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Sensorimotor Coupling in Music and the Psychology of the Groove

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The urge to move in response to music, combined with the positive affect associated with the coupling of sensory and motor processes while engaging with music (referred to as *sensorimotor coupling*) in a seemingly effortless way, is commonly described as the feeling of being in the groove. Here, we systematically explore this compelling phenomenon in a population of young adults. We utilize multiple levels of analysis, comprising phenomenological, behavioral, and computational techniques. Specifically, we show (a) that the concept of the groove is widely appreciated and understood in terms of a pleasurable drive toward action, (b) that a broad range of musical excerpts can be appraised reliably for the degree of perceived groove, (c) that the degree of experienced groove is inversely related to experienced difficulty of bimanual sensorimotor coupling under tapping regimes with varying levels of expressive constraint, (d) that high-groove stimuli elicit spontaneous rhythmic movements, and (e) that quantifiable measures of the quality of sensorimotor coupling predict the degree of experienced groove. Our results complement traditional discourse regarding the groove, which has tended to take the psychological phenomenon for granted and has focused instead on the musical and especially the rhythmic qualities of particular genres of music that lead to the perception of groove. We conclude that groove can be treated as a psychological construct and model system that allows for experimental exploration of the relationship between sensorimotor coupling with music and emotion.

Keywords: synchronization, beat, rhythm, popular music, emotion

Humans have a proclivity to move with music. Whether it is through the subtle marking of time by means of miniscule head bobs or toe taps or through elaborate dance moves, the engagement of people's motor systems while listening to music is commonplace and seems to have an almost automatic, irresistible quality to it. Moreover, engagement of the brain's action systems while listening to music appears to support a pleasing psychological state for the individual, the need to suppress urges to move in socially inappropriate settings notwithstanding. Because this sensorimotor coupling seems to be one of the most widespread ways in which people engage with and enjoy music—it is a common component of strong experiences with music (Gabrielsson & Lindstrom Wik, 2003)—there is a compelling case to be made for developing an empirical understanding of this phenomenon that spans multiple levels of analysis—from phenomenological to neural. Our goal is to establish this phenomenon as an object of study in psychology. To this end, we take a broad and integrative approach, described at the end of the introduction, to show that the basic principles of the phenomenon can be observed and quantified at several levels of analysis.

To discuss the phenomenon, it helps to give it a label. We refer to it as the *groove*. We recognize that the same underlying phenomenon might be described using a number of synonyms, but as we show later, the term *groove* exists in common parlance with a connotation that captures what we believe are critical elements of the phenomenon. The term has also existed within academic circles for some time, primarily within the musicology and ethnomusicology domains (Keil & Feld, 1994; Pressing, 2002); therefore, its exploration within psychology and neuroscience seems appropriate. Within the musicology and music theory domains, the term *groove* typically refers to rhythmic properties of pieces of music and/or the timing relationships of actions of individuals interacting with the music (Iyer, 2002; Keil & Feld, 1994; Pressing, 2002). For example, Keil and Feld (1994) regard *participatory discrepancies*—deviations from precise metronomic timing relationships—as a central source of groove. From a more psychological yet related perspective, Pressing (2002) described groove as "a kinetic framework for reliable prediction of events and time pattern communication" (p. 285), in which perceptual and productive rivalries are established against this framework. Finally, the psychological construal of groove as a sensorimotor phenomenon with an affective component has started to be examined (Madison, 2006), albeit mainly from a perceptual rather than experiential point of view, as has the closely related concept of *flow* (de Manzano, Theorell, Harmat, & Ullen, 2010).

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Madison (2006) operationally defined groove as "wanting to move some part of the body in relation to some aspect of the sound pattern" (p. 201) and proceeded to examine interindividual variability in ratings of perceived groove in 64 brief (8-s) musical exemplars drawn from a variety of styles and cultural traditions, alongside 14 other descriptors that connoted various forms of motion and emotional constructs of arousal and valence. Variation in groove ratings was similar to that observed for the other descriptors, and a factor analysis of the ratings showed that the descriptors *groove* and *driving* characterized one dimension of a four-factor solution. Notably, this dimension was distinct from a dimension characterized by *happy, rocking,* and *having swing*—attributes that might be expected to relate to the groove. No attempt was made, however, to examine any sensorimotor correlates of the groove or the degree to which the feeling of the groove or positive affect was induced in the listeners. In addition, although the listeners were able to apply the concept of groove as defined by the author to their perceptual judgments, no systematic attempt was made to establish the participants' native understanding of the concept.

In a detailed study of emotional responses to a small number of musical pieces drawn from a diverse set of genres, Grewe, Nagel, Kopiez, and Altenmüller (2007) observed the highest subjective ratings of arousal and valence in response to an energetic and somewhat comical dance piece (Quincy Jones's, "Soul Bossa Nova"), which also elicited the strongest desire to move from among the pieces tested. Though the notion of groove was not examined in this study, such coupling of a desire to move with positive affect is expected for pieces of music that would be perceived as high in groove. The study also reinforced the fact that many pieces (and perhaps entire genres) of music do not groove.

The term *groove* is commonly used by musicians to refer to a pleasing state in which the creation of music becomes seemingly effortless (Berliner, 1994; Pressing, 2002). Particularly when playing in an ensemble, the groove may be experienced when the interaction among the different instruments becomes seamless and the musical result feels right subjectively. In this regard, the sense of the groove may be closely related to the concept of flow, two characteristics of which are (a) that actions feel automatic and few or no attentional resources are required for executing action sequences and (b) that a state of positive affect is induced (Csikszentmihalyi, 1990; de Manzano et al., 2010). Although variability in the experience of flow was found to correlate with some physiological indicators of mental effort and affect in expert pianists, thus providing support for the psychological characterization of the flow state (de Manzano et al., 2010), there is so far no clear understanding of how sensorimotor performance measures correlate with subjective or other measures of flow or groove, or affective states, across a wide range of musical expertise. In sum, there is growing scientific interest in understanding the relationships between music and sensorimotor coordination, affect, and underlying physiological mechanisms.

Phenomenological, Behavioral, and Computational Approaches to Understanding the Groove

Our approach to characterizing the psychology of the groove spans several levels of analysis, and in the present article, we sought to answer several questions. First, is the concept of the groove consistently represented in the minds of individuals? Attaining some sort of consensus definition and demonstrating that the concept is reasonably pervasive and consistent in a large population are both prerequisites for examining a subjective phenomenon in the laboratory. Thus, rather than relying solely on music-theoretic definitions of groove or our own intuitions, we sought to derive a working definition from the definitions of a large number of undergraduate students who were asked to define the term, along with responses to a survey that contained a variety of descriptive phrases that we believed might be associated with the concept of the groove to varying degrees.

Second, is the groove an attribute of music that can be perceived and consistently judged? To what extent might additional factors, such as familiarity with a piece of music, influence the perceived attribute? To address these questions, we examined variability in the perceived degree of groove present in a large sample of 30-s music exemplars selected from a range of musical styles and tempi. At the same time, we assessed the interrelationship between perceived groove and the familiarity and enjoyment of the music. This experiment also served to develop a normative library of musical excerpts that varied in the degree of perceived groove for use in the further experiments.

Third, how is the experiential state of being in the groove shaped by sensorimotor tasks that are performed in association with music that varies in the degree of perceived groove? This question gets at the important distinction between appraising an attribute of the music (driven primarily by perception) and appraising the subjective quality of one's own sensorimotor interaction with the music. Accordingly, utilizing our newly obtained normative library of musical exemplars, categorized into three levels of groove, we engaged participants in sensorimotor interactions with the music across three levels of sensorimotor constraint: no tapping, isochronous bimanual tapping, and free-form (unconstrained) bimanual tapping. The trial-level data allowed us to examine the relationships between several subjective variables: perceived groove in the music, enjoyment of the task, the degree of groove experienced while tapping, and experienced difficulty while performing the task. The motivation for the tapping manipulation (isochronous vs. free-form) was the hypothesis that the most unconstrained condition would allow for the freest degree of self-expression in relation to the music and therefore the strongest sense of being in the groove.

Fourth, is sensorimotor coupling spontaneously manifested when listening to music that has a higher degree of groove? Video recordings obtained in the behavioral experiment described earlier allowed us to assess the degree of spontaneous movement during the no-tapping trials as a function of the groove category of the stimuli.

Finally, does a quantitative metric that compares the temporal structure in a participant's tapping behavior with the temporal structure of the music predict the subjective feeling of being in the groove? An answer to this question is of importance for further studies of the groove in which it would be advantageous to not have to rely on subjective ratings of being in the groove. To this end, we quantified the correspondence between the temporal structure in the music and the temporal structure of the tapping responses utilizing a model that serves to describe and compare the temporal structures present in a various data streams (Tomic & Janata, 2008).

Defining Groove as a Psychological Construct

Because our interest is in the concept of groove as a psychological construct, rather than a music-theoretic construct that focuses primarily on the metric/rhythmic properties of the music, we asked a large number of predominantly young adult participants to provide definitions of the groove in their own words and also to complete a survey that contained a variety of descriptive phrases that we believed would be associated with the concept of the groove to varying degrees.

Methods

Participants. We asked 215 participants (mean age = 20.6 ± 3.1 years; 132 female, 83 male), "Have you ever heard the term *groove* as applied to music?" Among participants, 74.6% answered in the affirmative. Of those, 153 (mean age = 20.8 ± 3.5 years; 90 female, 63 male) completed one of the versions of the survey. All participants provided informed consent in accordance with a protocol approved by the University of California, Davis, Institutional Review Board.

Surveys. Survey items were statements generated on the basis of a general intuition of the factors that contribute to experiencing the groove. Additional items were included that pertained to aspects of music that could be expected to influence an individual's enjoyment of music but that were not considered likely to influence the feeling of the groove. A total of 30 items were presented across the two versions of the survey that were developed; 14 items were presented in both versions. The survey items are shown in Figure 1. Responses to each item were made on an 8-point scale (1 = *strongly agree*, 2 = *agree,* 3 = *agree somewhat*, 4 = *neither agree nor disagree,* 5 = *disagree somewhat,* 6 = *disagree,* 7 = *strongly disagree*, 8 = *don't know*). Prior to endorsing the items on the survey, participants were asked to provide their own written definition of the groove.

Procedure. Two variants of the survey were administered in association with eight experiments. The experiments, two of them reported later as Studies 1 and 2, varied in their objectives but generally involved rating the degree of perceived groove, rating the degree of perceived complexity, and/or synchronizing body movements either with drum loops or excerpts of recorded polyphonic music. In half of the experiments, the survey was administered before the main tasks were performed. We note that this aspect of the overall project was not conceived of as a separate study. Rather, the provision of definitions and completion of the survey were included alongside other tasks that were the primary focus of the respective experiments. As such, the approach deviates from common practices of survey development, which limits somewhat the depth of insight we can achieve with the present effort.

Participants completed the survey in a quiet room by means of a Web-browser interface controlled by Ensemble, a Web-based system for experiment management and data collection (Tomic & Janata, 2007). Data were stored in a MySQL database for subsequent analysis.

Data analysis. Survey responses were analyzed with custom scripts written in MATLAB. For each item, responses of *don't know* were excluded from the calculation of the mean endorsement for that item. An omnibus F statistic was calculated with PROC MIXED in SAS to determine whether mean endorsements of the items differed from each other. Subsequently, a t test was performed for each item to determine whether its mean endorsement differed significantly from the value corresponding to the scale position *neither agree nor disagree*.

To determine the prevalence of concepts in individuals' groove definitions, the written definitions were parsed into individual words, spelling errors were corrected, and the words were then tallied and rank ordered.

Results

Figure 1 shows the survey statements sorted by their mean endorsement. Across the items, average endorsements ranged from *agree* to *disagree.* The variation in the level of endorsement of the items was significant, $F(52, 3015) = 25.18$, $p < .0001$. The most strongly endorsed items encompassed concepts of movement, positive emotion, a sense of integration with the music, and the presence of salient beats. These concepts were echoed in the written definitions that were generated before the survey items were seen (Table 1). After the terms *music* and *groove,* which were used primarily to set the context for the person's answer, the most common words emphasized concepts of movement and rhythm (*move, dance, beat, rhythm*). The next most common words emphasized a sense of feeling and compulsion (e.g., *feel, make, want*) perhaps in the context of integrating the movements of one's body with the music (e.g., *with, your, body*). The emphases on positive emotion and the urge to move with the music led us to adopt the following working definition of groove: The groove is that aspect of the music that induces a pleasant sense of wanting to move along with the music.

Discussion

Definitions of the concept of groove as it pertains to music and endorsements of concepts on the surveys converged on the idea that the groove is an aspect of the music that compels one to move and that this feeling is generally regarded as pleasurable. Further elaboration of the survey and associated factor analyses may be able to determine whether movement and emotion are separable constructs in individuals' concepts of groove. Nonetheless, given the view we gleaned—that groove is a sensorimotor phenomenon with affective consequences—we turn to examine the hypothesis that music that is regarded as having more groove promotes more movement and stronger rhythmic coupling with the music than does music with a lesser amount of perceived groove.

Study 1: Perceived Groove as a Function of Genre, Tempo, and Familiarity

Prior to initiating experiments to examine sensorimotor phenomena associated with a groove response to real musical excerpts, we sought to obtain a normative collection of stimuli that varied in the degree of perceived groove. Our objective was to draw potential exemplars from a relatively broad musical space and to examine whether factors, such as the musical genre from which the exemplar was drawn, the exemplar's tempo, its familiarity, and how much it was enjoyed, would influence the groove rating. On the basis of the results of the groove survey, we

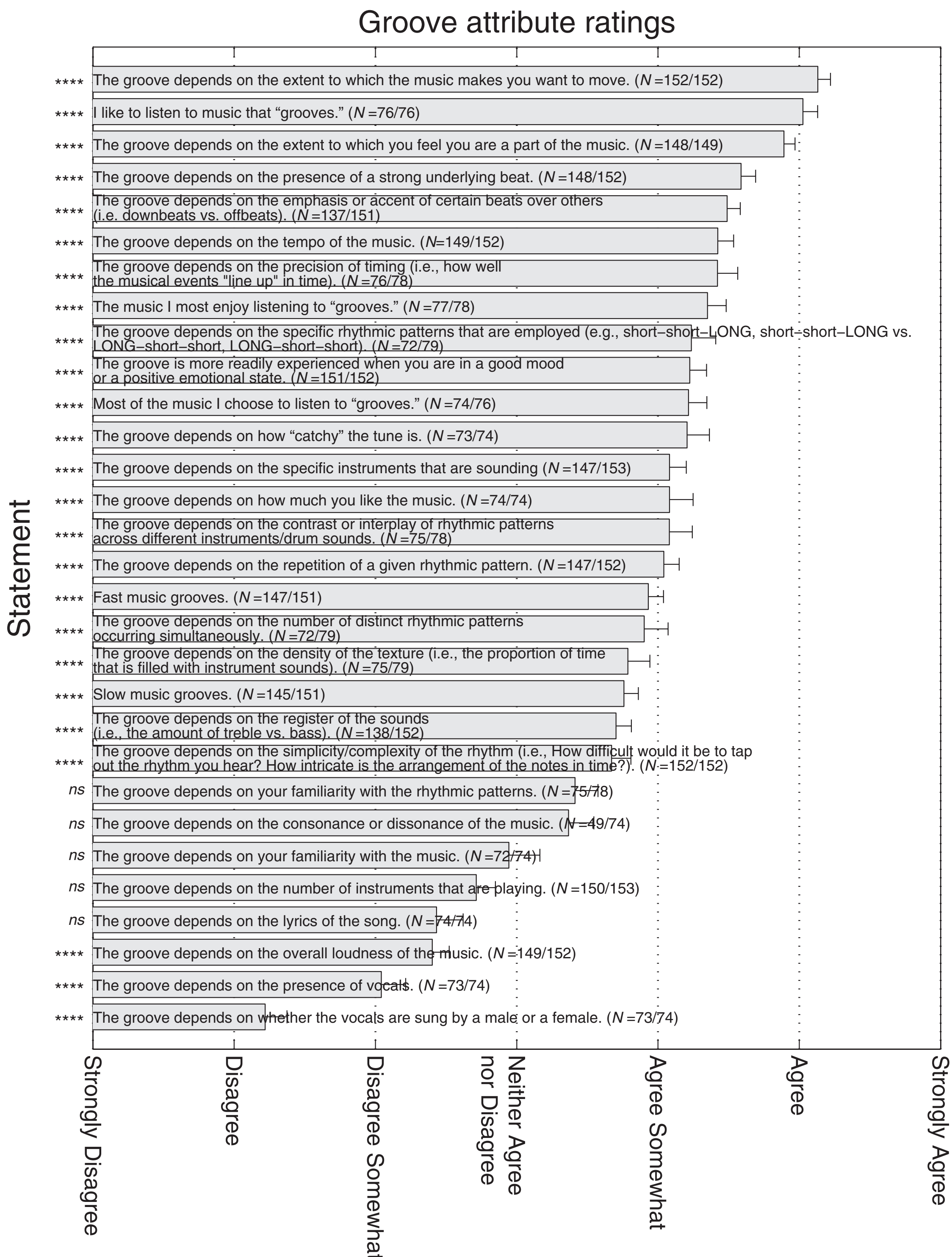

Figure 1. Rank-ordered average endorsements of statements aimed at characterizing lay usage and understanding of the concept of groove. Each statement is followed by an indication of the number of participants who provided an endorsement and the total number who were presented with the statement. Error bars indicate standard error of the mean. Asterisks indicate the probability of a significant difference in mean endorsement from *neither agree nor disagree*, with **** $p = .0001$.

Table 1
Word Frequencies Across 153 Definitions of the Term Groove

Word	Frequency
music	140
groove	85
move	53
beat	49
rhythm	46
dance	43
feel	36
with	36
make	30
your	25
want	22
flow	19
listen	19
song	19
body	18
enjoy	15

Note. Articles, pronouns, prepositions, common verbs, and words occurring less than 10 times have been excluded.

expected to observe an effect of tempo and enjoyment and also of genre to the extent that the genres we selected differed in the presence of salient rhythms and a strong sense of the beat.

Methods

Participants. Nineteen University of California, Davis, undergraduates participated in this experiment in exchange for partial course credit. All participants provided informed consent in accordance with a protocol approved by the University of California, Davis, Institutional Review Board.

Stimuli. We chose 148 musical excerpts for this experiment (see the Appendix). With the exception of 20 drum loops that were drawn from a MIDI compilation disk (*L.A. Riot*, 1997), all of the excerpts were obtained from the previews available from the iTunes Music Store. The initial 20 s of each 30-s excerpt were used. Exemplars were selected from four broad genres: folk, jazz, rock, and soul/R&B. Of the 32 exemplars from each genre, 16 were chosen to have a slower subjective tempo and 16 to have a faster subjective tempo. Across categories, the mean estimated tempo (Tomic & Janata, 2008) was 90.8 ± 6.6 beats per minute for the slow category and 115.6 ± 8.0 beats per minute for the fast category.

Procedure. Participants were tested individually in a quiet sound-attenuating room. They were seated in front of a table on which stood a computer monitor as well as a MIDI slider device that was used to obtain the groove ratings. Exemplars were played from speakers situated approximately 4 feet to either side of the participant at comfortable listening levels. Participants were presented with the following instructions:

> In the following experiment, we would like you to listen to a series of musical excerpts and rate the degree to which you feel the music you are hearing "grooves." We recognize that different individuals may define the term "groove" differently, so we would like you to use your own personal definition of "the groove" in making this judgment.
>
> Each excerpt lasts approximately 20 seconds. Occasionally, the music you hear will consist only of rhythmic sequences played using percussive instruments. Each of these drum loops lasts approximately 15 seconds. After each excerpt, regardless of whether you heard a song or a drum loop, you will be asked questions regarding your familiarity with and enjoyment of the music.
>
> Using the fader on the continuous response device, indicate to what extent the music you are hearing "grooves." Adjust the fader as often as necessary to reflect the ways in which your feelings of "groove" change on a moment-to-moment basis. A rating of zero means the music doesn't "groove" at all, whereas a rating of 10 means the music imparts a very strong feeling of "groove."

Exemplars were selected at random under the control of Ensemble (Tomic & Janata, 2007). The participants' task was to listen to the musical excerpt and adjust the position of the slider to reflect their moment-to-moment degree of perceived groove. The MIDI slider position was quantized into 128-step range by a MIDItools computer (www.electrovoce.com), and the MIDI signal was recorded by Digital Performer (MOTU, Inc.) in conjunction with an 828mkII interface (MOTU, Inc.). The audio signal was recorded on a separate channel alongside the MIDI data in Digital Performer.

Following each excerpt, the participants used a mouse to answer two questions that were displayed on a computer monitor in front of them: "How much did you enjoy what was just played (7-point scale displayed as radio buttons: 1 = *not at all*, 7 = *very much*)?" and "How familiar are you with what was just played (1 = *not at all*, 7 = *very familiar*)?" Participants completed two sets of 74 trials with a break between each set. The entire experiment lasted between 75 and 90 min.

Data analysis: Preprocessing. Data were preprocessed with MATLAB. MATLAB scripts were used to extract the time-varying groove rating responses from the Digital Performer files and to associate them with the postexemplar responses obtained by Ensemble. Because the stimuli were selected at random, and because there was no simple way to communicate stimulus identification codes from Ensemble to Digital Performer, the stimulus order was identified by correlating the audio waveform recorded in Digital Performer with the original audio waveforms of all of the exemplars.

A participant's groove rating of each exemplar was summarized by a single value that represented the steady state position of the slider during the musical excerpt. Preliminary inspection of the data in which all of the groove-rating traces were normalized and superimposed indicated that participants tended to adjust the slider to a final position within the initial 4 to 8 s of each excerpt and then keep it there. Thus, we took as the groove rating the mean slider value in the latter half of each epoch.

Statistical analyses. Reliability across participants in the groove ratings for the set of stimuli was assessed by calculating Cronbach's α on the stimulus-by-participant matrix of groove ratings using PROC CORR in SAS.

To examine effects of genre and tempo on groove ratings, the groove ratings were averaged for each participant across the 16 exemplars within a combination of genre and tempo. The mean groove ratings were entered into a mixed-effects model implemented in PROC MIXED in SAS. Genre (folk, jazz, rock, soul/R&B) and tempo (slow, fast) were treated as categorical fixed-effects variables, and familiarity and enjoyment were entered as continuous fixed-effects variables. We anticipated that the use of the MIDI slider might vary considerably across participants in making the groove ratings, so an intercept was modeled for each participant as a random variable.

The drum loops used in this experiment were included because they had been used exclusively in pilot experiments. When judged within the larger corpus of real musical excerpts, their ratings clustered together around intermediate values of the rating scale (data not shown). Given the lack of variance in ratings and the exclusive use of real musical excerpts in the subsequent experiments, we do not consider them further here.

Results

Groove ratings varied across the full range of values (from 0 to 127). The highest mean groove rating (108.7) was obtained for "Superstition," a strongly syncopated piece by Stevie Wonder from the soul/R&B genre, whereas the lowest mean groove rating (29.3) was in response to "Hymn for Jaco," by Adrian Legg, a very slow excerpt for single guitar from the folk genre (see the Appendix for a full list of the stimuli used and their mean groove ratings). Ratings of perceived groove in individual stimuli were very consistent across participants (standardized $\alpha = .81$).

Figure 2A illustrates that overall, the degree of perceived groove varied significantly as a function of genre, $F(3, 114) = 3.45$, $p < .02$, and tempo, $F(1, 114) = 25.12$, $p < .0001$, with higher tempo songs eliciting higher groove ratings. Pairwise comparisons indicated that groove ratings were significantly higher for soul/R&B excerpts than each of the other genres: rock, $t(114) = -3.14$, $p = .0022$; jazz, $t(114) = -2.77$, $p = .0066$; folk, $t(114) = -2.74$, $p = .0071$, whereas the mean groove ratings among the other genres did not differ significantly. Although it appears that fast and slow songs elicited comparable groove ratings for the most highly rated genre, soul/R&B, the Genre × Tempo interaction was not significant, $F(3, 114) = 0.14$, *ns*. Groove ratings were strongly related

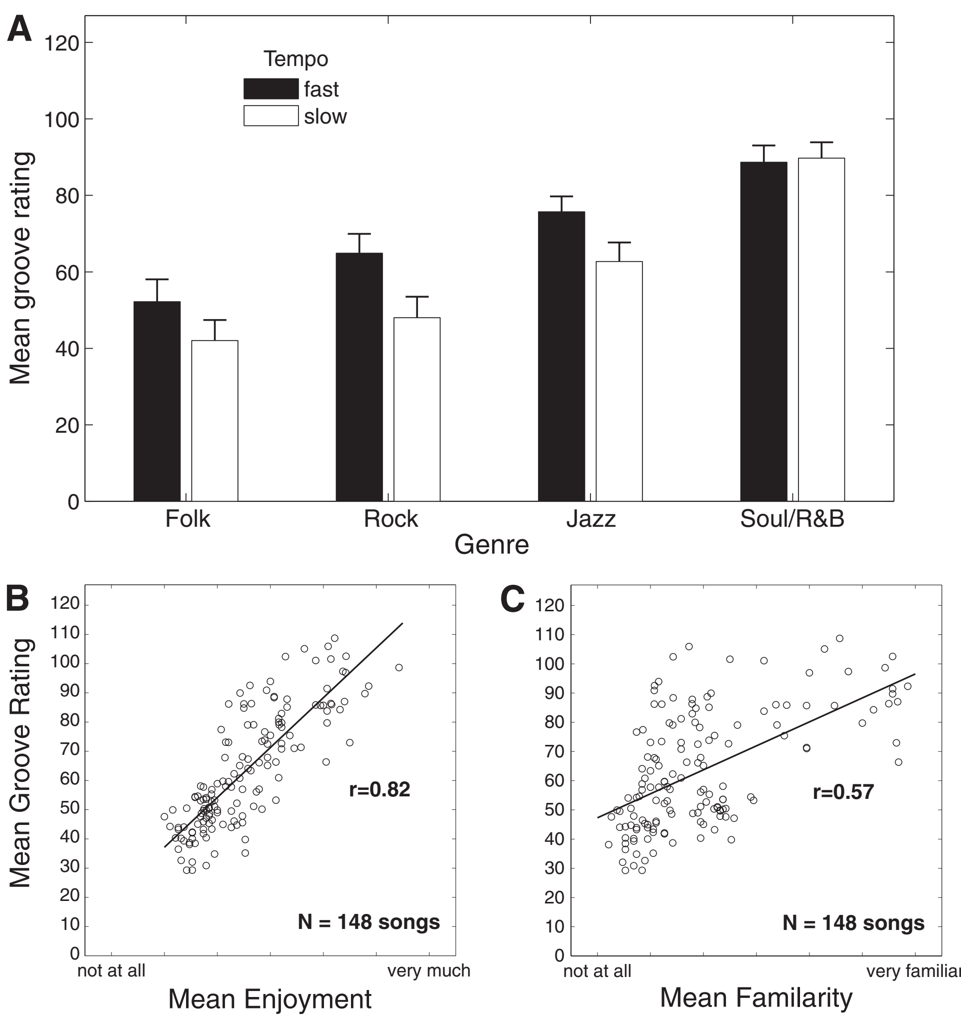

Figure 2. Determinants of perceived groove in 20-s excerpts of music. A: Mean groove ratings as a function of genre and tempo. Error bars indicate standard error of the mean. B: Perceived groove was strongly related to the enjoyment of those excerpts. Each circle represents one of the excerpts tested. C: Familiar excerpts were generally associated with higher levels of perceived groove, though many unfamiliar excerpts were rated as high in groove.

to how much a person enjoyed the excerpts, $F(1, 114) = 57.19$, $p < .0001$. Within the full model, the effect of familiarity was not significant, $F(1, 114) = 2.52$, *ns*, though when enjoyment was removed from the model, the effect of familiarity was significant, $F(1, 115) = 15.10$, $p = .0002$. When examined at the level of individual songs, the correlation between the mean level of enjoyment and perceived groove was very strong ($r = .82$, $p < .0001$; Figure 2B). The correlation between familiarity and perceived groove was also significant ($r = .57$, $p < .0001$) though weaker because of a considerable number of unfamiliar songs that were rated high in groove (Figure 2C).

Discussion

The genre and tempo of excerpts of real music were found to have a significant effect on groove ratings. The findings that faster tempo music and the soul/R&B genre elicited higher groove corroborate the strong endorsements of items related to movement, a strong sense of the beat, the rhythm, and the tempo in the survey described earlier. The soul/R&B genre typically places a strong emphasis on accentuated and danceable rhythms, and selections from this genre were included because it was expected that they would garner the highest groove ratings.

The general sentiment that the groove reflects a pleasurable state was echoed strongly in the ratings. Interestingly, the statement that the groove depends on one's familiarity with the music received a very neutral endorsement that was paralleled in the ratings in that the effect of familiarity was not significant if enjoyment was taken into account. However, the fact that familiarity and enjoyment, as well as familiarity and groove ratings, were significantly correlated suggests that perceived groove is mediated by a variety of factors.

Although there are many other genres that would be expected to vary in their average degree of groove and although one could find many other examples of high- and low-groove stimuli within the genres sampled here, our objective of identifying a large number of musical excerpts that varied in the degree of perceived groove was achieved, allowing us to move on to the next step of examining the sensorimotor aspects of engaging with a subset of these stimuli.

Study 2: Experiencing the Groove During Sensorimotor Behaviors

The objective of this study was to examine both spontaneous and guided sensorimotor coupling with excerpts of real music, drawn from Study 1, which varied in the degree of perceived groove. With regard to spontaneous coupling, we hypothesized that the number and extent of body movements (e.g., foot tapping, head bobbing, etc.) would increase as the degree of perceived and experienced groove increased, even in the absence of any instructions to generate such movements.

The guided examination of sensorimotor coupling comprised several bimanual tapping conditions and was driven by consideration of what the potential relationships might be between sensorimotor coordination with a musical stimulus and the affective experience associated with that behavior. To date, almost all synchronization paradigms have utilized the tapping of a single finger and some form of isochronous tapping instruction, the most musical one of which is to "find and tap along with the beat." A notable exception is the study by Fitch and Rosenfeld (2007) in which participants were asked to tap with the pulse established by an isochronous bass drum sound in the presence of woodblock rhythms that varied in the degree of syncopation. Syncopation refers to the presence of events at less expected moments in time, where expectations can be thought to fall on a temporal/metrical grid (Longuet-Higgins & Lee, 1984; Palmer & Krumhansl, 1990). As the degree of syncopation increased, the ability of participants to tap and recognize the rhythms decreased, and often participants reset the timing of their taps to coincide with the weak beats of the syncopated rhythm rather than the isochronous pulse.

Although moving isochronously along with the perceived beat likely represents the simplest route toward coupling with music and experiencing the groove, instructions to tap a single finger isochronously with the beat might be regarded as inhibitory when a person feels compelled to move more body parts or generate more complex rhythmic and syncopated patterns in interaction with the music. The requirement to inhibit behavioral expression may, in turn, dampen positive emotional experience. Thus, we were interested in extending the range of tasks to include free-form bimanual tapping, both in silence and in the presence of music that varied in the degree of perceived groove. We predicted that the free-form tapping task would permit stronger groove experiences, particularly in response to mid-groove and high-groove stimuli.

Given these considerations, the experiment crossed two variables: tapping condition (three levels: no tapping, bimanual isochronous, bimanual free-form) and stimulus category (four levels: silence, low groove, mid-groove, high groove). The combination of no tapping and silence was eliminated because it was not critical to any of the comparisons of interest and would have therefore unnecessarily prolonged the experiment and squandered the goodwill of our participants. The no-tapping condition allowed us to examine video recordings of the participants for their tendency to move spontaneously with excerpts that varied in the degree of perceived groove. The comparisons of tapping with and without music allowed us to assess the importance of musical (sensory) input for experiencing groove while tapping. We obtained both movement data (video of whole body, tapping on drum pad) and subjective ratings following each trial. Subjective ratings were appraisals of the perceived degree of groove in the excerpts (as in Study 1), the degree to which participants felt in the groove while tapping, and the difficulty they experienced while tapping.

Methods

Participants. Participants were 34 undergraduate students (25 female, 9 male; age range = 18–34; mean age = 20.6). Previous musical experience was not a requirement for participation. Of the 27 participants who reported having received some formal musical training, five participants reported having received between 2 and 4 years of training, and eight participants reported having received 5 or more years of musical training. None of the participants had participated in the previous groove rating study. All participants provided informed consent.

Apparatus. Each participant was seated alone in a sound-isolating chamber. Two Mackie HR824 studio speakers were placed approximately 2 m apart at one end of the room. A 23-in. display was placed between the speakers. The participant sat on the other side of the room, approximately 2 m away, facing the display and speakers. A Sony HVR-Z1U video camera was mounted on a tripod behind the computer monitor. A Roland Handsonic HPD-15 drum pad was affixed in four points to a customized pedestal and placed in front of the participant (Figure 3). The HPD-15 has a large circular pad divided into 15 sections, each of which can be programmed to a different MIDI note and sensitivity setting. The top half and center section of the circular drum pad were covered with paper, leaving only the bottom left and right sections uncovered. The two uncovered sections were assigned to different MIDI notes.

The MIDI responses from the drum pad as well as a copy of the audio signal that the participant heard were recorded with Digital Performer (MOTU, Inc.) software and used in analyses of the data. The audio outputs of the drum pad were muted, and the drum pad did not provide auditory feedback through its internal synthesizer. Thus, quiet dull thuds were the only auditory feedback the participants received from their own taps.

An intercom system was configured so that the participant and experimenter could communicate if necessary. However, once the tasks started, the experimenter did not normally interact with the participant except to see if he or she needed to take short breaks in between the three blocks of trials of the experiment.

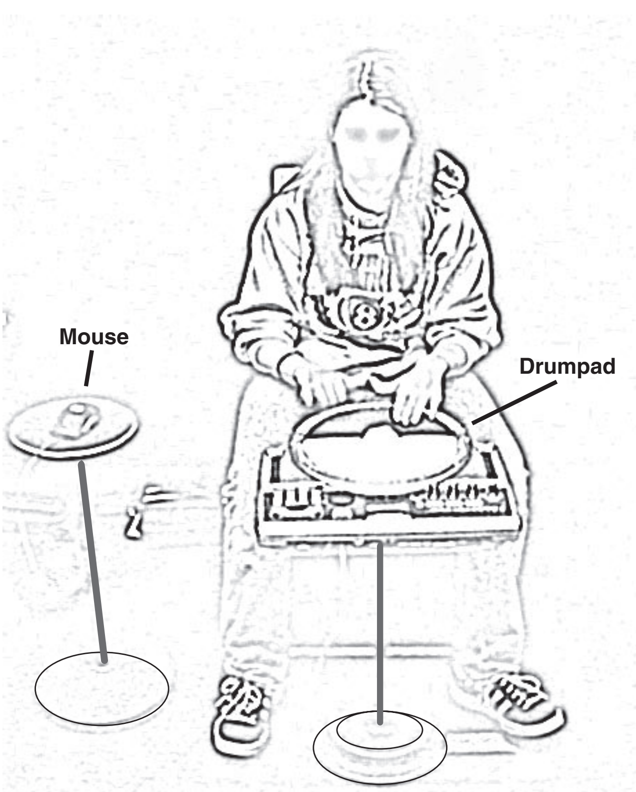

Figure 3. Illustration of the experimental setup in Study 2. The image is a Photoshop tracing of a still image obtained from the video recording of one of the participants performing the bimanual free-form tapping task. The Roland drum machine used as a tapping pad was mounted to a plate that was mounted to the rod of a microphone stand to provide an unobstructed view of the participants' legs and feet. A separate microphone stand table to the right of the participant served as a mouse pad so that participants could respond to the questions appearing on the monitor in front of them (outside the field of view) following each excerpt. The pedestal outlines and microphone stand shafts were added to the image.

Questions and stimuli were presented to the participant using Ensemble (Tomic & Janata, 2007). The resolution of the screen was reduced to 960 × 600 so that the participant could read instructions and questions from where he or she was sitting. A mouse was placed on a pedestal to the right of the participant so that he or she could make multiple-choice answers when they were presented on the monitor in front (Figure 3).

Survey. Prior to performing the tasks for the experiment, participants were presented with several survey forms. Participants were presented with the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) both before and after the main tasks, a simple handedness (left, right, or ambidextrous) question, a musical background form, and a groove definition form. The purpose of the PANAS was to assess the general impact of performing the experiment on the participants' affective states, with the hope that the experiment would be neutral in this regard. We did not expect the PANAS measure to interact with any of the variables of interest. The musical background form asked participants if they had normal hearing, if they had perfect pitch, what genres of music they listened to and were exposed to as a child, how many years of formal musical training they received, and what instruments they were proficient in. The groove definition form asked the participants, "Have you ever heard the term 'groove' as applied to music?" The answer was a forced-choice *yes* or *no* answer. This was followed by another question: "If so, please give us your definition of 'the groove.'" A text box was provided so that participants could enter their own definition of *the groove* if they answered *yes*. If they answered *no,* the next form would provide participants with the definition: "'The groove' is the aspect of music that compels the body to move." The definitions collected here were incorporated into the analysis described earlier in the Defining Groove as a Psychological Construct section.

Stimuli. We selected 48 of the stimuli from Study 1 on the basis of their mean groove ratings to form low-groove, mid-groove, and high-groove categories (Figure 4). The stimuli in the low-groove category were the 16 with the lowest mean groove rating in Study 1, the mid-groove category comprised the 16 excerpts with the middle mean groove rating, and the high-groove category comprised the 16 excerpts with the highest mean groove rating in the previous study. For this experiment, the full 30-s excerpt was presented. We added one additional stimulus condition, the absence of music, referred to as *silence* in the following text. In the case of no-music trials (described later), a 500-ms beep marked the start of the trial, and a second beep marked the end of the 30-s trial.

Tasks. The 48 musical stimuli and silence were associated with three tasks—no tapping, bimanual isochronous tapping, and free-form tapping—to create 144 possible trial combinations with music. For the isochronous tapping task with music, participants were instructed to find the beat (tactus) of the music. When tapping isochronously without music (silence), participants were instructed to tap at a constant rate that felt comfortable. In the free-form tapping task, participants were instructed to tap using any pattern that felt comfortable. For the tapping tasks, participants were instructed to tap only on the bottom left section of the drum with their left hand and only on the bottom right section with their right hand. Three of the 48 musical stimuli (one from each groove

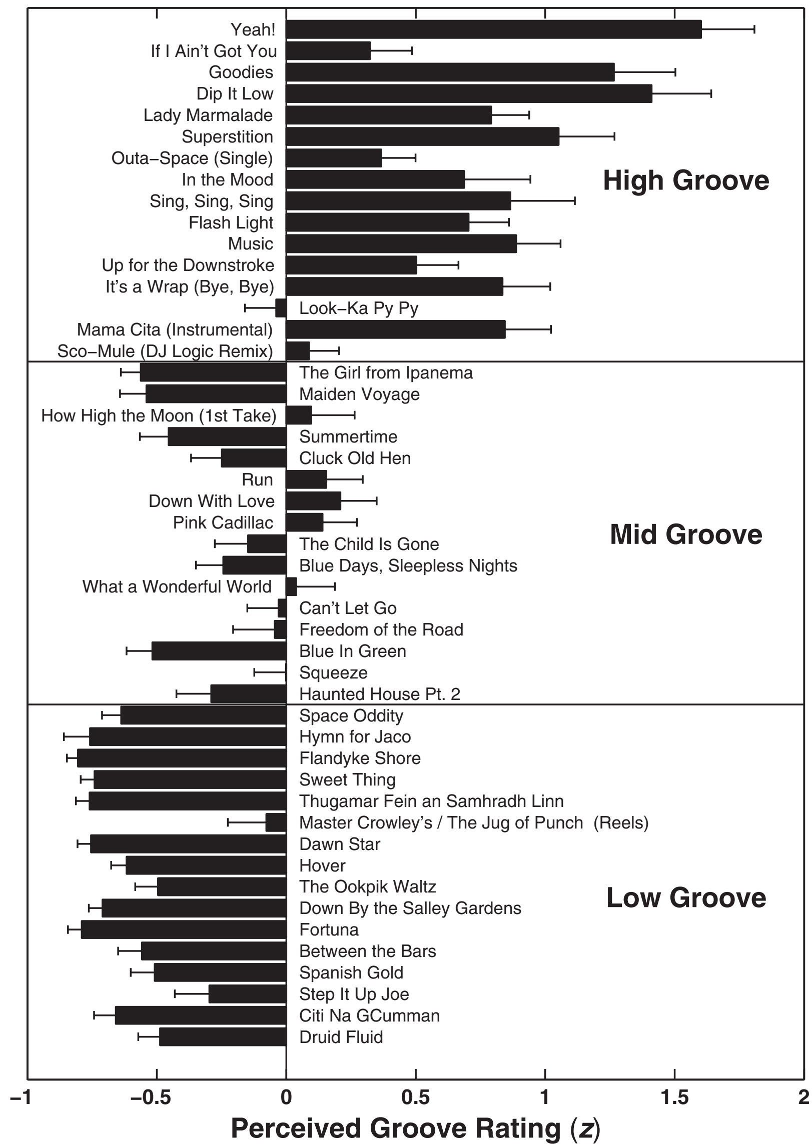

Figure 4. Standardized perceived groove ratings associated with each of the excerpts used in Study 2. The excerpts have been arranged in blocks according to the category to which they were assigned on the basis of the ratings obtained in Study 1. Error bars indicate one standard error of the mean.

category: low, mid-, and high) were randomly chosen as practice trials, each of which was associated with a different task (no tapping, bimanual isochronous tapping, or free-form tapping). The remaining 45 stimuli (15 from each groove category) were used for the rest of the experiment. Participants heard each stimulus only once. The trials were randomly chosen so that each task type was distributed uniformly between the stimulus groove categories. This resulted in five trials of a given task type for each groove category. For example, of the low-groove stimuli, five stimuli were associated with isochronous tapping, five were associated with free-form tapping, and five were associated with no tapping. The same was true of the mid-groove and high-groove stimuli. Because the trials were randomly chosen, one participant may have performed a different task than another participant for any given stimulus. In addition to the trials with musical stimuli, participants performed 15 free-form tapping trials and six isochronous trials with no music.

The 66 trials (45 musical stimuli, 15 free-form no music, and 6 isochronous no music) were divided into three blocks of 22 trials. Participants were given the option to take a short break in between each block of trials. The six isochronous trials without music were presented at the beginning (three trials) and end (three trials) of each block of trials. These trials were conceived of as control trials that established a form of baseline as the beginning and end of each block, and no further importance was accorded to their blocking as such. It is unlikely that their placement separate from the remaining trials affected the pattern of results in any way. The order of the remaining trials was uniformly randomized, with the exception that no consecutive trials with musical stimuli would involve the same task, and no consecutive trials would involve free-form tapping with no music.

Participants were instructed to start tapping as soon as the music started and to stop tapping as soon as the music finished. In the case of no-music trials, they were instructed to start tapping as soon as they heard the initial beep and to stop tapping when they heard the second beep. A tapping instruction appeared on the computer monitor, 3 s prior to the stimulus or beep indicating the type of task to be performed.

Following each task, participants were presented with a series of questions on the monitor in front of them, and they responded using the computer mouse placed on the pedestal to their right. The questions were selected on the basis of the task presented to the participant. For trials on which participants performed either free-form tapping or isochronous tapping, the following questions were presented:

1. To what extent did you feel "in the groove" while you were tapping (1 = *least groove*, 7 = *most groove*)?
2. To what extent did you feel that the musical excerpt grooved (1 = *least groove, 7 = most groove*)?
3. How difficult did you find the tapping task (1 = *not difficult at all,* 7 = *very difficult*)?
4. How much did you enjoy what was just played (1 = *not at all*, 7 = *very much*)?
5. Are you familiar with the excerpt that just played (1 = *yes*, 2 = *no*)?
6. How much would you have liked to continue performing the task (1 = *not at all*, 7 = *very much*)?

A 7-point rating scale was provided for Questions 1, 2, 3, 4, and 6 labeled with numbers 1 through 7. For musical stimulus trials during which participants did not tap, only Questions 2, 4, 5, and 6 were presented.

During no-music tasks (all of which involved tapping), only Questions 1, 3, and 6 were presented. Two additional questions were asked:

> Were you imagining that you were drumming/tapping to music (y/n)? If so, was the music from an excerpt you just heard, music that you didn't just hear but that you know from your past, or music that you just made up?

Data analysis. Data were analyzed using a combination of custom scripts written in MATLAB and statistical analyses performed in SAS.

Posttrial questions. Two sets of analyses were performed on the responses to the questions asked after each trial. The first considered responses as a function of the task condition and stimulus category, and the second examined the degree to which a person felt in the groove as a function of the other subjective variables that were assessed following each trial. We implemented the categorical analyses separately for each of the poststimulus questions, using PROC MIXED in SAS. Each model included participant mean ratings as a random variable to allow for differential usage of the rating scale. We also performed the second analysis using PROC MIXED and modeled the degree to which the person felt in the groove while tapping with all of the following variables entered as fixed effects into the model: (a) enjoyment of the music, (b) perception of the degree to which the music grooved, (c) experienced difficulty in tapping, and (d) familiarity of the excerpt. Individual participant mean ratings and estimates of each of the effects of the independent variables were entered as random variables to allow them to vary between participants.

Trial parsing. Analyses of both the tapping data and the video recordings required that these recordings be synchronized with the stimulus and trial information stored in Ensemble and then parsed into individual trials. The start and stop times for each trial were identified from the Digital Performer recording by an audio parsing routine written in MATLAB. Trials without music were parsed by identifying the start and stop beeping sounds. The stimulus identifiers within the Ensemble database and therefore the known audio recording were then matched with the audio recordings associated with the parsed trials. Specifically, the stimulus for each trial was taken from the Ensemble database and cross-correlated with the audio recording of each trial from Digital Performer. The cross-correlation provided lag times for which the 30-s stimulus from Ensemble and the parsed trial were maximally correlated. This provided us with an offset time for synchronizing a stimulus from Ensemble with a parsed trial. The cross-correlation also served as a validation that the Ensemble stimulus identifiers were matched correctly. Because the tapping data were recorded in Digital Performer on a separate track from the session audio, the tapping data from each trial could then easily be synchronized to the stimulus for that trial in the Ensemble database.

The audio track from the video recording was also cross-correlated with the audio recording from Digital Performer. This provided the means to synchronize the two media, and therefore, the trial parsing performed on the Digital Performer recording was also applied to the video recording.

Video coding. To assess the incidence of spontaneous movement behaviors in response to the musical stimuli, video recordings of the participants were coded for movement behaviors with Noldus Observer XT software. Two undergraduate coders independently viewed all of the experimental sessions and marked the start and stop times of individual behaviors drawn from a list of behaviors. The coders performed the coding without hearing the accompanying audio track, and they had no knowledge of the specific music category and task, though the isochronous tapping conditions were quite obvious.

The behaviors referred to movements of the following body parts: feet, legs, trunk, shoulders, arms, hands, fingers and head. Initially, behaviors were further fractionated to indicate movement of the left and/or right body part and whether the movement was visibly rhythmic or nonrhythmic, with rhythmic referring to a patterned movement persisting for at least 3 s. In addition, further distinctions were made between synchronized (isochronous) and nonsynchronized (free-form) movements. This level of coding granularity proved unwieldy however, resulting in many categories, some of which were not used consistently by the coders. Accordingly, the coded behaviors were collapsed into the body part categories, with coded movements reflecting rhythmic (including isochronous) movements. The dependent variable for each body part that was entered into statistical analyses was the proportion of the trial during which the behavior was expressed.

Of primary interest were movements that arose when participants heard music but did not have to perform a tapping task (no-tap condition). The data for each body part were analyzed separately using a fixed-effects model implemented using PROC MIXED in SAS in which coder and stimulus category were entered as categorical variables. To accommodate differences in overall amounts of movement between participants, intercepts corresponding to the mean degree of each participant's movement were entered as a random effect variable.

Results

A comparison of the pre- and postexperiment PANAS scores showed small but significant decreases in both the positive—initial: $M = 28.8$ ($SD = 1.2$); change: -4.5 (1.1), $t(31) = -4.236$, $p < .001$—and negative—initial: 14.8 (0.8); change: -1.8 (0.6), $t(31) = -2.827$, $p < .01$—composite scores, indicative of an overall flattening of affect over the course of the experiment, consistent with other experiments in our lab (Janata, Tomic, & Rakowski, 2007).

Posttrial questions. Participant responses to the posttrial questions are summarized in Figure 5. Enjoyment of the music varied significantly as a function of groove category, $F(2, 1400) = 151.56$, $p < .0001$, with the mid-groove category eliciting moderate levels of enjoyment ($M = 3.59$), and the high-groove category eliciting substantially higher enjoyment ratings. The effect of tapping condition was also significant, $F(2, 1400) = 8.28$, $p = .0003$, and reflected a significant preference of participants to simply listen to the music and not have to tap: Enjoyment of the music was hampered by the requirement to tap along isochronously, $t(1400) = -4.02$, $p < .0001$, as well as in any manner they pleased, $t(1400) = -2.55$, $p < .02$. Free-form and isochronous tapping requirements did not influence enjoyment of the music differentially, $t(1400) = 1.48$, *ns*, and there was no interaction of tapping demands and the groove category of the music, $F(4, 1400) = 0.26$, *ns*.

The ratings of the perceived degree of groove in the excerpts varied significantly across category as expected given the prescreening of the material in Study 1, $F(2, 1400) = 424.17$, $p < .0001$. Cronbach's α could not be used as in Study 1 to assess the reliability of perceived groove because of missing data for almost every excerpt due to the randomized use of excerpts for practice trials. However, Figure 4 shows the mean standardized ratings for each of the excerpts and indicates that with only a few exceptions, the items within categories were consistently different from the items in the other categories.

There was no effect of tapping demands on perceived degree of groove: main effect, $F(2, 1400) = 0.13$, *ns*; interaction, $F(4, 1400) = 0.48$, *ns*. When analyzed on a trial-by-trial basis, the

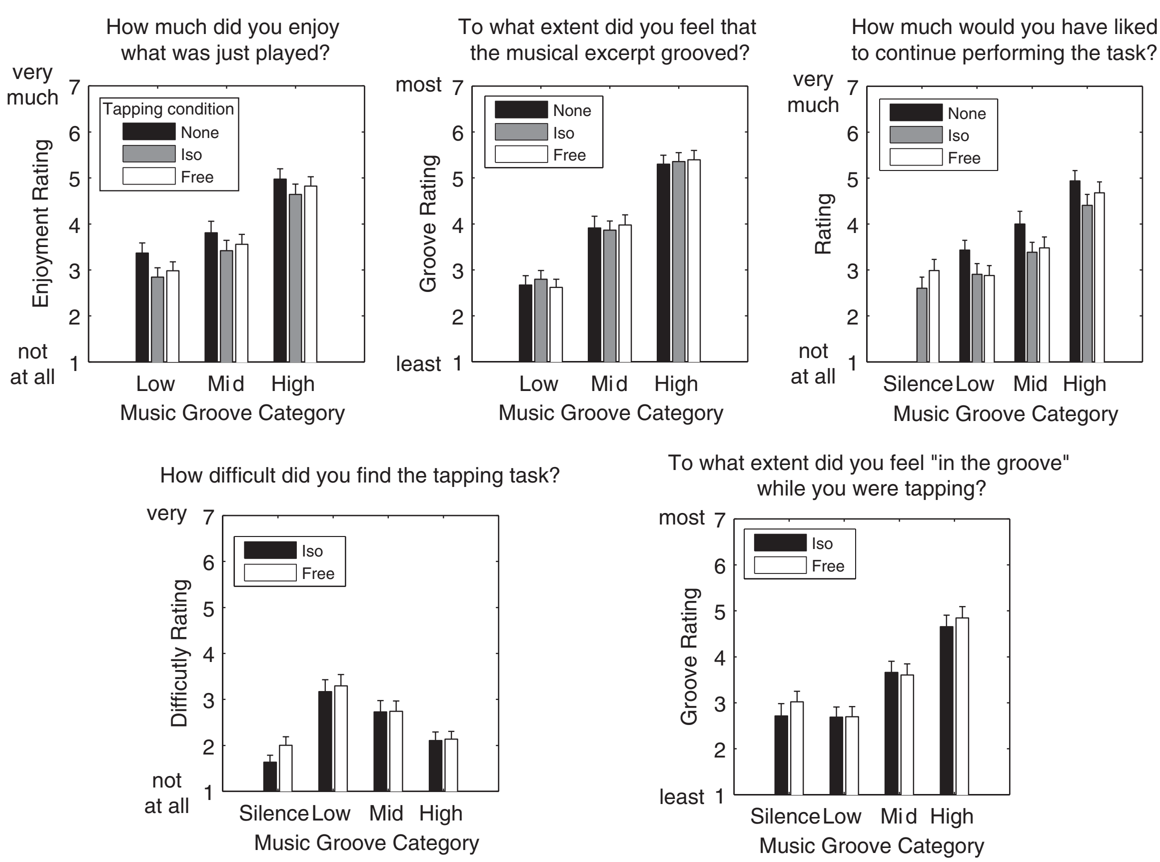

Figure 5. Mean posttrial subjective ratings as a function of groove category and tapping condition. None = listening in silence; Iso = bimanual isochronous tapping along with the perceived beat; Free = free-form bimanual tapping. Error bars indicate one standard error of the mean.

perceived degree of groove in the excerpts, although strongly associated with the sense of feeling in the groove while tapping, $F(1, 67.1) = 447.49$, $p < .0001$, was not influenced by the difficulty experienced while tapping, $F(1, 46.1) = 1.55$, *ns*. Together, these observations suggest that participants were able to dissociate, to some degree, their appraisals of the musical material from sensorimotor task demands.

When asked to reflect on sensorimotor aspects of their behavior during the trials, participants indicated they felt significantly more in the groove while tapping as the degree of groove in the music increased: main effect of stimulus category, $F(3, 1588) = 160.76$, $p < .0001$. The requirement to tap in silence engendered low feelings of being in the groove similar to those felt when tapping along with exemplars from the low-groove category, $t(1, 1588) = 1.77$, $p = .08$, though free-form tapping in silence elicited stronger feelings of being in the groove than the requirement to tap a steady beat of one's choosing, $t(1, 1588) = 2.66$, $p = .008$. Despite the complete freedom of rhythmic expression in silence, the feeling of groove was much weaker than when music of at least moderate groove was present, suggesting that some external source of rhythmic input is necessary to foster the feeling of being in the groove under these laboratory conditions. This statement should be qualified, however, by the fact that participants were not screened for the degree to which they spontaneously engage in tapping behaviors or the degree to which they enjoy tapping, drumming, or other rhythmic activities. Across the population, considerable variation in such behaviors, and perhaps a concomitant ability to feel in the groove while tapping absent musical accompaniment, is to be expected and should be examined in further studies.

Although participants experienced the tapping tasks as only weakly to moderately difficult, the effect of stimulus category was significant, $F(3, 1588) = 69.66$, $p < .0001$, although the tapping condition main effect and the Stimulus × Tapping interactions were not significant: tapping condition, $F(1, 1588) = 2.73$, *ns*; interaction, $F(3, 1588) = 1.21$, *ns*. Unsurprisingly, participants had a more difficult time tapping along with the low-groove music. Of interest were the two aspects of the difficulty ratings when participants tapped in silence. First, participants tapped without music and along with high-groove music with comparable ease. Together with the ratings of feeling in the groove, this result shows that feeling in the groove is not simply a function of the difficulty in performing a rhythmic behavior. If it were, tapping in silence or along with high-groove music should elicit similar feelings of being in the groove, but this is not the case. Once music is present as something that is to be interacted with, the degree of feeling in the groove and experienced difficulty are reciprocally related (see later). Second, free-form tapping in silence was experienced as more difficult than isochronous tapping in silence, $t(1, 1588) = 2.74$, $p = .006$, yet it also elicited stronger feelings of being in the groove, suggesting that some minimal amount of behavioral complexity is required to engage a sense of being in the groove.

The relationship between feeling in the groove and tapping and the other subjective variables described earlier was assessed using a multiple regression model, the results of which are shown in Table 2. The degree to which participants felt in the groove during the sensorimotor task was influenced primarily by the amount of groove they perceived in the music, followed by a negative relationship with the experienced degree of difficulty in performing the tapping task. Although enjoyment of the excerpt also contributed significantly to feeling in the groove, familiarity with the excerpt did not, corroborating the results from Study 1.

Table 2
Prediction of Feeling in the Groove by Other Subjective Variables

Effect	β	*SE*	*df*	*t*	*p*
Intercept	1.6954	0.2772	59.2	6.12	<.0001
Enjoyment of excerpt	0.1234	0.02971	36.7	4.15	.0002
Groove in excerpt	0.5208	0.03749	38.5	13.89	<.0001
Difficulty tapping	−0.2782	0.03660	32.6	−7.60	<.0001
Familiarity of excerpt	0.07916	0.09785	49.3	0.81	.4224

Video coding. Aside from the specific focus on the association between tapping behaviors and the experience of being in the groove, we were interested more broadly in the degree to which music that is high in groove spontaneously engenders movement in a listener. Study 1 indicated that the urge to move is associated with being in the groove, and we therefore predicted that high-groove music would elicit more spontaneous movement behavior in those trials in which listeners were asked to listen to the music without performing one of the two tapping conditions.

The mean percentage of time during trials consumed by spontaneous movements varied significantly as function of stimulus category for several body parts (Table 3). Foot movements (foot tapping) were the most prevalent and varied significantly as a function of stimulus category, $F(2, 836) = 13.27$, $p < .0001$, with approximately 10% more movements during high-groove music. The amount of head movement, for example, head bobbing up and down or left and right, also increased significantly with increasing groove, $F(2, 836) = 24.66$, $p < .0001$, reaching almost 18% for high-groove stimuli. For this one variable there was a significant difference (4%) in the ratings of the two coders, $t(1, 836) = 2.85$, $p < .005$, though the Coder × Stimulus Category interaction was not significant, $F(2, 836) = 2.04$, *ns*. Although the percentage of time consumed by trunk movements or hand movements was considerably less, the number of these movements nonetheless increased significantly with increasing groove: trunk, $F(2, 836) = 12.04$, $p < .0001$; hand, $F(2, 836) = 8.89$, $p = .0002$. Given that no-tap trials during which these movements were assessed occurred as counterparts to trials in which tapping was required, it is possible that participants inhibited their hand movements. In other words, in more natural contexts, the incidence of hand movements, for example, tapping, might be comparable with that of foot tapping.

To summarize, across all of the body parts, the amount of spontaneous movement increased in response to high-groove stimuli, with none of the comparisons between mid- and low-groove stimuli showing a significant difference.

Discussion

A closer examination of subjective experience and overt movements on a trial-by-trial basis across various combinations of movement tasks and music conditions served to further elaborate the groove construct. The perception of the amount of groove in the excerpts in the stimulus library replicated the results from Study 1. More importantly, the degree to which participants ex-

Table 3
Average Percentage of Time That Body Parts Were Moving During No-Tap Trials

Music category	Body part			
	Head	Trunk	Foot	Hand
High groove	17.8 (2.8)[a,b]	5.4 (1.1)[a,b]	30.6 (4.4)[a,b]	4.7 (0.9)[a,b]
Mid-groove	9.1	1.6	20.8	2.0
Low groove	6.4	0.9	19.9	0.8

Note. Values in parentheses indicate the standard error of the estimate. [a] Significantly ($p < .0001$) different from low groove. [b] Significantly different from mid-groove ($p < .004$).

perienced the groove was shown to depend on both sensory and motor factors. In general, the requirement to perform a tapping task reduced overall task enjoyment, though the magnitude of this reduction was less than the amount of variation as a function of the stimulus category. The perceived groove in the music carried over to experiencing groove while tapping in the sense that tapping in silence was associated with about as much of a feeling of groove as tapping along with low-groove stimuli, despite the fact that tapping in silence was regarded as significantly easier than tapping along with low-groove stimuli. This observation and the observation that experienced difficulty and feeling of groove while tapping are negatively correlated indicate that the experience of groove varies most dynamically when movements are associated with ongoing music. Further evidence that the groove is a sensorimotor phenomenon that couples music and movement was found in the spontaneous behavior of the participants: High-groove stimuli elicited a greater amount of movement from a number of body parts, most notably the head and feet.

Contrary to initial predictions, releasing the constraint of isochronous tapping by allowing participants to tap as they saw fit did not lead to greater feelings of being in the groove overall. The one exception was that free-form tapping in silence engendered a greater degree of groove than isochronous tapping at a tempo of one's choosing. This result is perhaps unsurprising if one considers that finding the beat and moving a single effector along with the beat (e.g., bobbing one's head) is the easiest form of sensorimotor interaction with a piece of music. To the extent that such an interaction fulfills a person's desire for interacting with the music, there is nothing to be gained, from an affective perspective, from more complex rhythmic expression. Although freedom of rhythmic expression added nothing to the groove experience for the individuals in this sample, it is possible that there is individual variation in groove proneness or desire to move with music, such that individuals high in such traits or individuals with more musical training might show more complex patterns of sensorimotor interaction across tapping and stimulus conditions and greater enjoyment when producing more complex patterns.

Modeling Music and Behavior

The data from Study 2 provided general evidence that the feeling of being in the groove is a sensorimotor phenomenon. Our next step in characterizing this phenomenon was to determine whether specific metrics of a person's tapping behavior could serve to predict the feeling of being in the groove. Similarly, we sought to determine whether there are global properties of the music that are correlated with the degree of perceived groove.

Given the reciprocal relationship between experiencing groove and experiencing difficulty during the tapping tasks, we suspected that increased experienced difficulty might be associated with increased behavioral variability and thereby with a decreased sense of being in the groove. In the case of isochronous tapping trials, the simplest measure of such variability is the standard deviation of the intertap interval distributions. However, in the case of bimanual free-form tapping, the identification and calculation of appropriate metrics becomes more complicated because the expected mean intertap interval about which to calculate the standard deviation is no longer a single value, given the presence of multiple metric levels in the event that the participant creates rhythmic patterns.

To accommodate the bimanual tapping data and to be able to compare the temporal structure of tapping responses with the temporal structure of the musical excerpts, we developed a computational framework that has at its core banks of damped oscillators that can be driven by arbitrary inputs, that is, continuous audio signals or discrete taps (Tomic & Janata, 2008). The model is conceptually similar to the model underlying Todd's sensorimotor theory of beat induction (Todd, Lee, & O'Boyle, 2002). Here, we utilized the basic computational engine described in Tomic and Janata (2008) along with a pair of additional measures that we describe later following a brief description of the preprocessing of the tapping data and the computational model.

Response Preprocessing

The tapping data from each trial were read into MATLAB using the MIDI Toolbox (Eerola & Toivianen, 2004). The data were then organized into three categories: left hand taps, right hand taps, and all taps. The category of all taps comprised all taps, regardless of whether they were left or right hand taps. Intertap intervals below a threshold of 50 ms were regarded as either a double strike in the case of isolated left hand or right hand taps or were regarded as a bimanual tap when produced by different hands. The second onset of an intertap interval below this threshold was removed.

When tapping data are to be analyzed with the resonator model described next, each tap is first converted to an impulse. The amplitude of each impulse is scaled linearly by the MIDI velocity value (a proxy for intensity) of the tap. The impulses are then binned into a grid with 100-Hz resolution, and this signal is fed into the model.

Resonator Model

Tapping data and corresponding musical stimuli from individual trials were processed with a resonator model (Tomic & Janata, 2008). The model essentially describes the temporal structure in the input information. In much the same way that a Fourier analysis generates a spectrum of the frequencies present in an input signal, the model generates a spectrum of the periodicities present in an input signal, be it the musical excerpts or the tapping data. The resulting spectrum allows a variety of inferences to be made about the temporal structure of the input signal, such as its tempo or meter (the number of evenly spaced beats into which a repeating span of time, such as a bar of music, can be divided). A salient aspect of this form of periodicity analysis is the use of reson filters. A key feature of these filters is their sensitivity to the recurrence of groups of onsets and accent patterns that help define the metric structure of the input. Moreover, not only does the output of such a filter provide an estimate of the prevalence of the periodicity to which it is tuned, but by virtue of being a damped oscillator, the filter output generates a prediction of when future events, occurring with the same periodicity as preceding events, are expected to occur. Thus, the model ultimately provides a means for comparing actual events with expected events. Although such application of the model is of relevance for studies of sensorimotor integration, here we use a simpler form of its output, namely the average profile (spectrum) of periodicities present across the 30-s musical excerpts and associated tapping records.

Stimuli first undergo several preprocessing stages, which are described here in highly condensed form. Detailed explanations and explanatory figures can be found in Tomic and Janata (2008).

Stimuli are first processed with the Auditory Periphery Module of the IPEM Toolbox (Leman, Lesaffre, & Tanghe, 2001), which models the information pattern along the auditory nerve (Van Immerseel & Martens, 1992), using a bank of 40 channels, each identified by its center frequency and possessing a bandwidth approximating a critical band in the cochlea. The time-varying amount of energy within each channel is estimated with a root-mean-square calculation in a sliding window. From this time-varying amplitude information, event onsets are modeled by approximating the first derivative and half-wave rectifying the result. Every eight adjacent channels are then summed to produce five bands. In sum, the output of this processing stage produces estimates of the onset patterns within five spectral regions. For example, the notes produced by a bass are represented more strongly in the lowest of the bands, whereas cymbal strikes are represented in the highest bands.

To estimate the periodicities present in the patterns of onsets, the output of each of the five bands is then passed through a bank of 99 reson filters with center frequencies spaced apart logarithmically and ranging from 0.25 Hz to 10 Hz. As noted earlier, each filter is driven by the recurrence of onsets that match the resonance frequency of that filter. Within each filter bank, a root-mean-square calculation is performed on each filter's output. This provides the first estimate of the energy present at each periodicity. By averaging across corresponding filters in the five filter banks (spectral regions), we arrive at an average representation of how the periodicity content of the overall input signal changes in time, which we call an *average periodicity surface*. The average periodicity surface is akin to a time–frequency (spectrogram) representation of a signal. A final compact representation of the periodicities present across the entire stimulus or tapping epoch is achieved by averaging the average periodicity surface across time to arrive at a *mean periodicity profile* (MPP; Figure 6). The MPP can be regarded as an average amplitude spectrum of the periodicities present in the input and serves as the basis for the analyses described later.

Model Metrics

To analyze behavioral performance measures obtained from the model using the same mixed model and multiple regression analyses described in Study 2, we defined two dependent variables. The first variable comprised the trial-by-trial correlations between stimulus and response MPPs. Because the MPPs are a description of the overall temporal structure in the excerpt, the correlation of the response MPP (MPP_R) with the stimulus MPP (MPP_S) is taken to reflect how well the overall temporal structures are matched and therefore the overall degree of sensorimotor coupling success on the part of the participant. The second variable was the number of peaks in the response MPPs, which provided an estimate of the number of different periods generated by a participant while tapping to each stimulus.

Correlation between stimulus and tapping MPPs. We calculated correlations between response MPPs (MPP_R) and stimulus MPPs (MPP_S) on a trial-by-trial basis for each participant. Figure 6 shows examples of MPPs for low- and high-groove stimuli and the average isochronous and free-form tapping MPPs that they engendered. In the case of the low-groove stimulus, there was considerable variation in the metric level that participants chose to synchronize with in the isochronous tapping condition, echoing previous observations regarding variation in preferred metric level (McKinney & Moelants, 2006), whereas there was greater consistency in the response profiles when the constraint of isochronous bimanual tapping was released. However, in the free-form tapping condition, participants did not match the structure of the stimulus as well on average, particularly at the lower frequencies.

Figure 6 also indicates the correlations between the average MPP_R and MPP_S. In the analysis described later, correlations were calculated for each stimulus (MPP_S) and individual participant's response to that stimulus (MPP_R). These correlations between MPP_R and MPP_S were transformed to z scores using the Fisher r-to-z transform (Fisher, 1970) and were entered into a mixed-model analysis (PROC MIXED, SAS), as in Study 2, to determine whether the correlations of the profiles differed as a function of groove category and tapping task. To account for overall differences in how well individual participants matched the temporal structure of the stimuli, each participant's mean z score was estimated as a random effect.

We further examined whether the correlations were predictive of the subjective ratings of feeling in the groove, task difficulty, and so forth that were obtained following each trial. To this end, we estimated a multiple regression model for each of the following variables: feel in the groove, difficulty, desire to continue, familiarity, and perceived groove in the music. We did not expect that either of the two latter variables would be predicted by the correlations, whereas we expected the feeling of being in the groove to be positively correlated with the strength of the correlation. Weaker correlations between MPP_R and MPP_S were expected when participants perceived the task as more difficult.

Number of peaks in the MPPs. One relatively simple measure of the temporal complexity in a musical excerpt or a tapping pattern is the number of peaks in the MPP. Stimuli or tapping patterns that are isochronous generate the smallest number of peaks, restricted to the beat frequency and higher harmonics, whereas stimuli and responses with more complex rhythms generate a larger number of peaks in the MPPs (Tomic & Janata, 2008). Therefore, we expected that the free-form tapping condition would result in an increase in the number of MPP peaks relative to the isochronous tapping condition.

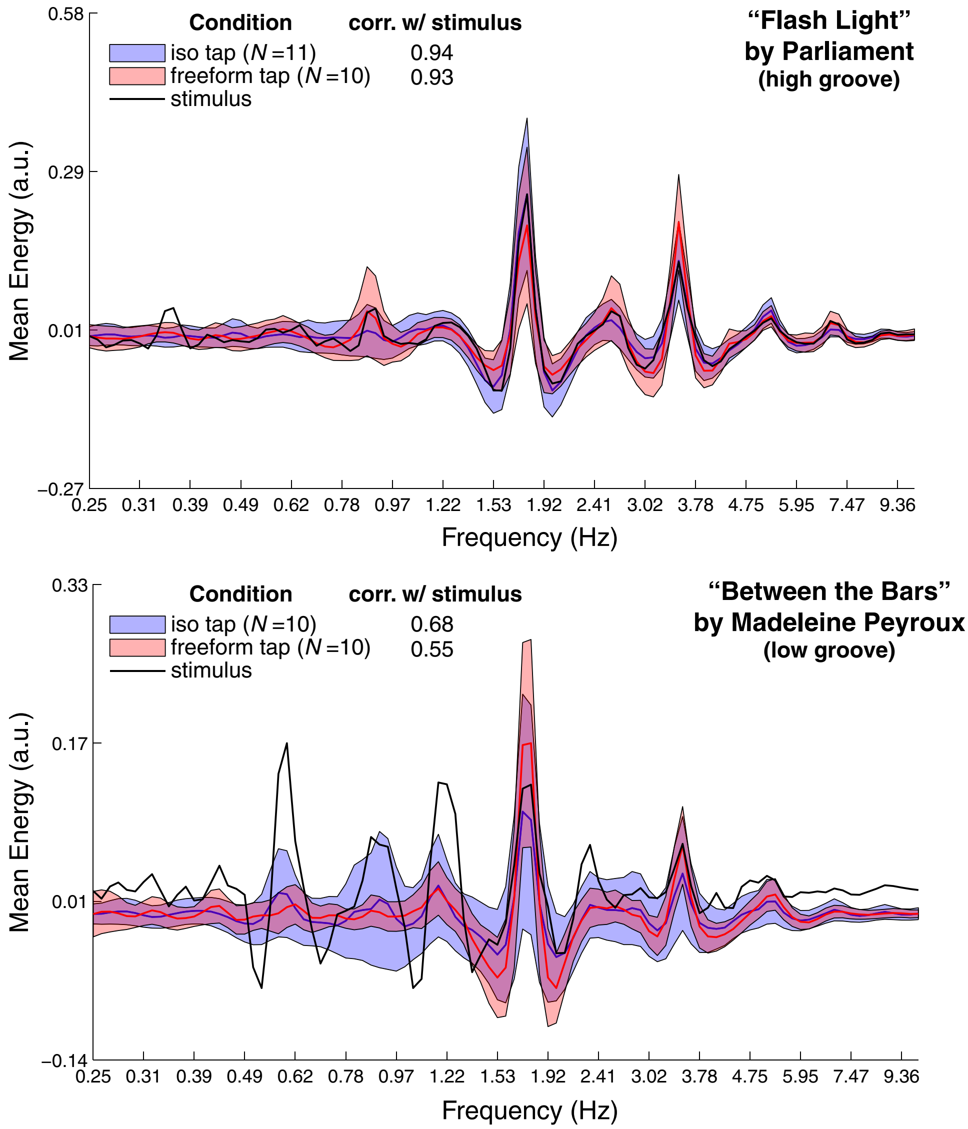

Figure 6. Examples of mean periodicity profiles associated with exemplars of high- and low-groove stimuli and the average tapping responses in the isochronous (iso) and free-form tapping conditions. Mean periodicity profiles are indicated by blue, red, and black solid lines for the isochronous, free-form, and stimulus data, respectively. The shaded regions indicate the standard deviation in the tapping response profiles across participants. Corr. w/ = correlation with.

Peaks in the MPPs were identified by smoothing the MPP with a 12th-order low-pass Butterworth filter (*butter* and *filtfilt* functions in MATLAB) and identifying changes of sign in the amplitude differences between adjacent filters. The heights of peaks were measured as the difference at the peak and the beginning of the flat region adjacent to the peak or as the start of the next peak in the event that peaks were separated by a trough with a single point at its minimum. Finally, we retained only peaks with amplitudes above a threshold set to the minimum MPP value plus 0.25 times the difference between the minimum and maximum MPP values.

The number of peaks in each MPP was counted and entered into a mixed-model analysis with groove category and tapping condition as factors. The numbers of peaks in the stimulus MPPs were also tallied and used as a covariate in the analysis to forego a trivial result, such as the number of peaks in the response MPPs depending entirely on the number of peaks in the stimulus MPPs.

Results

Figure 7A illustrates that the correlations between the music MPPs and tapping MPPs differed significantly as a function of the groove category, $F(2, 912) = 29.28$, $p < .0001$, but not as a function of the tapping condition, $F(1, 914) = 1.39$, *ns*. The interaction was also nonsignificant, $F(2, 912) = 1.44$, *ns*. Specifically, correlations were significantly higher in association with

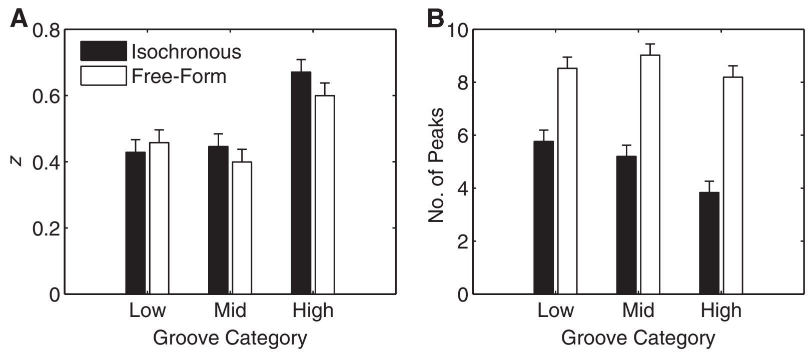

Figure 7. Properties of mean periodicity profiles generated while tapping along with music that varied in degree of groove. A: Correlations (*z* transformed *r* scores) between tapping and music mean periodicity profiles were significantly higher in association with stimuli rated high in perceived groove under both isochronous and free-form tapping instructions. B: The temporal patterning was more complex during free-form tapping (white bars) than during isochronous tapping (black bars) as indicated by a significantly greater number of peaks in the mean periodicity profiles. Error bars indicate one standard error of the mean.

high-groove than with either mid-groove, $t(912) = 6.94$, $p < .0001$, or low-groove stimuli, $t(912) = 6.26$, $p < .0001$. The correlations did not differ significantly between the latter two classes of stimuli, $t(912) = 0.66$, *ns*.

The correlation between MPP_R and MPP_S also accounted for variation in some of the subjective variables that were assessed following each trial. When examined in multiple regression models in which all of the other subjective variables had been entered as covariates, the correlation between MPP_R and MPP_S was positively correlated with the degree to which participants experienced feeling in the groove while tapping, $t(845) = 3.08$, $p = .0021$. Decreases in the correlation were a strong and significant predictor of increased experienced difficulty, $t(866) = -5.52$, $p < .0001$. However, the correlations were not predictive of the desire to continue with the task, the familiarity of the music, or the perceived amount of groove in the music. The latter variable approached significance, $t(891) = 2.80$, $p = .0943$, as would be expected given that stimuli were categorized according to the degree of perceived groove. However, when examined on a per-item basis in the multiple regression model, the perceived groove in the stimuli was clearly not as strongly associated with our measure of sensorimotor coupling as were the two subjective assessments of performance (experienced groove and difficulty).

The number of peaks in the stimulus MPPs did not differ significantly across groove category, $F(2, 45) = 1.25$, *ns*. Figure 7B shows that in the tapping data, the number of peaks was considerably higher in the free-form tapping conditions, $F(1, 237) = 237.56$, $p < .0001$, for all groove categories. The main effect of groove category was significant, $F(2, 923) = 4.10$, $p < .02$, as was the interaction, $F(2, 920) = 3.95$, $p < .02$. In the isochronous tapping condition, the number of peaks in MPP_R should have been the same across groove categories had the participant been able to maintain a steady beat throughout each excerpt. However, relative to the high-groove stimuli, a significant increase in the number of peaks in the MPP_Rs was observed for both the mid-groove stimuli, $t(920) = 3.28$, $p = .0011$, and the low-groove stimuli, $t(290) = 4.60$, $p < .0001$.

Discussion

Overall, our quantitative measure of the degree of sensorimotor coupling between listeners and musical exemplars affirmed the results of the survey and the subjective responses following each musical item in Study 2. Music that elicits a strong tendency to want to move is associated with a greater feeling of being in the groove when performing a sensorimotor coupling task, and individuals are better able to match the temporal structure of the music when it has a high degree of groove. In other words, the quality of the sensorimotor coupling is reflected in the subjective experience of being in the groove. Conversely, as the experienced difficulty goes up, both the sense of being in the groove and the quality of the sensorimotor coupling go down. The relationship between coupling behavior and perceived difficulty suggests that the sense of being in the groove is mediated by sensorimotor error-monitoring mechanisms.

The lack of an increase in the correlation between MPP_R and MPP_S in the free-form tapping condition relative to the isochronous tapping condition was a surprise, given that the freedom to produce more complex rhythmic patterns could be utilized to match more closely the temporal patterns in the stimulus. Although a greater number of MMP_R peaks was observed during free-form tapping across all groove categories, indicating that individual participants did exhibit greater behavioral variability when allowed to do so, this added freedom of expression neither increased nor decreased, on average, the precision of coupling with the temporal structure of the stimulus.

General Discussion

The primary objective of this article was to examine the psychological construct of the groove. This term is commonly used to describe music that has a characteristic of promoting movement that is coupled to the music, and it is also used to describe the subjective state of engaging in the interaction with the music, either as an active listener or performer. In the interest of generalizing to the broader population, the focus here was on examining the construct in a population of young adults and using a broad sample of real music, instead of focusing on expert musicians and a small number of musical pieces.

The construct that emerged, both from open-ended definitions provided by the participants and from the endorsement of a large set of statements, has at its core an emphasis on sensorimotor coupling with the music and positive affect. As such, the construct corroborates previous descriptions appearing in the literature (Iyer, 2002; Keil & Feld, 1994) and the idea that it is something that can be reliably rated by individuals without any specific musical training (Madison, 2006). Indeed, we found ratings of perceived groove to be reliable across participants within a sample and consistent across samples, and we showed that perceived groove is related to a sense of enjoyment.

Groove, Flow, and Fluency

In contrast to previous studies of the groove, we explicitly examined the experience of the groove as a sensorimotor phenomenon by engaging participants in a variety of tapping tasks and observing their spontaneous movement behaviors. We found that although a person's enjoyment of the music was reduced slightly when they were asked to tap along, their perception of the groove in the music was not. Similarly, neither the degree of experienced difficulty while tapping nor the correlations between tapping and stimulus MPPs influenced the perceived degree of groove in the music, even though they were strong predictors of experienced groove. Thus, participants exhibited a certain ability to dissociate an attribute of the music from introspection regarding an affective state or their ability to perform the task.

We found a strong negative relationship between feeling in the groove while tapping and the difficulty experienced while tapping but only when music was present. Both isochronous and free-form tapping in the absence of music were regarded as easy, but they did not elicit a strong sense of being in the groove. Thus, the feeling of being in the groove appears to depend both on a concurrent musical stimulus with which one is trying to couple and on the sense that the coupling is easy.

As noted in the introduction, another psychological state that is epitomized by successful sensorimotor coupling that induces positive affect is that of flow (Csikszentmihalyi, 1990). At least superficially, the concepts of groove and flow appear to be closely related. Both are often thought of as highly immersive states in which there is a strong component of sensorimotor interaction and a sense that the sensorimotor interaction is very fluid. Within the domain of music, de Manzano et al. (2010) found that certain physiological responses, such as increased heart rate, accompanied higher flow in expert pianists performing a familiar but challenging piece of their choosing. However, because their study did not examine explicit performance measures and ours did not examine physiological variables, the ability to compare flow and groove constructs remains limited. The consistent observation that flow arises when a person performs a difficult task well (Csikszentmihalyi, 1990) may provide an operational link between the two constructs. If perceived difficulty is central to both flow and groove experiences, the question becomes whether experienced flow and groove change in parallel as perceived difficulty varies. Stimuli from the low- or mid-groove categories may serve as a basis for seeking differences between the two constructs. For instance, if participants felt that they tapped well with a mid-groove stimulus with which it was more difficult to tap, would they feel flow but not feel in the groove?

Perhaps most important, a straightforward objective measure—the correlation between the stimulus and performance periodicity spectra—predicted experienced difficulty and experienced groove. Greater behavioral variability was associated with higher perceived difficulty and lower experienced groove. Together, the results suggest that an emotionally powerful form of experiencing music may be understood and studied in terms of task difficulty and sensorimotor mechanisms that are readily linked to experienced task difficulty, for example, error-correction mechanisms. In this regard, research on the relationship of fluency and positive affect is relevant. Increased fluency in the perception of object relationships results in greater liking of those objects (Reber, Winkielman, & Schwarz, 1998), and this principle has been extended to include sensorimotor fluency when perceiving visual objects that imply specific actions (Cannon, Hayes, & Tipper, 2010). It is tempting to consider that the amount of groove perceived in the music to which one is listening is a product of perceptual fluency, for example, the ability to anticipate onsets of specific instruments at specific times or the ease of imagining body movements in association with the music, but our data cannot speak directly to this point.

Considerable research effort has been devoted to understanding mechanisms of perception–action coupling and motor control in tapping paradigms utilizing auditory stimuli ranging from isochronous sequences of beeps to excerpts of Chopin etudes (for a review, see Repp, 2005). Although many task–stimulus interactions can be identified that make performance objectively worse (e.g., tapping out of phase with the stimulus train at fast tempi), the subjective sense of difficulty or emotional impact of sensorimotor coupling success has not been assessed. Even with musical stimuli, the focus tends to be on understanding the perceptual cues that promote more accurate beat finding (Large, 2000; Snyder & Krumhansl, 2001) or the influence of perceptual and motor processes on the apprehension of timing deviations within a musical excerpt (Repp, 2002) rather than on the emotional consequences.

Beyond Isochrony?

Although mechanistic accounts of sensorimotor coordination are indispensable for developing an understanding of rhythmic coordination in music in terms of brain mechanisms that support our rhythmic experiences with music, the ethological limitations of synchronization tapping paradigms with repeated tones also need to be recognized and contended with. One of the primary obstacles to overcoming the attraction of paradigms that utilize metronomes and single effectors is the absence of satisfactory computational frameworks within which to examine stimulus–response coupling. The framework we utilize here currently affords the ability to compare basic characteristics of bimanual tapping responses in both isochronous and rhythmically complex regimes with the temporal structure present in the audio information of real-world stimuli. Further refinement of model metrics, in particular the estimation of moment-to-moment timing relationships between stimulus and response, should enable detailed mechanistic accounts of sensorimotor coordination across a very wide array of paradigms.

Given our effort to develop a paradigm and model in which we could look for the presence of nonisochronous tapping behaviors, we were rather surprised to find that the free-form tapping condition neither increased pleasure nor improved coupling with the stimuli on average. In other words, the added freedom of rhythmic expression did not enhance any sense of being in the groove above and beyond the feeling that could be generated by simply finding the beat. Any prospective boost in positive affect that might be gained through more complex coupling patterns may be relatively small, at least in the average individual. It remains to be seen whether a sample of individuals that enjoys tapping rhythms along with music might experience greater groove in free-form compared with isochronous tapping conditions.

Further supporting the primacy of isochronous entrainment in the experience of the groove was the increase in head bobbing that we observed for high-groove stimuli. Head movements generate a vestibular signal that has been shown to underlie infants' sense of meter (Phillips-Silver & Trainor, 2005), and artificially induced vestibular stimulation in adults similarly influences rhythm perception (Trainor, Gao, Lei, Lehotovaara, & Harris, 2009). Vestibular stimulation also occurs when listening to loud (>90 dB) dance music and may thereby contribute to the pleasurable experiences associated with dancing to such music (Todd & Cody, 2000). In our case, head bobbing emerged as a spontaneous behavior, perhaps to reinforce the sense of pleasure of entrainment to the perceived beat of the stimulus. Further experiments, in which head movements are restricted, are needed to determine the magnitude of the contribution of vestibular stimulation to the experience of the groove.

In closing, we consider the construct of the groove in relation to the evolution of entrainment and social behavior. Synchronizing with the beat is the simplest form of entrainment, not only with a musical stimulus, but also with other individuals. As such, isochronous synchronized behaviors may be viewed as the simplest basis for forming social bonds (Merker, Madison, & Eckerdal, 2009; Phillips-Silver, Aktipis, & Bryant, 2010; Valdesolo, Ouyang, & DeSteno, 2010; Wiltermuth & Heath, 2009). Although seemingly simple, the ability to perceive and synchronize with a steady beat is a rare phenomenon in the animal kingdom that appears to be restricted to species in which individuals learn their vocalizations (Patel, 2006; Patel, Iversen, Bregman, & Schuiz, 2009; Schachner, Brady, Pepperberg, & Hauser, 2009). The capacity to perceive the beat in music may be present at birth (Winkler, Haden, Ladinig, Sziller, & Honing, 2009), and spontaneous entrainment with the isochronous drumming of an adult partner, but not a mechanical drumming device or drum sounds broadcast from a speaker, is present in 2.5-year-olds (Kirschner & Tomasello, 2009). Engaging in joint synchronized musical action, such as singing or singing and moving, increases cooperation in both adults (Wiltermuth & Heath, 2009) and 4-year-old children (Kirschner & Tomasello, 2010).

The preceding observations raise interesting questions with respect to the groove. To the extent that music implies the actions of a group (the musicians), is it the case that high-groove music essentially serves as an invitation to join the group by virtue of inducing an urge to move along with the actions of the group? To what extent are participatory discrepancies—timing deviations from metronomic timing among voices in the music or participants—which have been proposed as a key element of the groove (Keil, 1995; Keil & Feld, 1994) indicative of social interaction, in the sense that they help differentiate human and computer time keepers? In this regard, it would be interesting to compare perceived and experienced groove in two genres that are both associated with dancing and pleasure but differ considerably in their use of human and computer time keepers: funk and electronic dance music. More generally, many questions remain about the groove, extending from the way in which musical features (e.g., syncopation) promote a sense of groove and either do or do not facilitate sensorimotor coupling that is experienced as being in the groove to the idea that being in the groove encompasses a sense of social interaction that this is perhaps a key link to its positive emotional impact. We hope the present article serves as an impetus for further exploration for the behavioral and neural mechanisms that underlie the powerful experience of the groove.

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Appendix

Information About Songs Used in Study 1

Song name	Artist	Genre	Groove rating (0–127)
Superstition	Stevie Wonder	soul	108.7
It's A Wrap (Bye, Bye)	FH1 (Funky Hobo #1)	soul	105.9
Flash Light	Parliament	soul	105.1
Lady Marmalade	LaBelle	soul	102.5
Up for the Downstroke	The Clinton Administration	soul	102.4
Mama Cita	Funk Squad	soul	101.6
Music	Leela James	soul	101.1
If I Ain't Got You	Alicia Keys	soul	98.7
Sing, Sing, Sing	Benny Goodman and His Orchestra	jazz	97.4
In the Mood	Glenn Miller and His Orchestra	jazz	96.9
Sco-Mule (DJ Logic Remix)	Bernie Worrell, Chris Wood, Gov't Mule, and John Scofield	soul	93.9
Look-Ka Py Py	The Meters	soul	92.5
Goodies	Ciara featuring Petey Pablo	soul	92.3
Dip It Low	Christina Milian	soul	91.5
Outa-Space	Billy Preston	soul	90.9
Bring the Funk	Ben Harper	soul	89.9
Yeah!	Usher	soul	89.7
I Used to Love Someone	Anthony Hamilton	soul	88.7
Bring Me BBQ Baby	Joe Krown Organ Combo	soul	88.4
Flurries	Soulive	folk	87.8
Naughty Girl	Beyoncé	soul	87.0
Lose My Breath	Destiny's Child	soul	86.4
Sabrosa	Beastie Boys	soul	86.3
Fast Soul Music	London Elektricity	soul	86.2
Bad Tune	Earth, Wind, and Fire	soul	86.2
Come Fly With Me	John Stevens	jazz	86.0
Word Up	Cameo	soul	85.9
Cheek to Cheek	Frank Sinatra	jazz	85.7
What You Waiting For?	Gwen Stefani	rock	85.7
Be-Bop	Arturo Sandoval	jazz	85.1
Soul Ecstasy	Soul Ecstasy	soul	84.8
Dreaming of You	Selena	rock	84.3
Please	Toni Braxton	soul	83.8
Angela (Theme from "Taxi")	Bob James	jazz	82.9
The Eternal Triangle	Dizzy Gillespie, Sonny Rollins, and Sonny Stitt	jazz	81.2
Dot's Groovy	Chet Baker	jazz	80.0
Lay Down the Law	G. Love and Special Sauce	soul	79.8
Baby It's You	JoJo	soul	79.7
The Look of Love	Diana Krall	jazz	79.1
Jungle Blues	The Dirty Dozen Brass Band	jazz	79.1
Funk That	Armani and Ghost	soul	79.0
Straight From the Gate	The Headhunters	soul	78.2
N.E.S.T.A. (Never Ever Submit to Authority)	Antibalas Afrobeat Orchestra	soul	77.4
Reflector	Medeski, Martin, and Wood	rock	76.6
Two Franks	Count Basie, Frank B. Foster, and Frank Wess	jazz	75.4
Take Five	The Dave Brubeck Quartet	jazz	75.4
Hell	Squirrel Nut Zippers	jazz	73.8
Low Gravy	The Chenille Sisters	jazz	73.4
We Are More	Erin McKeown	folk	73.1
Too Much	Dave Matthews Band	rock	73.1
Kiss From a Rose	Seal	soul	73.0
The Stripper	David Rose	jazz	72.7
Don't Stop Me Now	Queen	rock	72.5
Somebody to Love	Jefferson Airplane	rock	71.3
Start Me Up	The Rolling Stones	rock	71.0

(*Appendix continues*)

Appendix (*continued*)

Song name	Artist	Genre	Groove rating (0–127)
Recipe for Love	Harry Connick, Jr.	jazz	70.8
The Illustrated Band	Vida Blue	rock	68.1
Summertime	Ella Fitzgerald and Louis Armstrong	jazz	67.9
TFS	Herbie Hancock	soul	67.8
Soulshine	Gov't Mule	rock	67.3
What a Wonderful World	Louis Armstrong	jazz	66.4
My One and Only Love	John Coltrane and Johnny Hartman	jazz	66.3
In a Sentimental Mood	John Coltrane and Duke Ellington	jazz	66.1
How High the Moon	Ella Fitzgerald	jazz	65.2
Walk on the Wild Side	Jimmy Smith	jazz	65.1
Party at Your Mama's House	Widespread Panic	rock	64.1
Squeeze	Robert Randolph and the Family Band	rock	63.4
The Child Is Gone	Fiona Apple	rock	62.3
Must Be Dreaming	Frou Frou	rock	60.9
Run	Beth Hart	rock	60.8
Freedom of the Road	Martin Sexton	folk	59.7
Lookout 31	Derek Trucks	rock	59.6
Can't Let Go	Lucinda Williams	folk	58.9
AHH08_loop10		drum loop	58.1
Uphill Both Ways	Reeves Gabrels	rock	58.0
Please Don't Dog Me	Lawrence Lebo	jazz	57.8
Lois Ann	Railroad Earth	folk	57.8
Down With Love	Blossom Dearie	jazz	57.0
The Girl From Ipanema	Astrud Gilberto, Joao Gilberto, and Stan Getz	jazz	57.0
New Jazz Fiddle	Asylum Street Spankers	jazz	56.9
Blue in Green	Miles Davis	jazz	56.1
AHH31_loop4		drum loop	55.3
Stomping Grounds	Bela Fleck and the Flecktones	folk	54.6
AHH20_loop3		drum loop	54.4
Roses and Hips	Keren Ann	folk	54.2
Tell It to Me	Old Crow Medicine Show	folk	54.1
AHH17_loop2		drum loop	53.6
AHH32_loop7		drum loop	53.6
Running Wild	Peppino D'Agostino	folk	53.3
AHH26_loop6		drum loop	53.3
Gold Rush	The Tony Rice Unit	folk	53.1
AHH09_loop6		drum loop	52.7
What's New	Clifford Brown and Helen Merrill	jazz	52.2
Some Other Time	Monica Zetterlund and the Bill Evans Trio	jazz	51.1
AHH23_loop5		drum loop	51.0
AHH03_loop10		drum loop	50.8
Mud	Greg Brown	folk	50.5
AHH29_loop1		drum loop	50.4
AHH09_loop1		drum loop	50.3
Till There Was You	Etta Jones	jazz	50.2
I Remember When	The Disco Biscuits	rock	49.9
AHH13_loop4		drum loop	49.9
Orange Sky	Alexi Murdoch	folk	49.8
AHH02_loop7		drum loop	49.7
Children of December	The Slip	rock	49.5
Carolina in My Mind	James Taylor	rock	49.0
AHH01_loop8		drum loop	48.8
Cheeseburger in Paradise	Jimmy Buffett	rock	48.6
Orion's Belt	The String Cheese Incident	rock	47.9
Time in a Bottle	Glen Campbell	folk	47.9
Octoroon	Laura Love	folk	47.6
AHH07_loop7		drum loop	47.6
AHH02_loop1		drum loop	47.1
Raise a Ruckus	Jesse Fuller	folk	46.5
Aural Oasis	Wynton Marsalis	jazz	46.1

(*Appendix continues*)

Appendix (*continued*)

Song name	Artist	Genre	Groove rating (0–127)
AHH28_loop3		drum loop	45.9
Spanish Gold	Michael Houser	folk	45.6
Sarba Miracinae (The Burdock Sirba)	Klezmer Conservatory Band	folk	45.3
AHH28_loop2		drum loop	45.1
Just to Be Near You	Laurie Macallister	folk	45.0
The Nashua Rose	The Slip	rock	44.7
Fire in the Brain	Club d'Elf, Dave Tronzo, Erik Kerr, Mat Maneri, and Mike Rivard	rock	44.3
All Things Reconsidered	Phish	rock	44.0
Stupid, Stupid Rain	Shawn Persinger	rock	43.9
Taxman	Nickel Creek	folk	43.9
Bottle of Hope	Tony Furtado and the American Gypsies	rock	43.4
If I Had Known	Greg Brown	folk	43.3
AHH14_loop2		drum loop	43.2
Comfortably Numb	Pink Floyd	rock	42.3
Ghost	Indigo Girls	folk	42.1
Strong, Strong Wind	Heart	rock	41.8
Bryter Layter	Nick Drake	folk	40.4
AHH01_loop2		drum loop	40.3
Yes I Am	Melissa Etheridge	rock	40.2
I Get the Blues When It Rains	Kate MacKenzie	folk	40.0
Better Man	Pearl Jam	rock	39.8
Master Crowley's/The Jug of Punch (Reels)	The Bothy Band	folk	39.3
Space Oddity	David Bowie	rock	38.7
Ray Dawn Balloon	Trey Anastasio	rock	38.5
Druid Fluid	Yo-Yo Ma, Mark O'Connor, and Edgar Meyer	folk	38.1
Flandyke Shore	The Albion Band	folk	36.5
Citi Na GCumman	William Coulter and Friends	folk	35.2
Dawn Star	Dean Magraw	folk	34.8
Fortuna	Kaki King	folk	32.6
Beauty of the Sea	The Gabe Dixon Band	rock	32.1
Sweet Thing	Alison Brown	folk	30.9
Thugamar Fin an Samhradh Linn	Barry Phillips	folk	29.3
Hymn for Jaco	Adrian Legg	folk	29.3

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