Seeing a drummer's performance modulates the subjective experience of groove when listening to popular music drum patterns

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Abstract

Spontaneous rhythmical movements, like foot-tapping and head-bobbing, often emerge when people listen to music, promoting the sensation of being in the 'groove': a psychological construct that additionally incorporates positive affect. Here we report the first study to investigate if seeing the music maker modulates this subjective experience of groove. Across trials participants (n = 36) listened to high and low groove drum beats, while concurrently observing a task-irrelevant point-light display (PLD) of the drummer. The PLD was either *fully-corresponding* with the audio or was incompatible across three other visual display conditions: a *static* PLD, a corresponding but *asynchronous* PLD (0.5s time shifted); or a *non-corresponding* PLD (e.g. low groove audio paired with high groove PLD). Participants rated: (a) their desire to move; and (b) the perceived groove in response to the auditory beats only, using 8-point Likert scales. In both measurements there were significant main effects of groove level and of visual display. Ratings were higher for high compared to low groove audio, and for the fully-corresponding condition compared to the other three visual conditions. The participants' desire to move was also rated higher in the static condition compared to the non-corresponding condition, while the two-way interaction was also significant: ratings were higher for the high compared to low groove audio in the fully-corresponding, static and asynchronous conditions, but not in the non-corresponding condition. These findings identify the importance of seeing as well as hearing the musician for an enhanced listening experience, which necessitates a multimodal account of music perception.

Key words: multisensory integration; visuo-motor priming; motor resonance; mirror neurons; music perception; audio-visual processing

Seeing a drummer's performance modulates the subjective experience of groove while listening to popular music drum patterns

One of the most fundamental ways we engage with music is through movement; these movements are often spontaneous, taking such forms as head bobbing and foot tapping, and are typically accompanied by pleasurable feelings. This phenomenon, commonly described as the sensation of 'groove', is gathering research interest. While recent studies have begun to investigate the musical properties associated with the experience of groove (e.g. Sioros, Miron, Davies, Gouyon & Madison, 2014; Stupacher, Hove & Janata, 2016; Witek, Clarke, Wallentin, Kringelbach & Vuust, 2014), the impact of seeing the music maker's body movements is currently underexplored. This is despite a growing interest in multisensory integration research within the music perception literature (e.g. Schutz & Lipscomb, 2007; Petrini et al., 2009; Zatorre, Chen, & Penhune, 2007).

Multisensory integration (MSI) theory states that the perception of everyday events requires the fusion of information from multiple senses. According to *optimal integration theory*, the relative influence of each modality depends on its perceived reliability in conveying information (Alais & Burr, 2004; Massaro, 2004). Several key principles of MSI have been identified. MSI is more likely or stronger when a number of uni-sensory stimuli are perceived to either come from approximately the same place (the spatial rule: King & Palmer, 1985; Meredith & Stein, 1986), or occur at approximately the same time (the temporal rule: King & Palmer, 1985; Meredith, Nemitz & Stein, 1987). Since stimuli from different sensory modalities (e.g. visual and auditory) require different amounts of time to be processed, there is a window of multisensory integration, wherein stimuli occurring more than 0.2 seconds apart are unlikely to be perceived as comprising a single event (van Wassenhove, Grant & Poeppel, 2007). MSI is also more likely to occur or be stronger when the uni-sensory stimuli cause relatively weak responses on their own (the principle of inverse effectiveness: Meredith & Stein, 1983; 1986), or when they contain congruent semantic information (principle of semantic congruence: Laurienti, Kraft, Maldjian, Burdette & Wallace, 2004). Research has begun to investigate multisensory integration in music perception, to understand how the different sensory modalities involved in music performance might interact and alter the perception of each other (c.f., Coutinho & Scherer, 2017; Lee & Noppeney, 2014). In this context, the current research investigates whether seeing the music-maker's movements can affect the subjective experience of groove.

Early research into groove from an ethnomusicological perspective described the musical properties with which it is associated. At the core of groove are timing patterns (Iyer, 2002; Keil & Feld, 1994) and rhythmic features, such as an isochronous pulse created by interconnecting rhythms (Iyer, 2002). More recently, music cognition research has identified a range of factors that contribute toward a sense of groove, including: microtiming (Davies, Madison, Silva & Gouyon, 2013; Frühauf, Kopiez & Platz, 2013; Kilchenmann & Senn, 2015; Senn, Kilchenmann, von Georgi & Bullerjahn, 2016), tempo (Etani, Marui, Kawase, & Keller, 2018), beat salience and the density of events between beats (Madison, Gouyon, Ullén, & Hörnström, 2011), listener attitude and rhythmic variability (Senn, Kilchenmann, Bechtold & Hoesl, 2018), as well as listener preferences (Hofmann, Wesolowski & Goebl, 2017), and syncopation (Madison & Sioros 2014; Senn et al., 2018; Sioros, et al., 2014; Witek et al., 2014; Witek, Popescu, Clarke, Hansen, Konvalinka, Kringelbach & Vuust, 2017). Moreover, Witek et al.'s (2014) work forms part of a complementary body of research in psychology that has begun to study groove from a perceptual and subjective experiential perspective.

In an influential study that sought to define and characterise groove as a psychological construct, Janata, Tomic and Haberman (2012) found that a broad range of musical excerpts can be reliably evaluated for their perceived groove. There is considerable consistency for groove ratings across musical genres and styles, which suggests the subjective experience of groove consists of psychological factors that are independent of musical style (Madison, 2006). The *desire to move* is a central feature of this experience, with greater neural activation in motor and motor-related brain areas when people listen to high compared to low groove music (Stupacher, Hove, Novembre, Schütz-Bosbach & Keller, 2013). Recent work has also established that an affective component accompanies this motor response, suggesting a bi-directional relationship between movement and pleasure (Janata et al., 2012; Witek et al., 2014). Indeed, there is now a consensus in the literature that groove is a psychological construct comprising a sensori-motor response coupled with a strong affective component (see Witek, 2016).

While previous research has focussed on the auditory qualities of music that modulate perceived groove, the impact of seeing a performer's movements on the audience's experience of groove is yet to be examined. There is a related body of evidence showing visual information can influence how an audience responds to and perceives music. In a meta-analysis of studies investigating music evaluation of liking, expressiveness and performance quality, Platz and Kopiez (2012) found a medium effect size for the visual component. There is also some evidence that visual information has a relatively greater effect on audience ratings of performance quality compared to audio information (Griffiths & Reay, 2018).

In particular, a performer's body movements are a visual method of communication that may be very relevant to groove perception. Body movement conveys information on a range of aspects of music-making. In terms of musical content, this includes perceived musical structure (Vines, Krumhansl, Wanderley & Levitin, 2006), timing information such as phrasing and rubato (Juchniewicz, 2008), and aspects of pitch (Thompson & Russo, 2007). Perceived and experienced emotion in performance is also communicated visually by musicians. Vines et al. (2006) found visual information could either augment or reduce perceived tension. Since tension is a measure correlated with emotional response (Vines et al., 2006), the visual information was believed to affect subjective emotional responses to music. While some studies show visual information can convey emotion more effectively than audio information (De Carlo & Guitella, 2004; Livingstone, Thompson, Wanderley & Palmer, 2015), observing the musician's actions can specifically communicate the emotion-related components of their musical performance (Coutinho & Scherer, 2017; Krahé, Hahn & Whitney, 2013).

When observing human actions, the neurocognitive processes underlying the imitation of that movement will also lead to automatic activation of premotor areas in the observer's brain, which correspond to execution of the observed action (Rizzolatti & Sinigaglia, 2010). This motor 'resonance' effect is well established in the action observation literature, but it is presently unclear if observing a musician's movement is in anyway related to the observer's subjective ratings of groove. Given that high groove music elicits stronger activations of motor regions in the brain compared to low groove music (Stupacher et al., 2013), it is conceivable that concurrent action observation may enhance this motor response further, which in turn may impact the experience of groove.

Collectively these findings suggest that seeing a musician's movements can convey both musical and emotional information, which may be important conduits for groove. This is due to their capacity to both communicate musical features that promote groove, and strengthen the affective component of music perception. These two sources of visual information may then supplement the associated motor resonance effect, which is derived through action observation *per se*. On these grounds the main aim of the current study was to investigate whether the subjective experience of groove in an auditory stimulus is affected by observing the music maker's actions.

In the present study participants rated high and low groove drum beats across trials. See Table 1. These songs had received either a particularly high or low groove rating in the study by Janata et al. (2012), where participants had rated over one hundred and fifty songs. In line with previous research, we presented drum patterns in isolation (c.f., Davies et al., 2013; Etani et al., 2018; Frühauf et al., 2013; Senn et al., 2018; Witek et al., 2014), rather than obtaining groove ratings of musical arrangements involving multiple instruments. In accordance with Janata et al.'s (2012) findings we hypothesised that groove ratings would be higher for the high groove drum beats compared to the low groove drum beats.

To investigate our main research question, participants rated these high and low groove drum beats while observing a task-irrelevant point-light display (PLD) of the drummer under four visual display conditions. First, the *fully-corresponding* condition contained congruent dynamic visual information displaying the drummer's performance (as in a live music experience). Second, the *static* condition, displayed a still image from this PLD, and so acted as a baseline for rating the auditory stimuli. If observing the music maker can *enhance* the subjective experience of groove, ratings should be higher in the fully-corresponding than in the static condition. We also investigated whether the fully-corresponding condition affected groove ratings differently compared to two conditions presenting incompatible audio-visual combinations, which are discussed next.

While the fully-corresponding condition might conceivably enhance the subjective experience of groove, a discord between the audio and visual stimuli may produce an interference effect for several reasons. When there is a mismatch between the auditory and visual components one or more principles of multisensory integration may be violated, such that the two sensory channels are less likely to be combined into a single *coherent* percept. If so, this should lead to an interference effect in the present auditory task from the task-irrelevant visual stimulus.

Interference effects have been found in speech perception tasks. One example is the McGurk effect (McGurk & MacDonald, 1976), whereby the pairing of a voice articulating a consonant with an incongruent video of a face articulating a different consonant led participants to report hearing a different consonant than the one performed in either the auditory or visual channel. While these findings are within speech rather than music perception, it is argued that music shares many characteristics with speech, since both are composed of perceptually discrete elements organised in time-varying sequences (Petrini et al., 2009). Indeed, Quinto, Thompson, Russo and Trehub (2010) demonstrated the McGurk effect in sung stimuli, while Schulz and Lipscomb (2007) found similar effects for the perception of note length when participants observed marimba players with varying gesture lengths. In both speech and music perception we therefore create a single percept by integrating both relevant and irrelevant visual information with the available audio information; with incompatible stimuli having the potential to interfere with perceptual judgements.

Finally, behavioural experiments showing the clearest examples of the aforementioned motor resonance effect typically use an interference-based paradigm. For instance, observing an incongruent rhythmical action interferes with the kinematics both of concurrent (Kilner, Paulignan & Blakemore, 2003) and even subsequent execution of a different rhythmical action (Eaves, Turgeon & Vogt, 2012; Eaves, Haythornthwaite & Vogt, 2014). Similarly it is plausible that observing an incompatible drumming action may interfere with concurrent perception of the action-related sound. This is because the audio-generated motor response would differ from the visually-generated motor response, for example, in terms of rhythmical timing, which could degrade multisensory integration.

The final two visual display conditions were therefore incompatible. First, an *asynchronous* condition presented a PLD that was 0.5 seconds time shifted from the auditory track. Second, a *non-corresponding* condition provided a semantically incongruent PLD, e.g. high groove audio with low groove visual. These two conditions broadly violate the temporal and semantic congruence rules of MSI, respectively. Thus we investigated whether the subjective experience of groove depends on the degree of correspondence between the acoustic stimulus and the observed movement. Given the importance of rhythmic features and timing patterns to groove (Iyer, 2002; Keil & Feld, 1994) as well as past research beyond music perception that has revealed interference effects when simultaneous incongruent bodily movements are observed (e.g. Kilner et al., 2003; McGurk & MacDonald, 1976), it is likely these two incompatible conditions produce an interference effect, with the potential to diminish the subjective experience of groove compared to the fully-corresponding condition in which conditions for MSI were considered optimal.

In summary we hypothesised that observing a musician’s actions can modulate the subjective experience of groove, leading to either facilitation (in the case of compatible audio and visual inputs) or interference effects (in the case of incompatible audio and visual inputs).

Method

Participants

Thirty-six adults (25 female, mean age = 26.22, *SD* = 8.97 years) volunteered to take part in the experiment (no remuneration provided). Twenty-two reported having played a musical instrument, with twenty receiving some form of musical training (*M* = 3.19, *SD* = 3.64 years training) and eight receiving some form of dance training (*M* = 0.91, *SD* = 2.05 years training). All had normal or corrected-to-normal sight and reported no hearing impairments. Written informed consent was obtained prior to participation, as was ethical approval from York St. John University.

Design

This study used a two-factorial repeated measures design. The first variable of 'groove level' was manipulated via the auditory stimuli (high vs. low groove). The second independent variable of 'visual display' was manipulated via the PLD content, relative to the concurrent audio drum beat (fully-corresponding vs. static vs. asynchronous vs. non-corresponding).

There were two dependent variables. At stimulus offset participants rated the auditory stimulus using an 8-point Likert scale. First they were asked: (Q1) 'To what extent did you feel the audio made you want to move?'. This question was adapted from Witek et al.'s (2014) research question, in the sense that participants in the present study were explicitly directed to rate the audio stimuli, rather than the rhythm. Note, in Witek el al.'s (2014) original paper they asked: 'To what extent does this rhythm make you want to move?'. In Janata et al.'s (2012) study, which explored both the lay usage and understanding of the concept of groove, the highest ranking statement used to characterise groove was in terms of 'the extent to which the music makes you want to move'. In line with these two previous studies, we used Q1 to both isolate and assess the desire to move, that is, as the core sensorimotor component of the subjective experience of groove.

Immediately after responding to Q1, participants in the present study were asked: (Q2) 'To what extent did you feel the audio grooved?'. This was adapted from the question employed by Janata et al. (2012), where our approach again explicitly directed the participants toward rating the audio rather than the visual stimuli. Janata et al.'s (2012) question was: 'To what extent did you feel that the musical excerpt grooved?' Overall, their study showed clear evidence that the concept of groove is widely appreciated and understood in terms of a pleasurable drive toward action. In the present study, the purpose of Q2 was therefore to tap the psychological construct of groove, defined in a 'global' sense, as encompassing both the desire to move and the related component of positive affect. To establish a common understanding for what was meant by the term groove in our Q2, at the start of the experiment we provided participants with the following definition, which was adapted from Janata et al. (2012): ‘Groove is the urge to move in response to music, combined with a positive emotional state. Since groove is associated with a sense of being a part of the music, it is commonly described as a feeling of being in the groove.’

Materials

The drum beats for five high groove and five low groove songs were included in the main experimental trials, giving ten different songs in total. These songs had received either a particularly high or particularly low groove rating in the study by Janata et al. (2012), where participants had reviewed over one hundred and fifty songs. We matched pairs of songs as closely as possible across the two groove conditions based on instrumentation, time signature, tempo and vocal characteristics. See Table 1. It was not possible, however, to match pairs of songs based on genre. Since we selected all our songs from the list published by Janata et al. (2012), on the basis they represented either particularly high or low groove ratings in that study, this led to all the high groove songs in the present study being from the genre of soul, and the low groove songs from the genres of either folk or rock. For the notation of all drum patterns, and examples of the audio-visual stimuli, please see Appendix S1 and S2, respectively, in the Supplemental Material Online section.

--- Insert Table 1 about here ---

A professional drummer was recruited to play each drum beat for the audio-visual stimuli. The drummer had fifteen years professional drum training with extensive experience of session work, involving both recording and live musical performance. During the drummer’s performance we recorded two stimuli simultaneously: one audio recording of his drumming and one PLD of his movements. An audio recorder (Zoom H2, Japan) was used to record all the audio tracks, while the drummer paced each beat to a metronome played through headphones (Sennheiser). The drummer was not naïve to the purpose of the study. It is therefore likely his interpretation of the songs within this context generated some general effects on the rhythmical and temporal properties of the performance to maximise and minimise groove within the high and low condition, respectively (c.f., Madison & Sioros, 2014; see notation of the drum patterns in Appendix S1 in the Supplemental Material Online section).

For the visual stimuli we created a PLD of the same performance using a 3-D motion capture system. Temporal-spatial positions were collected using a computer running motion capture software (Nexus 1.2.103, Vicon Motion Systems, Oxford, UK) linked to six motion-sensitive infra-red cameras sampling at 100 Hz (MX13, Vicon Motion Systems, Oxford, UK). Kinematic data from five of the drummer's major joint centres (ankle, knee, shoulder, elbow, wrists) on both sides of his body, plus both temples on his head were tracked in 3-D (that is, in the X, Y and Z planes) during his drumming performance. These anatomical landmarks were selected after pilot testing revealed these body positions either passed through the greatest range of motion while drumming, or best illustrated the core rhythmical and expressive features of the performance. These data were visualised using motion capture software as dynamic points of white light moving against a black background (see Figure S1 in the Supplemental Material Online section).

An extensive body of literature has long established that the human visual perception system is highly sensitive to the invariant features of biological motion when presented in this PLD format (see Hodges, Williams, Hayes & Breslin, 2007). Furthermore, an advantage in observational learning has been shown when viewing PLDs with fewer rather than greater numbers of joint-centre markers (Eaves, Breslin, Van Schaik, Robinson & Spears, 2011).

Screen capture software (Frapps, Beepa Pty Ltd.) was used to produce movie clips of each performance, which were displayed in the PLD format using Vicon. Each PLD movie clip was then aligned with the relevant audio track using video editing software (Camtasia, TechSmith, Michigan, USA) to produce the combined (i.e., fully-corresponding) audio-visual stimuli. Two separate excerpts were extracted for each song, lasting 10 seconds each, giving twenty unique drum tracks for the experimental trials. During each excerpt the beat was continuously reflective of the overall track, avoiding any one-off drum fills or transitions. These twenty excerpts were used as the base stimuli for editing according to the four visual display conditions.

In the *fully-corresponding* condition the audio and visual information were fully time-synchronised, as would be the case in a normal drumming performance. In the *static* condition the same audio clips were presented while a static image of the drummer's PLD was also presented (see Figure S1 in the Supplemental Material Online section). For the *asynchronous* condition the same audio and visual information was presented as in the fully-corresponding condition, but these stimuli were time shifted so that the PLD lagged behind the corresponding auditory track by 0.5 seconds. In the *non-corresponding* condition an auditory stimulus from one groove condition was paired with a visual stimulus from the opposite groove condition (e.g., high groove audio beat paired with low groove PLD recording). In the non-corresponding condition pairs of songs were matched as closely as possible across the two groove conditions for time signature and tempo, to create an approximate alignment of the salient temporal-spatial features across the 10 second audio and visual stimuli. The two excerpts from each song were both presented within each of the four visual conditions, creating eighty experimental trials.

Since two excerpts of each experimental drum beat were presented within each of the four visual display conditions (i.e., eight presentations of the same song across the entire experiment), we took two steps to control for participants simply recalling and repeating their earlier rating for each excerpt. First, it was particularly difficult to identify each song from only the drum instrumentation, that is, without characterisation from the other instruments in the original recordings. Second, we created 'filler' stimuli to increase the range of beats presented.

Five high and five low groove filler tracks were created using the same process as for the experimental stimuli. The filler excerpts were matched across the two groove conditions for tempo and time signature (85, 86, 95, 100, 101 BPMs), but these trials were not included in the analyses. The drummer was instructed to create these rhythmical drum beats intuitively on the basis he felt they would represent high vs. low groove content at each of the designated time signatures. All ten of these filler excerpts were presented under each of the four visual display conditions, giving forty filler stimuli in total. Accordingly, one hundred and twenty stimuli were presented in total: eighty experimental trials and forty filler trials. These trials were pseudo-randomised into five blocks of twenty-four trials, presented in a counterbalanced order. Each block was balanced for the number of experimental and filler trials, and also for the number of trials relating to both groove conditions and the four visual display conditions. Trial order was then fully randomised within each block. Each block lasted approximately six minutes, interspaced with two minute rest periods.

The experiment was generated via e:prime (2.0) software running on a laptop computer (Dell Latitude E5540 laptop PC, USA), with a 15.6 inch screen, situated on a desk approximately 60 centimetres in front of the participants. Sound was presented through a speaker system (Harman/Kardon, UK) attached to the laptop. The volume setting was fixed across all participants. SPSS Statistics for Windows, version 24 was used for all data analysis (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp).

Procedure

During an initial familiarisation phase, participants were told how the PLDs were created, before viewing two repetitions of six unrelated actions in PLD format (e.g., kicking, walking, throwing). Participants verbally identified each action type they observed. Since no errors were reported in this task, we confirmed all participants could easily recognise and interpret the actions despite the initial novelty of the PLD format.

The concept of ‘groove’ was then defined to participants via text presented on-screen. (see ‘Design’ section above). Participants then performed eight practice trials, which were identical to the main experimental trials. There were two trials for each of the four visual conditions, involving one high and one low groove audio filler track per visual condition.

On each trial in the main experiment participants viewed a black fixation cross (1 second) in the centre of a light grey screen, followed by a combined audio-visual stimulus (10 seconds). At stimulus offset participants were prompted via on-screen instructions to give two ratings about the content of the *auditory* stimulus alone: (Q1) ‘To what extent did you feel the audio made you want to move?’, and (Q2) ‘To what extent did you feel the audio grooved?’ For each rating participants used an 8-point Likert scale (0 = not at all; 7 = very much so). Finally, participants reported on each trial if the drummer was moving or static via a key press (yes / no), before they began the next trial. This ensured the participants’ attention to the display was equitable across the four visual display conditions. Trials with incorrect responses to this final question were removed from the analyses (1.7%). Participants were required to sit still throughout the main experimental trials.

Results

An a priori power analysis was conducted using G*power (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that the total number of participants needed to observe an effect size of 0.51 was n = 24. The effect size used in this calculation was based on Platz and Kopiez's (2012) meta-analysis reporting a medium effect for the visual component in studies where participants rated musical qualities. A repeated measures MANOVA was the statistical test used as a basis for the assumptions of this a priori power analysis along with an alpha level of 0.05 and power (1-beta) of 0.95. The sample used in the present study (n = 36) was therefore considered sufficient to observe such an effect.

The four visual display conditions consisted of twenty experimental trials each. Within each visual display condition, mean scores were calculated over the ten trials in each groove condition, which consisted of five different songs, two excerpts per song. Intraclass correlation coefficients (ICC) were calculated, which reflect the proportion of variance in an observation due to the between-participant variability in the true scores (Koo & Li, 2016; Ludbrook, 2010). Using the responses participants provided over the four visual display conditions, the ICC was calculated separately for the high and for the low groove conditions for Q1 and Q2. The reliability was excellent (see Table 2).

Prior to conducting a two-way repeated measures multivariate analysis of variance (MANOVA), a series of Pearson's correlations were used to assess the relationships between the dependent variable scores for each independent variable. This was to test the MANOVA assumption that the dependent variables would be correlated with each other in the moderate range (Meyers, Gamst & Guarino, 2006). As can be seen in Table 3, a meaningful pattern of correlations was observed between the two dependent variables.

A 2 groove level (high vs. low) × 4 visual display (fully-corresponding vs. static. Vs. asynchronous vs. non-corresponding) MANOVA was run on the mean scores for both dependent variables. Where necessary, any violation of the sphericity assumption was adjusted for using the Greenhouse–Geisser correction. Alpha levels were set to 0.05, and effect sizes were calculated as partial eta squared values (η_p^2). To reduce type I error rates, Bonferroni corrections were used in all post-hoc pairwise comparisons. Descriptive statistics are reported in Table 4.

Overall a statistically significant MANOVA effect was found for both groove level, $F(2, 34) = 5.78$; $p = .007$; Wilk's $\Lambda = .746$, $\eta_p^2 = .25$, and visual display, $F(6, 30) = 4.66$; $p = .002$; Wilk's $\Lambda = .517$, $\eta_p^2 = .48$. The two-way interaction was also significant, $F(6, 30) = 2.95$; $p = .022$; Wilk's $\Lambda = .629$, $\eta_p^2 = .37$. These effects were then explored within the MANOVA for each dependent variable individually.

--- Insert Table 2 about here ---

--- Insert Table 3 about here ---

--- Insert Table 4 about here ---

Q1: To what extent did you feel the audio made you want to move?

There was a significant main effect of groove level. See Table 5 and Figure 1. Overall, participants reported a stronger desire to move after listening to high groove ($M = 3.35$, $SD = .51$) compared to low groove audio ($M = 3.17$, $SD = .51$). The main effect of visual display was also significant. Post-hoc pairwise comparisons revealed desire to move was significantly stronger for the fully-corresponding condition (*M* = 3.41, *SD* = .57) compared to both the asynchronous (*M* = 3.20, *SD* = .50, *p* = .003, *d* = .53) and non-corresponding conditions (*M* =3.13, *SD* = .50, *p* = .001, *d* = .63). Desire to move was also significantly higher in the static (*M* = 3.31, *SD* = .51) compared to the non-corresponding condition (*p* = .007, *d* = .48). All other comparisons were not significant.

The two-way interaction between groove level and visual display was significant. Post-hoc pairwise comparisons within each visual display condition found participants reported a significantly stronger desire to move when listening to high groove compared to low groove audio in the fully-corresponding (*M* = 3.57 vs. 3.24, *p* = .004, *d* = .51), static (*M* = 3.42 vs. 3.20, *p* = .035, *d* = .36) and asynchronous conditions (*M* = 3.30 vs. 3.09, *p* = .024, *d* = .39), but not in the non-corresponding trials (*M* = 3.10 vs. 3.16, *p* = .507, *d* = .11). For the high groove audio tracks only, pairwise comparisons across visual display conditions revealed a significantly higher rating for the fully-corresponding condition (*M* = 3.57) compared to both the asynchronous (*M* =3.23, *p* = .004, *d* = .51) and non-corresponding conditions (*M* = 3.01, *p* < .001, *d* = .71). The difference between the fully-corresponding and static condition (*M* = 3.42) approached but did not reach levels of significance (*p* = .081, *d* = .30). All other comparisons were not significant.

--- Insert Table 5 about here ---

--- Insert Figure 1 about here ---

Q2: To what extent did you feel the audio grooved?

There was a significant main effect of groove level. See Table 5 and Figure 2. Participants reported a stronger perception of groove for the high groove (*M* = 3.45, *SD* = .51), compared to low groove drum beats (*M* = 3.27, *SD* = .46). The main effect of visual display was also significant. Post-hoc pairwise comparisons showed perceived groove was significantly higher for the fully-corresponding condition (*M* = 3.6, *SD* = .53), compared to the static (*M* = 3.26, *SD* = .53, *p* = .001, *d* = .60), asynchronous (*M* = 3.3, *SD* = .48, *p* = .015, *d* = .42), and non-corresponding conditions (*M* = 3.27, *SD* = .54, *p* = .015, *d* = .43). All other pairwise comparisons were not significant. The two-way interaction was also not significant.

--- Insert Figure 2 about here ---

Discussion

This was the first study of its kind to examine the effect of observing a musician's actions on the subjective experience of groove. First, we replicated the finding of Janata et al. (2012) whereby the musical excerpts we selected from their study were reliably appraised for perceived groove. In the present study, significantly higher ratings were obtained for high compared to low groove audio clips in both dependent variables. Second, the impact of the visual display was highly significant in the concurrent auditory perception task in both measures. Seeing a musician's movements during their musical performance does indeed affect the subjective experience of groove. To our knowledge this is a novel finding, since previous research has focussed primarily on the auditory qualities of music that moderate perceived groove, rather than on the visual qualities of the performer.

Since our results reaffirm Janata et al.'s (2012) distinction between high and low groove excerpts, we provide further evidence that the songs included in the present study represent a useful library through which it is possible to investigate the psychological construct of groove. We extend their findings to drum tracks presented in isolation, without characterisation from vocals or other instrumentation. This was also despite the relatively short clip duration used in this experiment. This initial result also provided an important manipulation check that was necessary in the current study. Only after confirming this could we reliably address our main manipulation of interest, namely the impact of the visual display on the subjective experience of groove. Our approach to measuring the psychological construct of groove, as defined and assessed by Janata et al. (2012), was twofold. In the first question (Q1) we aimed to isolate the participants' self-reported desire to move in response to the audio, which was intended as a proxy for the core sensori-motor component of groove. In the second question (Q2) we aimed to tap the psychological construct of groove at a more holistic, global level. In the following sections we address the overlapping findings from these two measures, as well as the disparities between them.

Our main finding was that seeing the musician's body movements significantly modulated the subjective experience of groove across the two dependent variables. As anticipated, seeing the drummer's action when it fully-corresponded with the action-related sound increased groove ratings compared to the static baseline condition (specifically when rating the global construct of groove), while the incompatible conditions significantly reduced groove ratings compared to the fully-compatible condition in both measures (i.e., the desire to move and the global construct of groove). When rating only their desire to move there was also a significant reduction for the non-corresponding compared to the static baseline condition. Overall these results clearly demonstrate that concurrent visual information can either enhance or interfere with different components of the subjective experience of groove, depending on the degree of correspondence between the visual and auditory stimuli. We believe it is then useful to conceptualise these results within the framework of multisensory integration, as follows.

In general, the fully-corresponding visual condition resulted in higher ratings in both the desire to move and the global construct of groove. This broadly confirms that when we hear a musician play their instrument there is a tendency to integrate the corresponding visual information, when it is available, with the auditory modality. According to multisensory integration theory, this would form a single coherent perceptual experience of the event (Alais & Burr, 2004; Massaro, 2004). In the present study we submit this as the prominent explanation for why our participants reported a more intense experience of groove in the fully-corresponding condition. In contrast, the two incompatible conditions were designed to portray a mismatch between the auditory and visual modalities, which intended to violate either one or more principles of multisensory integration. Since the participants generally reported lower ratings of groove for these two conditions in both measures, one explanation is that the perceived mismatch led to a reduction in multisensory integration across the two sensory modalities, leading to an interference effect in the present auditory task.

These findings are largely consistent with previous research showing visual information influences perception both of musical qualities (e.g. Juchniewicz, 2008; Platz & Kopiez, 2012; Schutz & Lipscomb, 2007; Vines et al., 2006; Thompson & Russo, 2007) and the perceived and felt emotions of audiences (De Carlo & Guitella, 2004; Krahe et al., 2013; Livingstone et al., 2015). Moreover, the current results are the first to show that the effects of visual information on music perception extend to the subjective experience of groove.

In the participants' responses to Q2, the main effect of visual display not only showed that groove ratings were higher in the fully-corresponding condition than in the static condition, but also that the fully-corresponding condition was rated higher than both the asynchronous and non-corresponding conditions. This shows that perceived groove was not simply enhanced by observing any human movement, but specifically by seeing the musician's natural (i.e., fully-corresponding) performance. If the effect was due to seeing movement *per se*, the three visual conditions containing dynamic motion would have been rated equally, which was not the case. Furthermore, since no conditions presented either audio or visual information in isolation, the different ratings obtained across the visual conditions cannot be explained in terms of an additional attentional requirement under a particular visual condition.

With regards to the enhancement effect, the participants' ratings were specifically higher for Q2 in the fully-corresponding compared to in the static condition. Our results therefore support the idea that listening to music in the absence of a visual display of the performer (e.g. blind auditions, recorded performances, radio broadcast, etc.) can significantly alter the listener's perception of that music (Shultz & Lipscomb, 2007). Given that positive affect is intrinsic to the experience of groove (Janata et al., 2012; Witek et al., 2014), this finding indicates that observing the musician's action enhances the listener's pleasure and enjoyment of the music. This result clearly substantiates the benefits of combined audio-visual displays, for example, the use of large screens showing a musician's performance in a live venue, and the integration of music and movement in cinematography and the theatre. It is likely that this enhancement occurs either by: (a) increasing covert motor activity as a result of merely observing the performer's movement (Rizzolatti & Sinigaglia, 2010); or (b) communicating the musical properties (e.g. rhythmic features, timing patterns and meter; Iyer, 2002; Keil & Feld, 1994) and the positive affect that are intrinsic to groove (Witek et al., 2014), or indeed this effect may be derived through a combination of these means.

Seeing the musician's corresponding action significantly enhanced the listener's experience of the high groove music, compared to when seeing the static image, for ratings of the global construct of groove (Q2). Despite showing a trend in the same direction for Q1, the difference between the fully-corresponding and static condition was not significant for high groove music. This disparity may be explained by the nature of the questions themselves. By asking participants how much they felt the audio grooved (Q2), we encouraged them to focus on the aural qualities of the excerpts and the construct of groove as a whole (i.e., the sensori-motor response coupled with the affective component). In contrast Q1 more directly aimed to isolate and emphasise only the motor component. Since greater neural activation in motor and motor-related brain areas has been found when people listen to high compared to low groove music (Stupacher et al., 2013) it is possible that observing the musician's movements did not enhance activation in motor related areas beyond what is already achieved by listening to high groove music. As such, action observation did not enhance the desire to move further.

The answers to Q1 were intended to reflect the subjective experience of covert motor activation in response to the stimuli. Clearly a more direct assessment of the motor involvement arising from simply hearing high groove music compared to hearing this music while seeing the musician's fully-corresponding actions could be achieved through neuroimaging techniques. Multimodal brain imaging techniques should now be used to investigate the related premotor involvement, such as event related desynchronisations in the mu rhythms of electroencephalography recordings (EEG), or changes in the cortico-spinal excitability assessed via transcranial magnetic stimulation (TMS; c.f., Stupacher et al., 2013).

Building on this approach, an interesting avenue for future research could be to adopt the paradigm used in the current study to assess groove ratings after participants had engaged in different types of instructions for *how* to observe the visual display. In our study, participants were required to watch the display, without receiving any further guidance on what features they should focus their attention on. A growing body of neurophysiological research has recently shown that, compared to when simply watching an action, cortical activity in motor regions of the observer's brain can significantly increase when participants imagine they are performing the action they are also currently observing, that is, motor imagery *during* action observation (e.g., Eaves, et al., 2016a; see for a review Eaves, Riach, Holmes & Wright, 2016b). In this case, the observed action provides a visual guide for imagery of the same action, where potentially both the observed and imagined actions can co-occur as two complementary sensorimotor representations (Scott, Taylor, Chesterton, Vogt & Eaves, 2018). The interesting question is whether such increased motor activation can also facilitate the subjective experience of groove.

As predicted, the main effect of the visual display also identified an inference effect across both measures of groove, since the responses to Q1 and Q2 were lower in the asynchronous and non-corresponding visual conditions compared to the fully-corresponding condition. This finding is in line with the research into both speech (e.g. McGurk & MacDonal, 1976) and music perception (Quinto et al., 2010; Schulz & Lipscomb, 2007) showing analogous interference effects when incompatible body movements are observed during an auditory task. Collectively these results show that when incompatible body movements are observed during an auditory stimulus they can alter the perception of that auditory stimulus, whether in the context of either speech or music. It is likely that the interference effects found in the present study are a consequence of the two incompatible visual display conditions broadly violating the principles of multisensory integration, namely the temporal rule (King & Palmer, 1985; Meredith et al., 1987) and the principle of semantic congruence (Laurient et al., 2004). In these two conditions MSI is predicted to be weaker, meaning the listener cannot benefit from strengthened sensory signals that would result from combined auditory and visual modalities.

An alternative explanation of the interference effects found in the present study could be that observation of incompatible actions triggers activation of a conflicting motor response at the cortical level (c.f., Eaves, Behmer, & Vogt, 2016), which then altered the perception of the music, disrupting the conveyance of groove. This explanation is consistent with research showing humans are sensitive to the observed kinematics of rhythmical actions (e.g., Eaves et al., 2012), as well as evidence showing that passively observing human movement activates motor areas in the observer's brain that correspond with execution of the observed action (see Rizzolatti & Sinigaglia, 2010).

In support of this proposal, the responses to Q1 confirmed that the desire to move was greater in the static compared to the non-corresponding condition. Furthermore, the two-way interaction between groove level and visual display condition identified that the desire to move was significantly higher for high compared to low groove music in all visual display conditions apart from the non-corresponding condition. In the non-corresponding condition there was a trend for ratings in the opposite direction, but it was not significant. Watching a high groove performance paired with a low groove audio stimulus was rated higher than when watching the low groove performance, paired with high groove audio. Since the conflict between the visual and auditory stimuli was at its greatest in this condition, these data provide tentative evidence of an audience member's desire to move in response to the visual component, regardless of its compatibility with the musical excerpt. Notably, the desire to move remained consistently low throughout all low groove conditions, suggesting an inverse ceiling effect for these trials, against which the high groove conditions could then be characterised.

In the non-corresponding condition the integration of modality information was less likely (King & Palmer, 1985; Meredith et al., 1987; Laurient et al., 2004). As such, participants would have relied on one input over the other, which in turn would reduce their desire to move, compared to the possible additive effect that was likely present for the two modalities in the fully-corresponding condition. Indeed, Griffiths and Reay (2018) recently showed that incongruent audio-visual pairings can lead to the visual component having the greatest influence on an audience member's evaluation of a musical performance. A similar result was not observed for the second incompatible condition which displayed asynchronous body movement. This was not too surprising given that Vatakis and Spence (2006a; 2006b) found that people are less sensitive to asynchrony in musical video clips. It therefore seems reasonable to suggest that the activation of a conflicting motor response coupled with the violation of the principle of semantic (and potentially temporal) congruence in the non-corresponding condition would lead to greater interference effects overall, as obtained in the present results.

This study was not without some potential limitations. First, while our measures were based closely on those used in published literature (Janata et al., 2012; Witek et al., 2014), we acknowledge some inherent constraints. For Q2 participants were asked to evaluate their desire to move in conjunction with their own affective response. It is possible that participants misinterpreted this question and instead assessed the stimuli for groove content in a more objective, general way that was less dependent on their own subjective experience. This is unlikely however since no participants disclosed this strategy in the post-experiment debrief. Second, the two incompatible visual displays provided only a general rather than strict manipulation of the MSI principles. While there were clear sematic incongruences between the visual and auditory modalities in the non-corresponding condition, the high groove PLD also contained temporal-spatial information that did not correspond with those features of the audio beat. Although this helped to reduce the potential for integrating the two modalities, we cannot determine the relative contributions of the different MSI principles that were violated in this condition. Despite this, the small differences in BPM across the high vs. low groove audio and visual clips (see Table 1) did permit a tight synchronisation of the core timing features relating to meter over the 10 second clip duration. In the asynchronous condition the 0.5 second time shift between the two modalities generally produced a large discord in the temporal domain, but inadvertently this also created the occasional synchronicity between temporal features within different songs. Future research could address this by using fewer stimuli with more tightly controlled temporal characteristics. Finally, a possible alternative explanation of our findings could be due to our explicit use of the term ‘groove’ in the questionnaire. This term may have stronger associations in genres like funk, soul and jazz, while other genres have the potential to evoke strong entrainment reactions (such as heavy metal, and samba), but are less likely to be associated with the term groove. It was probably for this reason that it was not possible in the present study to match the stimuli we selected from Janata et al.’s (2012) study based on genre. Future research should therefore investigate the extent to which genre may influence groove ratings, independent of the qualities inherent in the music itself.

In conclusion, a key finding of this study was that when reporting their subjective experience of groove, individuals responded differently to the same musical excerpt depending on the visual information with which it is presented. This is despite the fact that participants were specifically asked to rate the auditory component of the stimuli, rather than a combination of the audio and visual cues. Our findings show that observing a musician's physical performance can enhance perceptions of groove, but only when the combination of auditory and visual information is fully-compatible; that is, when the rules of sensory integration are not violated. Conversely, when incompatible body movements are observed, interference effects lead to a diminished experience of groove. These findings necessitate an understanding of musical performance from a multisensory perspective. While this exploratory study represents a first step toward investigating the role of visual information in groove perception, further research is required. Our study now paves the way for future experiments to systematically investigate the underlying mechanisms that lead to both the enhancement and interference effects observed here.

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Supplementary Material

Tables and figures/audio files with the index "S" are available as Supplemental Online Material, which can be found attached to the online version of this article at http://msx.sagepub.com. Click on the hyperlink "Supplemental material" to view the additional files.

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Declaration of Conflicting Interests

The Authors declare that there is no conflict of interest.

References

Alais, D., & Burr, D. (2004). The ventriloquist effect results from near-optimal bimodal integration. *Current Biology*, *14*, 257-262.

Di Carlo, N. & Guaitella, I. (2004). Facial expressions of emotion in speech and singing. *Semiotica*, *149*, 37-55.

Coutinho, E., & Scherer, K. R. (2017). The effect of context and audio-visual modality on emotions elicited by a musical performance. *Psychology of Music*, *45*(4), 550–569.

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.

Eaves, D. L., Breslin, G., Van Schaik, P., Robinson, E., & Spears, I. R. (2011). The short-term effects of real-time virtual reality feedback on motor learning in dance. *Presence: Teleoperators and Virtual Environments*, *20*(1), 62-77.

Eaves, D. L., Turgeon, M., & Vogt, S. (2012). Automatic imitation in rhythmical actions: Kinematic fidelity and the effects of compatibility, delay, and visual monitoring. *PLoS One*, *7*(10), e46728. doi:10.1371/journal.pone.0046728

Eaves, D. L., Haythornthwaite, L., & Vogt, S. (2014). Motor imagery during action observation modulates automatic imitation effects in rhythmical actions. *Frontiers in Human Neuroscience*, *8*(28). doi:10.3389/fnhum.2014.00028

Eaves, D. L., Behmer, L. P., & Vogt, S. (2016). EEG and behavioural correlates of different forms of motor imagery during action observation in rhythmical actions. *Brain and Cognition*, *106*, 90-103.

Eaves, D. L., Riach, M., Holmes, P. S., & Wright, D. J. (2016b). Motor imagery during action observation: a brief review of evidence, theory and future research opportunities. *Frontiers in Neuroscience, 10*(514). doi:10.3389/fnins.2016.00514

Etani, T., Marui, A., Kawase, S., & Keller, P. (2018). Optimal tempo for groove: Its relation to directions of body movement and Japanese nori. *Frontiers in Psychology*, *9*(462). doi:10.3389/fpsyg.2018.00462

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Frühauf, J., Kopiez, R., & Platz, F. (2013). Music on the timing grid: The influence of microtiming on the perceived groove quality of a simple drum pattern performance. *Musicae Scientiae*, *17*(2), 246–260.

Griffiths, N. K., & Reay, J. L. (2018). The relative importance of aural and visual information in the evaluation of western canon music performance by musicians and nonmusicians. *Music Perception: An Interdisciplinary Journal*, *35*(3), 364-375.

Hodges, N. J., Williams, A. M., Hayes, S. J., & Breslin, G. (2007). What is modelled during observational learning? *Journal of Sports Sciences*, *25*(5), 531-545.

Hofmann, A., Wesolowski, B. C., & Goebl, W. (2017). The tight-interlocked rhythm section: Production and perception of synchronisation in jazz trio performance. *Journal of New Music Research*, *46*(4), 329-341.

Iyer, V. (2002). Embodied mind, situated cognition, and expressive microtiming in African-American music. *Music Perception: An Interdisciplinary Journal*, *19*(3), 387-414.

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.

Juchniewicz, J. (2008). The influence of physical movement on the perception of musical performance. *Psychology of Music*, *36*(4), 417-427.

Keil, C., & Feld, S. (1994). *Music grooves*. Chicago: University of Chicago Press.

Kilner, J. M., Paulignan, Y., & Blakemore, S.-J. (2003). An interference effect of observed biological movement on action. *Current Biology, 13*(6), 522-525.

Kilchenmann, L., & Senn, O. (2015). Microtiming in swing and funk affects the body movement behavior of music expert listeners. *Frontiers in Psychology: Performance Science*, *6*(1232). doi:10.3389/fpsyg.2015.01232

King, A. J., & Palmer, A. R. (1985). Integration of visual and auditory information in bimodal neurones in the guinea-pig superior colliculus. *Experimental Brain Research*, *60*(3), 492-500.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155-163.

Krahé, C., Hahn, U., & Whitney, K. (2015). Is seeing (musical) believing? The eye versus the ear in emotional responses to music. *Psychology of Music*, *43*(1), 140-148.

Laurienti, P. J., Kraft, R. A., Maldjian, J. A., Burdette, J. H., & Wallace, M. T. (2004). Semantic congruence is a critical factor in multisensory behavioral performance. *Experimental Brain Research*, *158*(4), 405-414.

Lee, H., & Noppeney, U. (2014). Music expertise shapes audiovisual temporal integration windows for speech, sinewave speech, and music. *Frontiers in Psychology*, *5*(868). doi:10.3389/fpsyg.2014.00868

Livingstone, S. R., Thompson, W. F., Wanderley, M. M., & Palmer, C. (2015). Common cues to emotion in the dynamic facial expressions of speech and song. *The Quarterly Journal of Experimental Psychology*, *68*(5), 952-970.

Ludbrook, J. (2010). Confidence in Altman–Bland plots: A critical review of the method of differences. *Clinical and Experimental Pharmacology and Physiology, 37*(2), 143-149.

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

Madison, G., Gouyon, F., Ullén, F., & Hörnström, K. (2011). Modeling the tendency for music to induce movement in humans: first correlations with low-level audio descriptors across music genres. *Journal of Experimental Psychology. Human Perception and Performance, 37*(5), 1578–1594.

Madison, G., & Sioros, G. (2014). What musicians do to induce the sensation of groove in simple and complex melodies, and how listeners perceive it. *Frontiers in Psychology, 5*(894). doi:10.3389/fpsyg.2014.00894

Massaro, D. W. (2004). From multisensory integration to talking heads and language learning. In G. Calvert, C. Spence, & B. E. Stein (Eds.), *Handbook of multisensory processes* (pp. 153-176). Cambridge, MA: MIT Press.

McGurk H., MacDonald J. (1976). Hearing lips and seeing voices. *Nature, 264*, 746–748.

Meredith, M. A., Nemitz, J. W., & Stein, B. E. (1987). Determinants of multisensory integration in superior colliculus neurons. I. Temporal factors. *Journal of Neuroscience*, *7*(10), 3215-3229.

Meredith, M. A., & Stein, B. E. (1983). Interactions among converging sensory inputs in the superior colliculus. *Science, 221*(4608), 389-391.

Meredith, M. A., & Stein, B. E. (1986). Visual, auditory, and somatosensory convergence on cells in superior colliculus results in multisensory integration. *Journal of Neurophysiology*, *56*(3), 640-662.

Meyers, L. S., Gamst, G., & Guarino, A. J. (2006). *Applied multivariate research: Design and implication.* Thousand Oaks, CA: Sage Publications.

Petrini, K. , Dahl, S., Rocchesso, D., Waadeland, C.H., Avanzini, F., Puce, A., & Pollick, F.E. (2009). Multisensory integration of drumming actions: musical expertise affects perceived audiovisual asynchrony. *Experimental Brain Research*, *198*(2-3), 339-352.

Platz, F., & Kopiez, R. (2012). When the eye listens: A meta-analysis of how audio-visual presentation enhances the appreciation of music performance. *Music Perception: An Interdisciplinary Journal*, *30*(1), 71-83.

Quinto, L., Thompson, W. F., Russo, F. A., & Trehub, S. E. (2010). A comparison of the McGurk effect for spoken and sung syllables. *Attention, Perception, & Psychophysics*, *72*(6), 1450-1454.

Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: Interpretations and misinterpretations. *Nature Reviews. Neuroscience*, *11*(4), 264-274. doi:10.1038/nrn2805

Scott, M., Taylor, S., Chesterton, P., Vogt, S., & Eaves, D. L. (2018). Motor imagery during action observation increases eccentric hamstring force: an acute non-physical intervention. *Disability and Rehabilitation*, *40*(12), 1443-1451.

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. doi:10.1371/journal.pone.0199604

Senn, O., Kilchenmann, L., von Georgi, R., & Bullerjahn, C. (2016). The effect of expert performance microtiming on listeners' experience of groove in swing or funk music. *Frontiers in Psychology: Performance Science, 7*(1487). doi:10.3389/fpsyg.2016.01487

Schutz, M., & Lipscomb, S. (2007). Hearing gestures, seeing music: Vision influences perceived tone duration. *Perception, 36*, 888-897.

Sioros, G., Miron, M., Davies, M., Gouyon, F., & Madison, G. (2014). Syncopation creates the sensation of groove in synthesized music examples. *Frontiers in Psychology*, *5*(1036). doi:10.3389/fpsyg.2014.01036

Stupacher, J., Hove, M. J., & Janata, P. (2016). Audio features underlying perceived groove and sensorimotor synchronization in music. *Music Perception: An Interdisciplinary Journal, 33*(5), 571–589.

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.

Thompson, W. F., & Russo, F. A. (2007). Facing the music. *Psychological Science*, *18*, 756-757.

Van Wassenhove, V., Grant, K. W., & Poeppel, D. (2007). Temporal window of integration in auditory-visual speech perception. *Neuropsychologia*, *45*(3), 598-607.

Vatakis, A., & Spence, C. (2006a). Audiovisual synchrony perception for speech and music using a temporal order judgment task. *Neuroscience Letters, 393*, 40–44.

Vatakis, A., & Spence, C. (2006b). Audiovisual synchrony perception for music, speech, and object actions. *Brain Research, 1111*, 134–142.

Vines, B. W., Krumhansl, C. L., Wanderley, M. M., & Levitin, D. J. (2006). Cross-modal interactions in the perception of musical performance. *Cognition*, *101*(1), 80-113.

Witek, M. A. G. (2016). Filling In: Syncopation, Pleasure and Distributed Embodiment in Groove. *Music Analysis, 36*(1), 138-160.

Witek, M. A. G., Clarke, E. F., Wallentin, M., Kringelbach, M. L., & Vuust, P. (2014). Syncopation, body-movement and pleasure in groove music. *PloS One*, *9*(4), e94446. doi:10.1371/journal.pone.0094446

Witek, M. A. G., 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.

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: Auditory-motor interactions in music perception and production. *Nature Neuroscience, 8*, 547-558.