEB*	*B(β)*	*SEB*
Acceleration	Constant	28.87**	.741	8.31**	.403
	Syncopation	-.070(-.765)**	0.16	-	-
	Syncopation^2	-	-	-.001(-1.574)**	<.001
Synchronisation	Constant	.790**	.021	.781**	.028
	Syncopation	-.003(-.885)**	<.001		
	Syncopation^2	-	-	<.001(-.2.066)**	<.001
Complexity	Constant	-	-	.879**	.002
	Syncopation	-	-		
	Syncopation^2	-	-	<.001(-2.328)**	<.001

Table 1 Regression coefficients. Syncopation = linear predictor. Syncopation^2 = quadratic predictor. ***p* < .001.

Contrasts		*p*
Hand	Low vs. Medium	>.999
	Low vs. High	<.001**
	Medium vs. High	<.001**
Torso	Low vs. Medium	>.999
	Low vs. High	.002*
	Medium vs. High	.001*
Low	Hand vs. Torso	<.001**
Medium	Hand vs. Torso	<.001**
High	Hand vs. Torso	<.001**

Table 2 Test of simple effects for interaction between syncopation (Low, Medium and High) and body-part (hand and torso) on movement acceleration. Corrected for multiple comparisons using the Bonferroni method. **p* < .005, ***p* < .001.

Contrasts		*p*
Musician[1]	Low vs. Medium	>.999
	Low vs. High	.002*
	Medium vs. High	.003*
Non-Musician	Low vs. Medium	.195
	Low vs. High	<.001**
	Medium vs. High	<.001**
Low	Musician vs. Non-Musician	.384
Medium	Musician vs. Non-Musician	.877
High	Musician vs. Non-Musician	.054^

Table 3 Test of simple effects for interaction of syncopation (Low, Medium and High) with musical training (Musicians, non-musicians) on movement synchronisation. Corrected for multiple comparisons with the Bonferroni method. * *p* < .005, ***p* < .001, ^marginally significant.

Figure Captions

Fig. 1 Effect of **a.** syncopation (Low, Medium and High) on movement acceleration in hand and torso and regression curves for **b.** hand and **c.** torso. Coloured lines represent curves for individual subjects, bold black curve for averaged responses across subjects. Error bars = standard error. ** $p < .001$.

Fig. 2 Effect of **a.** syncopation (Low, Medium and High) and musical training on synchronisation indices and regression curves for **b.** hand and **c.** torso. Coloured lines represent curves for individual subjects, bold black curve for averaged responses across subjects. Error bars = standard error. *$p < .05$, ^marginally significant.

Fig. 3 Proportion of **a.** trials with metric periodicities in hand and torso and **b.** proportion of trials with metric periodicities in Low, Medium and High syncopation conditions. Error bars = standard error. *$p < .05$, ** $p < .001$.