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Sensorimotor Coupling In Music And The Psychology Of The Groove

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Abstract

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 (1) that the concept of the groove is widely appreciated and understood in terms of a pleasurable drive toward action, (2) that a broad range of musical excerpts can be appraised reliably for the degree of perceived groove, (3) 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, (4) that high groove stimuli elicit spontaneous rhythmic movements, and (5) 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, especially 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.

Sensorimotor Coupling In Music And The Psychology Of The Groove

Humans have a proclivity to move with music. Whether it is through the subtle marking of time via miniscule head bobs or toe taps to elaborate dance moves, the engagement of our 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, in order to show that the basic principles of the phenomenon can be observed and quantified at several levels of analysis.

In order to discuss the phenomenon it helps to give it a label. We will 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 below, 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), and so 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 regard *participatory discrepancies* – deviations from precise metronomic timing relationships – as a central source of groove. From a more psychological yet related perspective, Pressing (2002) regards groove as, “a kinetic framework for reliable prediction of events and time pattern communication,” 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).

Madison (2006) operationally defined groove as “wanting to move some part of the body in relation to some aspect of the sound pattern,” and proceeded to examine inter-individual 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 4-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 and colleagues (2007) observed the highest subjective ratings of arousal and valence in response to an energetic and somewhat comical dance piece (Quincy Jones', 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*, of which two characteristics are 1) that actions feel automatic and few or no attentional resources are required for executing action sequences, and 2) an induced state of positive affect (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 relationship between music, 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 paper 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 the 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 versus 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 above 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.

Two hundred fifteen subjects [age: 20.6 ± 3.1 y (mean \pm s.d.); 132 female] were asked, "Have you ever heard the term 'groove' as applied to music?" to which 74.6% answered in the affirmative. Of those, 153 [age: 20.8 ± 3.5 y (mean \pm s.d.); 90 female] completed one of the versions of the survey. All subjects provided informed consent in accordance with a protocol approved by the UC Davis Institutional Review Board.

Surveys.

Survey items were statements generated based on 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 which 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 indicated 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."

--- insert Figure 1 about here ---

Procedure.

Two variants of the survey were administered in association with 8 experiments. The experiments, two of them reported below in studies 1 and 2, varied in their objectives, but generally involved either rating the degree of perceived groove, the degree of perceived complexity, and/or synchronizing body movements either with drum loops or excerpts or 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 via 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 using 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 using 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.”

In order 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 compunction (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.

--- insert Table 1 about here ---

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, and the exemplar's tempo, familiarity, and how much it was enjoyed would influence the groove rating. Based on the results of the groove survey we 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 and procedures.

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

Stimuli. One hundred forty eight musical excerpts were chosen for this experiment (Appendix A). With the exception of 20 drum loops that were drawn from a MIDI compilation disk ("LA Riot", Keyfax Software, 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 (bpm) and 115.6 ± 8.0 bpm for the slow and fast categories, respectively.

Procedure. Subjects 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 ~4 ft 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 subject's 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)?” Subjects completed two sets of 74 trials with a break between each set. The entire experiment lasted between 75 and 90 minutes.

Data analysis.

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

A subject’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 subjects tended to adjust the slider to a final position within the initial 4-8 seconds 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 subjects in the groove ratings for the set of stimuli was assessed by calculating Cronbach's α on the stimulus-by-subject 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 subject 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 subjects in making the groove ratings, so an intercept was modeled for each subject 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, the ratings of them clustered together around intermediate values of the rating scale (data not shown). Given the lack of variance in ratings and the exclusive use on 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, while 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 Appendix A 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 $\alpha = 0.81$).

Figure 2A illustrates that overall, the degree of perceived groove varied significantly as a function of Genre [$F(3,114)=3.45, p<0.02$] and Tempo [$F(1,114)=25.12, p<0.0001$], 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: $t(114)=3.14, p=0.0022$; jazz: $t(114)=2.77, p=0.0066$; folk: $t(114)=-2.74, p=0.0071$], 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 interaction between Genre and Tempo was not significant [$F(3,114)=0.14, n.s.$]. Groove ratings were strongly related to how much a person enjoyed the excerpts [$F(1,114)=57.19, p<0.0001$]. Within the full model, the effect of familiarity was not significant [$F(1,114)=2.52, n.s.$], though when enjoyment was removed from the model, the effect of familiarity was significant [$F(1,115)=15.10, p=0.0002$]. When examined at the level of individual songs, the correlation between the mean level of enjoyment and perceived groove was very strong ($r=.82, p<0.0001$; Figure 2B). The correlation between familiarity and perceived groove was also significant ($r=0.57, p<0.0001$) though weaker due to a considerable number of unfamiliar songs that were rated high in groove (Figure 2C).

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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 above. 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 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 also the fact that within the genres sampled here one could find many other examples of high and low groove stimuli, 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 & 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.

While 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 “freeform” bimanual tapping, both in silence and in the presence of music that varied in the degree of perceived groove. We predicted that the freeform tapping task would permit stronger groove experiences, particularly in response to mid-groove and high-groove stimuli.

Given these considerations the experiment crossed two factors: tapping condition (3 levels: no tapping, bimanual isochronous, bimanual freeform) and stimulus category (4 levels: silence, low groove, mid groove, high groove). The no tapping in silence combination was eliminated as 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 and Procedures

Participants. 34 undergraduate students (25 females; age range 18-34; mean age 20.6) participated in the experiment. Previous musical experience was not a requirement for participation. Of the 27 participants who reported having received some formal musical training, 5 participants reported having received between 2-4 years of training,

and 8 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” 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.

--- insert Figure 3 around here ---

The MIDI responses from the drum pad, as well as a copy of the audio signal that the participant heard were recorded using Digital Performer (MOTU, Inc.) Software and used in analyses of the data. The audio outputs of the drum pad were muted and 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.

Questions and stimuli were presented to the participant using Ensemble (Tomic & Janata, 2007). The resolution of the screen was reduced to 960x600 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 PANAS (Positive Affect Negative Affect Scale; Watson, Clark, & Tellegen, 1988) survey 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 inquired participants if they have normal hearing, if they have perfect pitch, the genres of music they listen to and were exposed to as a child, how many years of formal musical training they received, and a list of the instruments they are 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 above in the section "Defining groove as a psychological construct."

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

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Tasks. The 48 musical stimuli and "silence" were associated with three tasks: no tapping, bimanual isochronous tapping, and free form tapping, to comprise 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 only tap on the bottom left section of the drum with his or her left hand and the bottom right section with his or her right hand. Three of the 48 musical stimuli (one from each

“groove” 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 5 trials of a given task type for each groove category. For example, of the low-groove stimuli, 5 stimuli were associated with isochronous tapping, 5 were associated with free-form tapping, and 5 were associated with no-tapping. The same was true of the mid-groove and high-groove stimuli. Since 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 6 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 (3 trials) and end (3 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 anyway. 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 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 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 responded using the computer mouse placed on the pedestal to their right. The questions were selected based on the task presented to the participant. For trials 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 seven point rating scale was provided for questions 1,2,3,4, and 6 labeled with numbers 1-7. 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.

Post-trial 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. The categorical analyses were implemented using PROC MIXED in SAS, separately for each of the post-stimulus questions. Each model included subject mean ratings as a random variable to allow for differential usage of the rating scale. The second analysis was also performed 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: 1) enjoyment of the music, 2) perception degree that the music grooved, 3) experienced difficulty in tapping, and 4) familiarity of the excerpt. Individual subject 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 “beep” and stop “beep” 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. Since 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. In order to assess the incidence of spontaneous movement behaviors in response to the musical stimuli, video recordings of the participants were coded for movement behaviors using Noldus Observer XT software. Two undergraduate coders independently viewed the entire 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 non-rhythmic, with rhythmic referring to a patterned movement persisting for at least 3 seconds. In addition, further distinctions were made between synchronized (isochronous) and non-synchronized (freeform) movements. This level of coding granularity proved unwieldy however, resulting in many categories, some of which weren't 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 post-experiment PANAS scores showed small but significant decreases in both the positive (initial: $M = 28.8$ ($SD = 1.2$); change: -4.5 (1.1), $t(31) = -4.236$, $p < 0.001$) and negative (initial: 14.8 (0.8); change: -1.8 (0.6), $t(31) = -2.827$, $p < 0.01$) 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).

--- insert Figure 5 around here ---

Post-trial questions. Participant responses to the post-trial questions are summarized in Figure 5. Enjoyment of the music varied significantly as a function of groove category [$F(2,1400)=151.56$; $P<0.0001$], with the mid-groove category eliciting moderate levels of enjoyment (mean= 3.59), and the high-groove category eliciting substantially higher enjoyment ratings. The effect of tapping condition was also significant [$F(2,1400)=8.28$; $P=0.0003$], 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 [$t(1400)=-4.02$; $P<0.0001$] as well as in any manner they pleased [$t(1400)=-2.55$; $P<0.02$]. Freeform and isochronous tapping requirements did not influence enjoyment of the music differentially

[$t(1400)=1.48$; *n.s.*], and there was no interaction of tapping demands and the groove category of the music [$F(4,1400)=0.26$; *n.s.*].

The ratings of the perceived degree of groove in the excerpts varied significantly across category as expected given the pre-screening of the material in Study 1 [$F(2,1400)=424.17$; $P<0.0001$]. Cronbach's α could not be used as in Study 1 to assess the reliability of perceived groove on account 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 items in the other categories.

There was no effect of tapping demands on perceived degree of groove [main effect: $F(2,1400)=0.13$; *n.s.*; interaction: $F(4,1400)=0.48$; *n.s.*]. When analyzed on a trial-by-trial basis, the perceived degree of groove in the excerpts, while strongly associated with the sense of feeling in the groove while tapping [$F(1,67.1)=447.49$, $p<0.0001$] was not influenced by the difficulty experienced while tapping [$F(1,46.1)=1.55$, *n.s.*]. 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: $F(3,1588)=160.76$; $P<0.0001$]. The requirement to tap in silence engendered similarly low feelings of being in the groove as tapping along with exemplars from the low groove category [$t(1,1588)=1.77$; $P=0.08$], though freeform tapping in silence elicited stronger

feelings of being in the groove than the requirement to tap a steady beat of one's choosing [$t(1,1588)=2.66;P=0.008$]. 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 [$F(3,1588)=69.66;P<0.0001$], although the tapping condition main effect and stimulus X tapping interactions were not [tapping condition: $F(1,1588)=2.73; n.s.$; interaction: $F(3,1588)=1.21; n.s.$].

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 below). Second, freeform tapping in silence was experienced as more difficult than isochronous tapping in silence [$t(1,1588)=2.74;P=0.006$], yet it also elicited stronger feelings of being in the groove, suggesting that some minimal amount of behavioral complexity is required in order to engage a sense of being in the groove.

--- insert Table 2 around here ---

The relationship between the feeling in the groove and tapping and the other subjective variables described above was assessed using a multiple regression model, the results of which are shown in Table 2. The degree to which a person 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.

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 will spontaneously engender 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.

--- insert Table 3 around here ---

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 [$F(2,836)=13.27$; $P<0.0001$], with ~10% more movements during high groove music. The amount of head movement, e.g. head bobbing up-and-down or left-and-right, also increased significantly with increasing groove [$F(2,836)=24.66$, $P<0.0001$], reaching almost 18% for high groove stimuli. For this one variable there was a significant difference (4%) in the ratings of the two coders [$t(1,836)=2.85$, $P<0.005$], though the coder X stimulus category interaction was not significant [$F(2,836)=2.04$, n.s.]. While the percentage of time consumed by trunk movements or hand movements was considerably less, the amount of these movements nonetheless increased significantly with increasing groove [trunk: $F(2,836)=12.04$, $P<0.0001$; hand: $F(2,836)=8.89$, $P=0.0002$]. 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, e.g. tapping, might be comparable to 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 experienced 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 freeform 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. While freedom of rhythmic expression added nothing to the groove experience to 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 inter-tap interval (ITI) distributions. However, in the case of bimanual freeform tapping, the identification and calculation of appropriate metrics becomes more complicated because the expected mean ITI 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.

In order 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, i.e. 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 & Janata (2008) along with a pair of additional measures that we describe below following a brief description of the preprocessing of the tapping data and the computational model.

Response pre-processing

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 "all taps" comprised all taps, regardless of whether they were left or right hand taps. ITIs 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 regarded as a bimanual tap when produced by different hands. The second onset of an ITI below this threshold was removed.

When tapping data are to be analyzed with the resonator model described below, 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 using 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 *reson* filters is their sensitivity to the recurrence of groups of onsets and accent patterns that help define the metric structure of the input. Moreover, the output of such a filter provides not only 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. While 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.

Preprocessing stages. 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 using a root-mean-square (RMS) 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 will be represented more strongly in the lowest of the bands whereas cymbal strikes will be represented in the highest bands.

In order 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 above, each filter is driven by the recurrence of onsets that match the resonance frequency of that filter. Within each filter bank, an RMS 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 below.

--- insert Figure 6 about here ---

Model metrics

In order 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. Since 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 subject. Figure 6 shows examples of MPPs for low and high groove stimuli and the average isochronous and freeform 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 freeform 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 below, correlations were calculated for each stimulus (MPP_S) and individual participant's response to that stimulus (MPP_R). These correlations between MPP_R with MPP_S were transformed to z -scores using the Fisher r -to- z transform (Fisher, 1970) and 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, etc. that were obtained following each trial. To this end, we estimated a multiple regression model for each of the “feel in the groove”, “difficulty”, “desire to continue”, “familiarity”, and “perceived groove in the music” variables. 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 freeform tapping condition would result in an increase in the number of MPP peaks relative to the isochronous tapping condition.

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 the start of the next peak in the event that peaks were separated by a trough with a single point at its minimum. Finally, only those peaks whose amplitude was above a threshold set to the minimum MPP value plus 0.25 times the difference between the minimum and maximum MPP values were retained.

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 in order 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 [$F(2,912)=29.28$, $P<0.0001$], but not as a function of the tapping condition [$F(1,914)=1.39$, n.s.]. The interaction was also non-significant [$F(2,912)=1.44$, n.s.]. Specifically, correlations were

significantly higher in association with high groove than with either mid groove [$t(912)=6.94, p<0.0001$] or low groove stimuli [$t(912)=6.26, p<0.0001$]. The correlations did not differ significantly between the latter two classes of stimuli [$t(912)=0.66, n.s.$].

--- insert Figure 7 about here ---

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 [$t(845)=3.08, p=0.0021$]. Decreases in the correlation were a strong and significant predictor of increased experienced difficulty [$t(866)=-5.52, p<0.0001$]. 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 [$t(891)=2.80, p=0.0943$] 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 [$F(2,45)=1.25, n.s.$]. Figure 7B shows that in the tapping data the number peaks was considerably higher in the freeform tapping conditions [$F(1,237)=237.56, p<0.0001$] for all groove categories. The main effect of groove category was significant [$F(2,923)=4.10, p<0.02$] as was the interaction [$F(2,920)=3.95,$

$p < 0.02$]. 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 [$t(920) = 3.28, p = 0.0011$] and low [$t(290) = 4.60, p < 0.0001$] groove stimuli.

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 freeform 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 MPP_R peaks was observed during freeform tapping across all groove categories, indicating that individual subjects 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 paper 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 while 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 periodicity profiles (MPPs), while being strong predictors of experienced groove, influenced the perceived degree of groove in the music. 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 freeform tapping in the absence of music was regarded as easy, but it 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* 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, since 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 subjects 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 importantly, 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, e.g. 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, e.g. 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). While 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?

While 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 non-isochronous tapping behaviors, we were rather surprised to find that the freeform 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 freeform compared to 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 (Jessica 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, will be 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; J. 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 do or don't 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 paper 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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Figure captions

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 subjects 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 ****= 0.0001 .

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.

Figure 3. Illustration of the experimental setup in Study 2. The image is a Photoshop tracing of still image obtained from the video recording of one of the participants performing the bimanual freeform 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 in order 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.

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 based on the ratings obtained in Study 1. Error bars indicate 1 standard error of the mean.

Figure 5. Mean post-trial subjective ratings as a function of groove category and tapping condition. Tapping conditions: None = listening in silence, Iso = bimanual isochronous tapping along with the perceived beat, Free = free-form bimanual tapping.

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 freeform tapping conditions. Mean periodicity profiles are indicated by blue, red, and black solid lines for the isochronous, freeform, and stimulus data, respectively. The shaded regions indicate the standard deviation in the tapping response profiles across participants.

Figure 7. Properties of mean periodicity profiles (MPPs) generated while tapping along with music that varied in degree of groove. A) Correlations (z transformed r scores) between tapping and music MPPs were significantly higher in association with stimuli rated high in perceived groove under both isochronous and freeform tapping instructions.

B) The temporal patterning was more complex during freeform tapping (white bars) than during isochronous tapping (black bars) as indicated by a significantly greater number of peaks in the MPPs.

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 |

* articles, pronouns, prepositions, and common verbs, and words occurring < 10 times have been excluded.

Table 2. Prediction of feeling in the groove by other subjective variables.

| Effect | β | <i>std. err.</i> | <i>df</i> | <i>t</i> | <i>p</i> |
|------------------------|---------|------------------|-----------|----------|----------|
| Intercept | 1.6954 | 0.2772 | 59.2 | 6.12 | <.0001 |
| enjoyment of excerpt | 0.1234 | 0.02971 | 36.7 | 4.15 | 0.0002 |
| 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 | 0.4224 |

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) ^{†§} | 5.4 (1.1) ^{†§} | 30.6 (4.4) ^{†§} | 4.7 (0.9) ^{†§} |
| Mid groove | 9.1 | 1.6 | 20.8 | 2 |
| Low groove | 6.4 | 0.9 | 19.9 | 0.8 |

Note: Values in parentheses indicate the std. error of the estimate. †=significantly ($p < 0.0001$) different from low groove; §=significantly different from mid-groove ($p < 0.004$).

Appendix A

| 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 & Glenn Miller & His Orchestra | Jazz | 96.9 |
| Sco-Mule (DJ Logic Remix) | Bernie Worrell, Chris Wood, Gov't Mule & 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 | Anthony Hamilton | Soul | 88.7 |
| Someone | | | |
| Bring Me BBQ Baby | Joe Krown Organ Combo | Soul | 88.4 |
| Flurries | Soulive | Folk | 87.8 |
| Naughty Girl | Beyonce | Soul | 87.0 |
| Lose My Breath | Destiny's Child | Soul | 86.4 |
| Sabrosa | Beastie Boys | Soul | 86.3 |
| Fast Soul Music | London Elektriccity | Soul | 86.2 |
| Bad Tune | Earth, Wind & 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 | Gwen Stefani | Rock | 85.7 |
| For? | | | |
| 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 & Sonny Stitt | Jazz | 81.2 |
| Dot's Groovy | Chet Baker | Jazz | 80.0 |
| Lay Down the Law | G. Love & 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 & 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 & Wood | Rock | 76.6 |
| Two Franks | Count Basie, Frank B Foster & 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 |
| Recipe for Love | Harry Connick, Jr. | Jazz | 70.8 |
| The Illustrated Band | Vida Blue | Rock | 68.1 |
| Summertime | Ella Fitzgerald & 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 & Johnny Hartman | Jazz | 66.3 |
| In a Sentimental Mood | John Coltrane & 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 & 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 | 58.1 |
| | | loop | |
| 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 & 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 & The Flecktones | Folk | 54.6 |
| AHH20_loop3 | | drum | 54.4 |
| | | loop | |
| Roses and Hips | Keren Ann | Folk | 54.2 |
| Tell It to Me | Old Crow Medicine Show | Folk | 54.1 |
| AHH17_loop2 | | drum | 53.6 |
| | | loop | |
| AHH32_loop7 | | drum | 53.6 |

| | | | |
|--------------------|--|------|------|
| | | loop | |
| Running Wild | Peppino D'Agostino | Folk | 53.3 |
| AHH26_loop6 | | drum | 53.3 |
| | | loop | |
| Gold Rush | The Tony Rice Unit | Folk | 53.1 |
| AHH09_loop6 | | drum | 52.7 |
| | | loop | |
| What's New | Clifford Brown & Helen Merrill | Jazz | 52.2 |
| Some Other Time | Monica Zetterlund & The Bill Evans Trio | Jazz | 51.1 |
| AHH23_loop5 | | drum | 51.0 |
| | | loop | |
| AHH03_loop10 | | drum | 50.8 |
| | | loop | |
| Mud | Greg Brown | Folk | 50.5 |
| AHH29_loop1 | | drum | 50.4 |
| | | loop | |
| AHH09_loop1 | | drum | 50.3 |
| | | loop | |
| Till There Was You | Etta Jones | Jazz | 50.2 |
| I Remember When | The Disco Biscuits | Rock | 49.9 |
| AHH13_loop4 | | drum | 49.9 |

| | | | |
|-----------------------------|----------------------------|------|------|
| | | loop | |
| Orange Sky | Alexi Murdoch | Folk | 49.8 |
| AHH02_loop7 | | drum | 49.7 |
| | | loop | |
| Children Of December | The Slip | Rock | 49.5 |
| Carolina in My Mind | James Taylor | Rock | 49.0 |
| AHH01_loop8 | | drum | 48.8 |
| | | loop | |
| 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 | 47.6 |
| | | loop | |
| AHH02_loop1 | | drum | 47.1 |
| | | loop | |
| Raise a Ruckus | Jesse Fuller | Folk | 46.5 |
| Aural Oasis | Wynton Marsalis | Jazz | 46.1 |
| AHH28_loop3 | | drum | 45.9 |
| | | loop | |
| Spanish Gold | Michael Houser | Folk | 45.6 |
| Sarba Miracinae (The | Klezmer Conservatory Band | Folk | 45.3 |

| | | | |
|---------------------|--|------|------|
| Burdock Sirba) | | | |
| AHH28_loop2 | | drum | 45.1 |
| | | loop | |
| 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 & Mike Rivard | Rock | 44.3 |
| All Things | Phish | Rock | 44.0 |
| Reconsidered | | | |
| Stupid, Stupid Rain | Shawn Persinger | Rock | 43.9 |
| Taxman | Nickel Creek | Folk | 43.9 |
| Bottle of Hope | Tony Furtado & The American Gypsies | Rock | 43.4 |
| If I Had Known | Greg Brown | Folk | 43.3 |
| AHH14_loop2 | | drum | 43.2 |
| | | loop | |
| 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 | 40.3 |
| | | loop | |

| | | | |
|-------------------------|---|------|------|
| Yes I Am | Melissa Etheridge | Rock | 40.2 |
| I Get the Blues When It | Kate MacKenzie | Folk | 40.0 |
| Rains | | | |
| Better Man | Pearl Jam | Rock | 39.8 |
| Master Crowley's / The | The Bothy Band | Folk | 39.3 |
| Jug of Punch (Reels) | | | |
| Space Oddity | David Bowie | Rock | 38.7 |
| Ray Dawn Balloon | Trey Anastasio | Rock | 38.5 |
| Druid Fluid | Yo-Yo Ma, Mark O'Connor, Edgar Meyer | Folk | 38.1 |
| Flandyke Shore | The Albion Band | Folk | 36.5 |
| Citi Na GCumman | William Coulter & 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 | Barry Phillips | Folk | 29.3 |
| Samhradh Linn | | | |
| Hymn for Jaco | Adrian Legg | Folk | 29.3 |

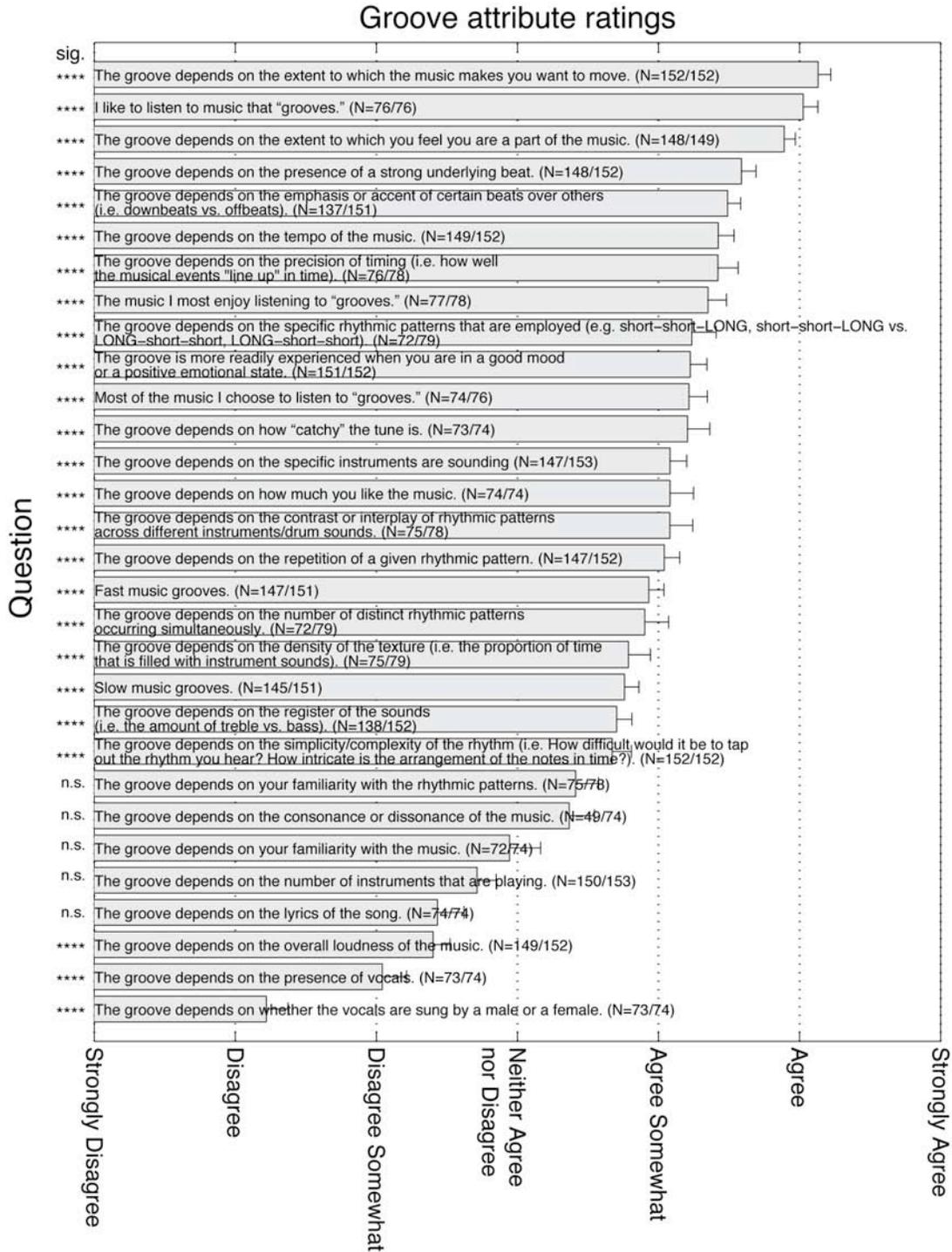


Figure 1

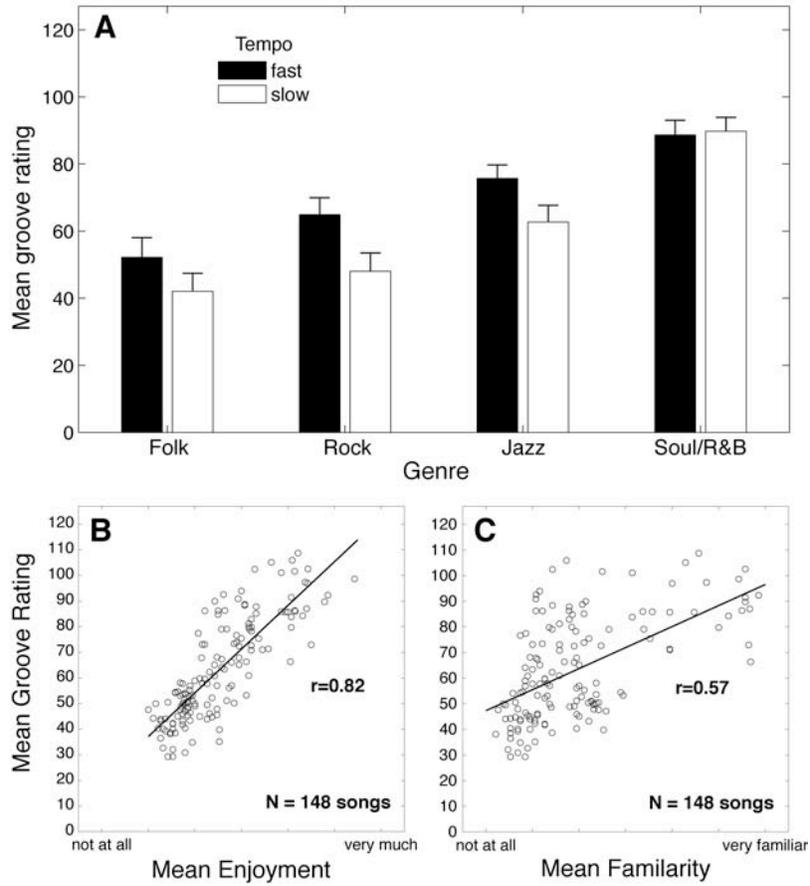


Figure 2

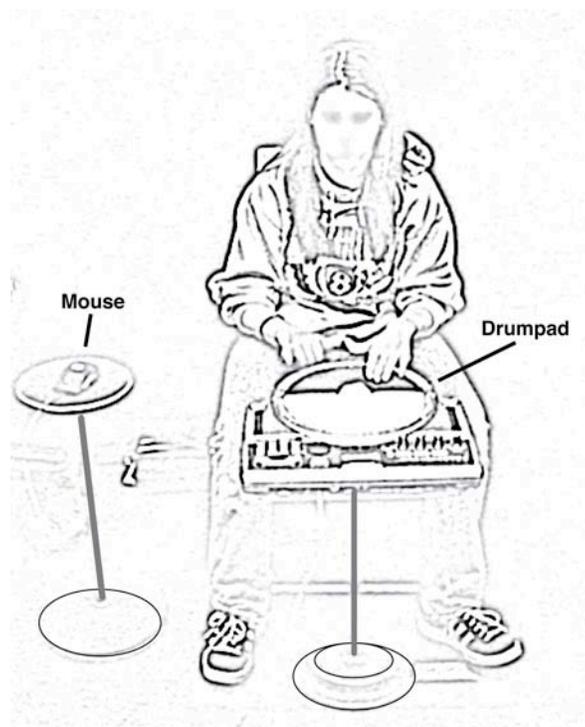


Figure 3

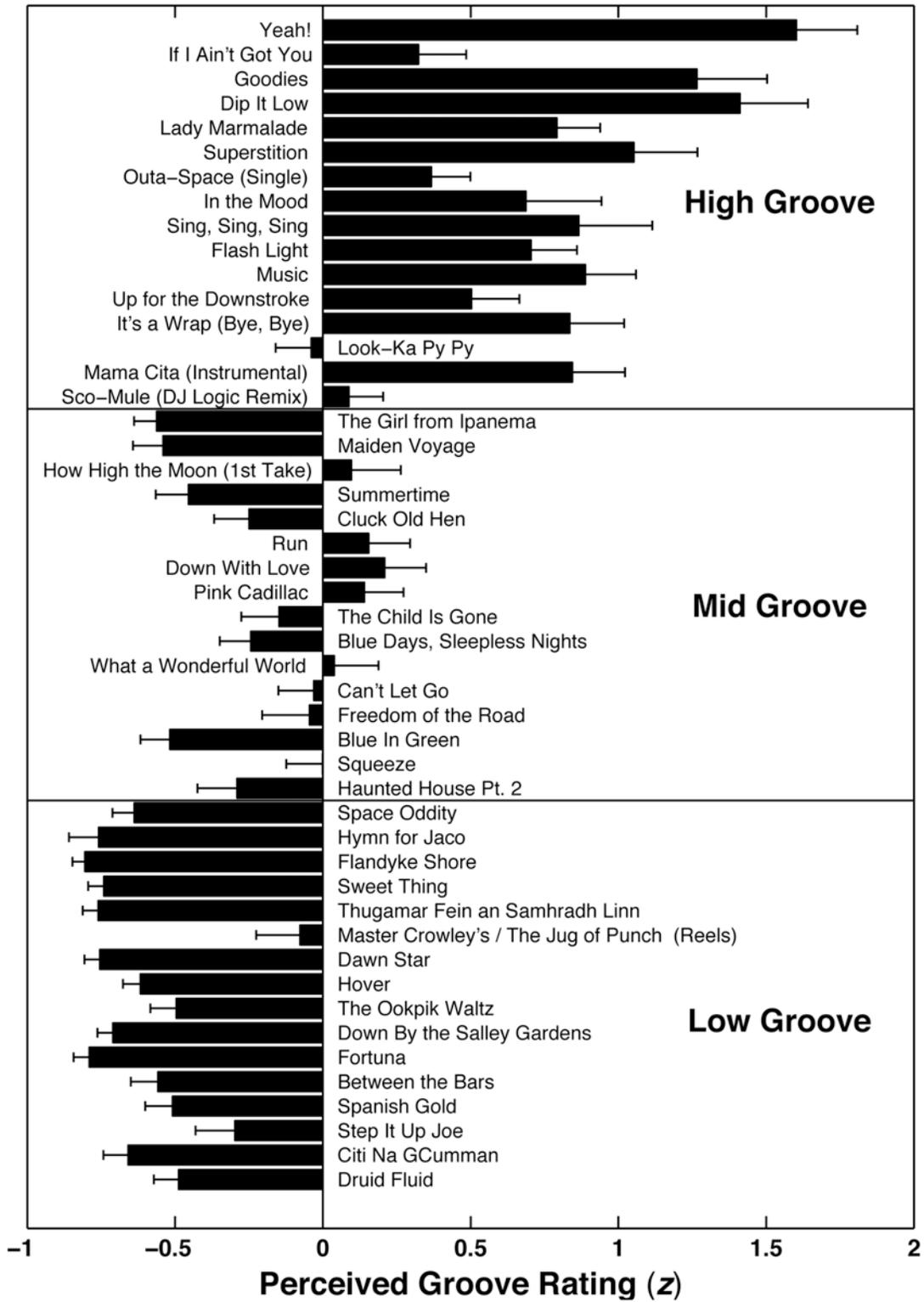


Figure 4

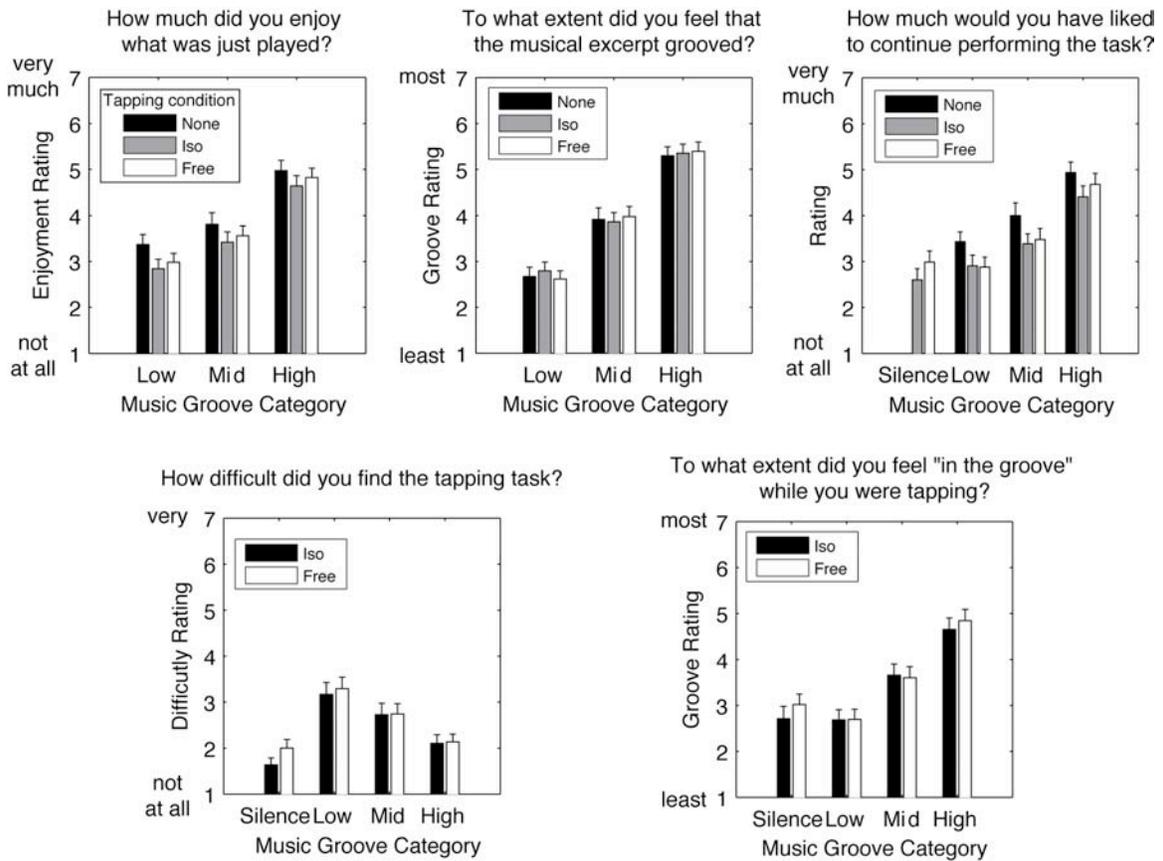


Figure 5

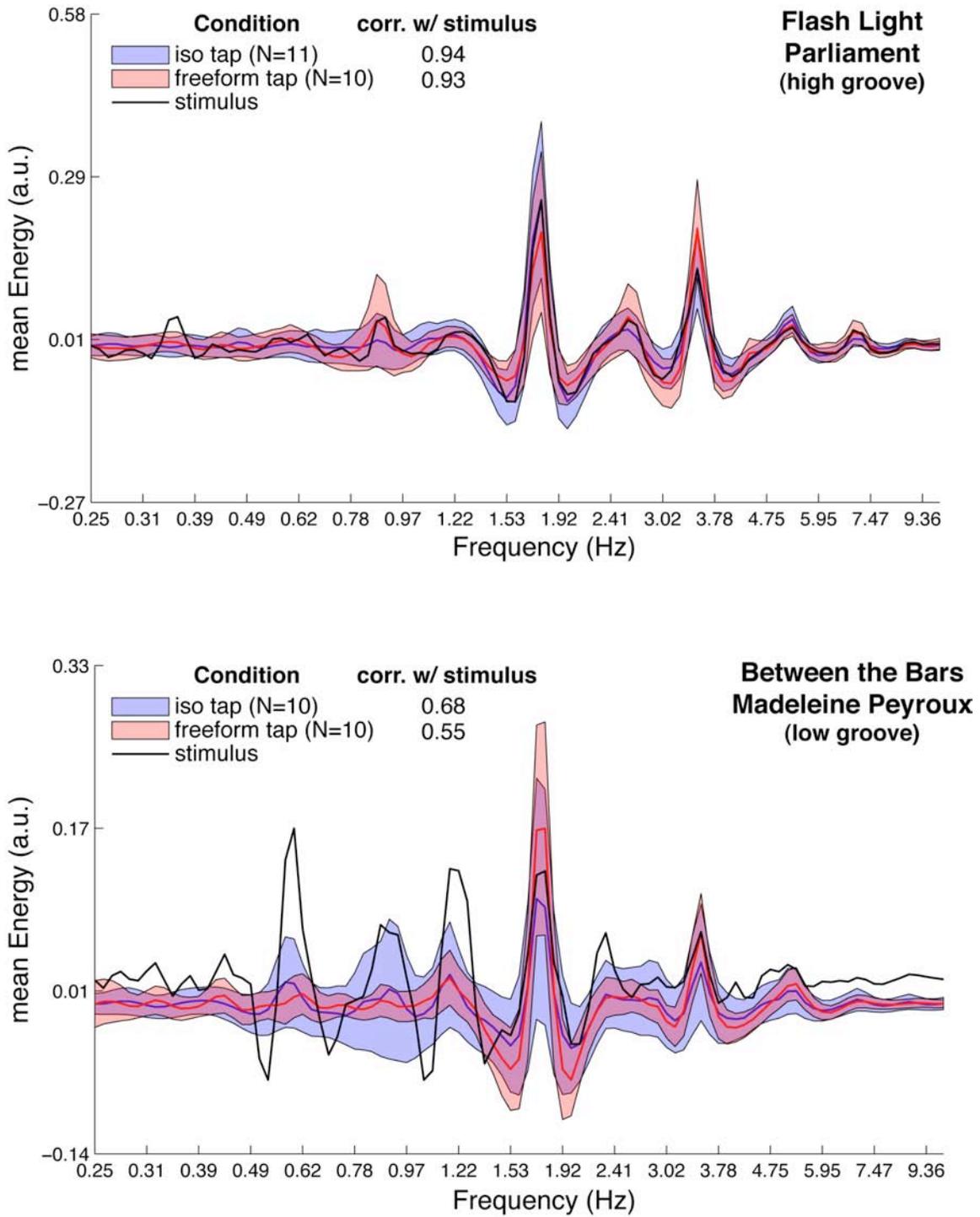


Figure 6

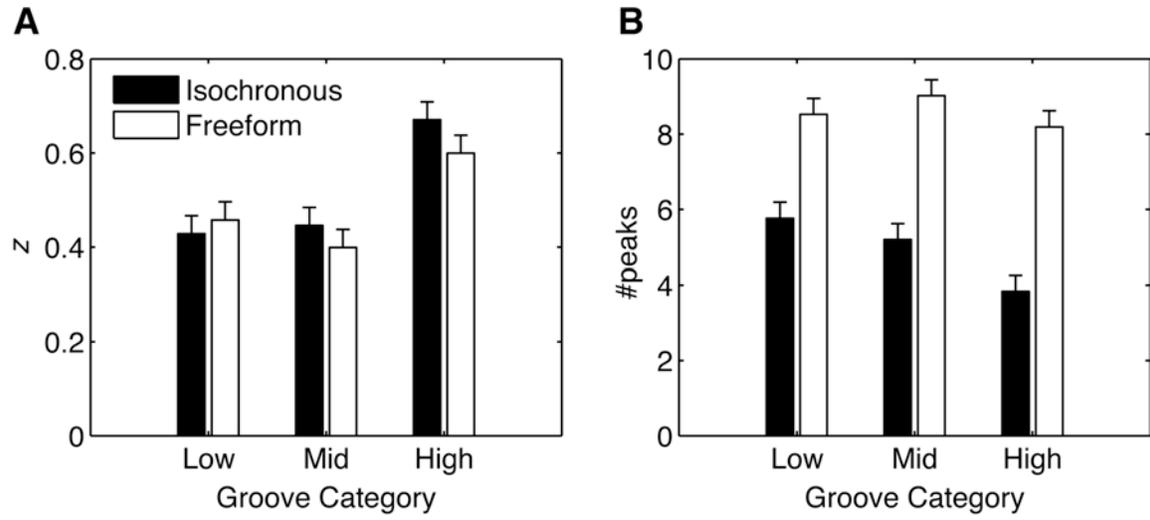


Figure 7