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PROCEEDINGS

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Investigation of Mu Oscillations to Naturalistic Groove Music

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Abstract

In the field of music psychology, a groove is described as a multifaceted participatory experience linked with the concepts of immersion, desire to move, positive affect, and social connection. While several intra- and extra-musical features have been reported to influence groove experiences in the previous literature, it is still unclear how groove music is processed in the brain. In the current electroencephalogram (EEG) study, 8 participants listened to naturalistic stimuli differing in level of a groove (high, mid, low) while they were instructed to sit still. Subjective groove ratings (wanting to move, enjoyment, and familiarity) were also collected. In line with previous literature, we hypothesized that stimuli that received higher as opposed to lower groove ratings would induce larger Mu oscillations as an indicator of greater motor inhibition during the passive listening task. Results of the spectral analysis showed no difference in Mu power to stimuli with different groove levels. Yet, this finding should be approached with care. We propose that 1) further data collection, 2) consideration of different stimuli selection, 3) simultaneous movement measures, 4) alternative analysis, and (5) design approaches might be necessary for future research in understanding the complex nature of groove experiences and how they are processed in the brain.

Introduction

Groove is associated with experiences of immersion, desire to move, positive affect, and social connection (Duman et al., 2021). Previous literature has reported several intra- and extra-musical variables associated with the experience of groove. Tempo (Etani et al., 2018), pitch (Hove et al., 2020; Stupacher et al., 2016), rhythmic (Fitch, 2016; Madison et al., 2011; Witek et al., 2014, 2017), and harmonic (Matthews et al., 2019) complexity as well as familiarity (Senn et al., 2018), musical preferences (Senn, Rose, et al., 2019) and musicianship (Senn, Bechtold, et al., 2019; Witek et al., 2017) are among the variables that influence the experience of groove.

A few studies have investigated groove with a neuroscientific approach. Increased neuroscientific understanding of groove could lead to implementation in specific groups of individuals, for instance to create clinical advice concerning patients with Parkinson's Disease (Hove & Keller, 2015; Nombela et al., 2013). Some studies explained groove within a predictive coding framework and proposed the groove experience as part of brain function that facilitates successful predictions (Stupacher et al., 2022; Vuust et al., 2018; Vuust, 2018). More specifically, in a functional magnetic resonance imaging (fMRI) study, Matthews et al. (2020) reported rhythms with medium complexity to result in higher groove ratings and linked with reward, motor and beat perception-related brain regions. In another fMRI study, Engel et al. (2022) found that listening to 'in sync' samba percussion excerpts (produced by various instruments) activated motor-related brain regions and reinforced audio-motor links (compared with 'out of sync' excerpts). They further propose this motor activity as foundational for the experience of groove.

An electroencephalogram (EEG) study (Cameron et al., 2019) reported stronger neural entrainment towards rhythms produced by humans, which correlated positively with a desire to move ratings (compared with mechanical versions created with precise timings using MIDI samples). These findings were interpreted as suggesting an interaction between low-level stimulus features with high-level cognitive processing and groove as a complex musical experience. In a transcranial magnetic stimulation (TMS) study, Stupacher et al. (2013) found that listening to high-groove music activated motor systems to a greater extent than low-groove music. Importantly, activation of motor areas (even during motor planning and an absence of overt movements) is suggested to support the processing of auditory information (Patel & Iversen, 2014).

A recent study demonstrated enhanced Mu activity during passive music listening, which is believed to reflect motor inhibition (Ross et al., 2022). Neural activity around beta (13–30 Hz) and Mu bands (near somatosensory areas around 8–12 Hz and its harmonics 18–22 Hz) are known to be involved in sensory-motor processing (Engel & Fries, 2010; Khanna & Carmena, 2015). Specifically, one study (Mazaheri et al., 2009) described Mu activation as an indicator of inhibition of motor activity. Another study (Pfurtscheller, 1981) reported that beta desynchronization in central brain regions is involved in the activation of the sensory-motor cortex and is an indicator of voluntary movement. In contrast, using EEG and electromyography (EMG), a recent study (Nijhuis et al., 2022) reported no influence of musical groove on cortico-muscular coherence (measured with beta power) during isometric contraction. This lack of clarity encourages further research on the topic.

Aims and Hypothesis

The aim of this study was to examine Mu oscillations to naturalistic stimuli – commercial music recordings – rated from high to low groove. To the best of our knowledge, no previous study has reported Mu oscillations to naturalistic stimuli with varying degrees of groove. Thus, the current exploratory work focuses on investigating cortical Mu activation to musical stimuli associated with various levels of groove. Greater Mu power was hypothesized for the stimuli that received higher groove ratings (compared with low groove) as an indicator of greater motor inhibition.

Method

Participants

Eight healthy Finnish participants (aged *M* = 25.38, *SD* = 1.3, 2 female) in good physical condition took part in the experiment.

Stimuli

Stimuli were selected in two steps. First, in a detailed online survey, participants (*N* = 105) listened to 30 short musical excerpts (from various genres of commercial music, with a tempo around 120 -/+ 20 bpm) and rated groove-related items (i.e., wanting to move, enjoyment and familiarity) for each excerpt (further details about the survey can be found in Duman et al., 2021, and Duman et al., 2022). Based on these groove ratings, 3 stimuli were selected for each groove level (low, mid, and high) for the current experiment (presented in Table 1). Each of the 9 stimuli lasted around 25 seconds and was presented 5 times in randomized order.

Table 1. Stimuli with initial wanting to move ratings.

	Artist	Song	Wanting to Move Rating
1	Bruno Mars	Uptown Frank	4.11
2	Daft Punk	Get Lucky	4.05
3	Earth, Wind, & Fire	September	4.03
4	Florence the Machine + Calvin	Say My Name	3.44
5	Lyn Collins	Think About It	3.37
6	Gotye	Somebody that I Used to Know	3.00
7	Stevie Wonder	I Just Call to Say I Love You	2.96
8	Kaleida	Think	2.57
9	Gwen Stefani	Cool	2.49

Procedure

The data collection took part in the EEG lab of the Department of Music, Art and Culture Studies, University of Jyväskylä, Finland. Upon arrival, participants were informed about the procedure, their rights as participants, and informed consent papers were collected. Participants completed a *passive listening task* while wearing an EEG system (BioSemi 64 channels). They were seated, asked to listen to the presented stimuli and to try not to move while their eyes were fixed on a point in space. The data collection took about 25 minutes. Subsequently, participants were presented with the stimuli to collect ratings of a) enjoyment, b) wanting to move, and c) familiarity with each track on a 5-point Likert scale.

Pre-processing

Data were pre-processed using the EEGLAB toolbox (Delorme & Makeig, 2004) in MatLab (2019b). Data were filtered using 1 Hz and 50 Hz high and low pass filters, respectively, referenced to the average of all channels and downsampled to 128 Hz. Next, pre-processed data were submitted to independent component (IC) analysis (Onton & Makeig, 2006). ICs were visually inspected with the help of the *IC Label* function (Pion-Tonachini et al., 2019), and a maximum of 10 artifact-like components (including eye, muscle, line, and other) among the highest-weighted 25 ICs were removed from the data. Data were epoched to 11 seconds [-1 10]. Finally, a baseline correction was applied to the epoched data referencing the 1000 milliseconds before the sound onset.

Analysis

The pre-processed data were analyzed using *mne-python* package (Gramfort et al., 2013). Spectral decomposition was applied with *Welch's* method using *psd_welch* function with multitaper (window length set to 4 seconds) to investigate spectral power to musical stimuli with various levels of groove at the individual and group level.

Results

As expected, participants' groove ratings were in line with the initial online experiment. In agreement with previous literature findings (Madison et al., 2011; Senn et al., 2018), and because Pearson's correlations demonstrated a significant relationship, in the initial study, between ratings of wanting to move and familiarity, $r(103) = .63$, $p < .001$, and enjoyment, $r(103) = .69$, $p < .001$, subsequent analyses were completed based only on the wanting to move ratings. Figure 1 demonstrates averaged wanting to move ratings of the stimuli. While for high-groove stimuli, a smaller variability across participants' ratings was observed (also reflecting a ceiling effect), a greater variability was noticed for mid and low-groove stimuli. This could indicate the subjective nature of participants' movement experiences.

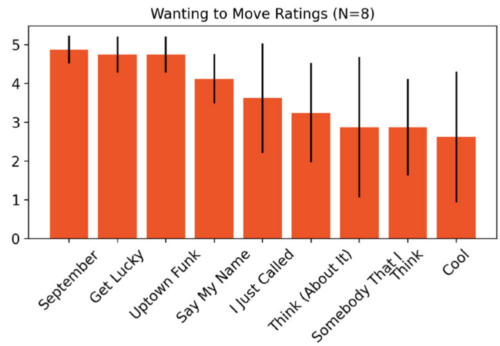

Figure 1. Wanting to move ratings of the stimuli.

Although according to the previous literature (such as Ross et al., 2022), a greater Mu power to high groove stimuli would be expected, no difference in Mu power was observed for stimuli with different levels of groove in the grand averaged spectral decomposition. Figure 2 shows the power spectral density distribution of the data averaged across participants.

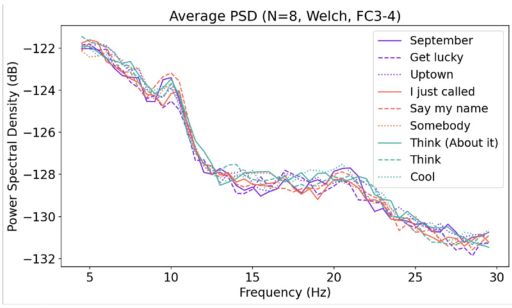

Figure 2. Power spectral density representation of the stimuli averaged across participants.

Since there can be inter-subject variation in spectral characteristics of the EEG signal

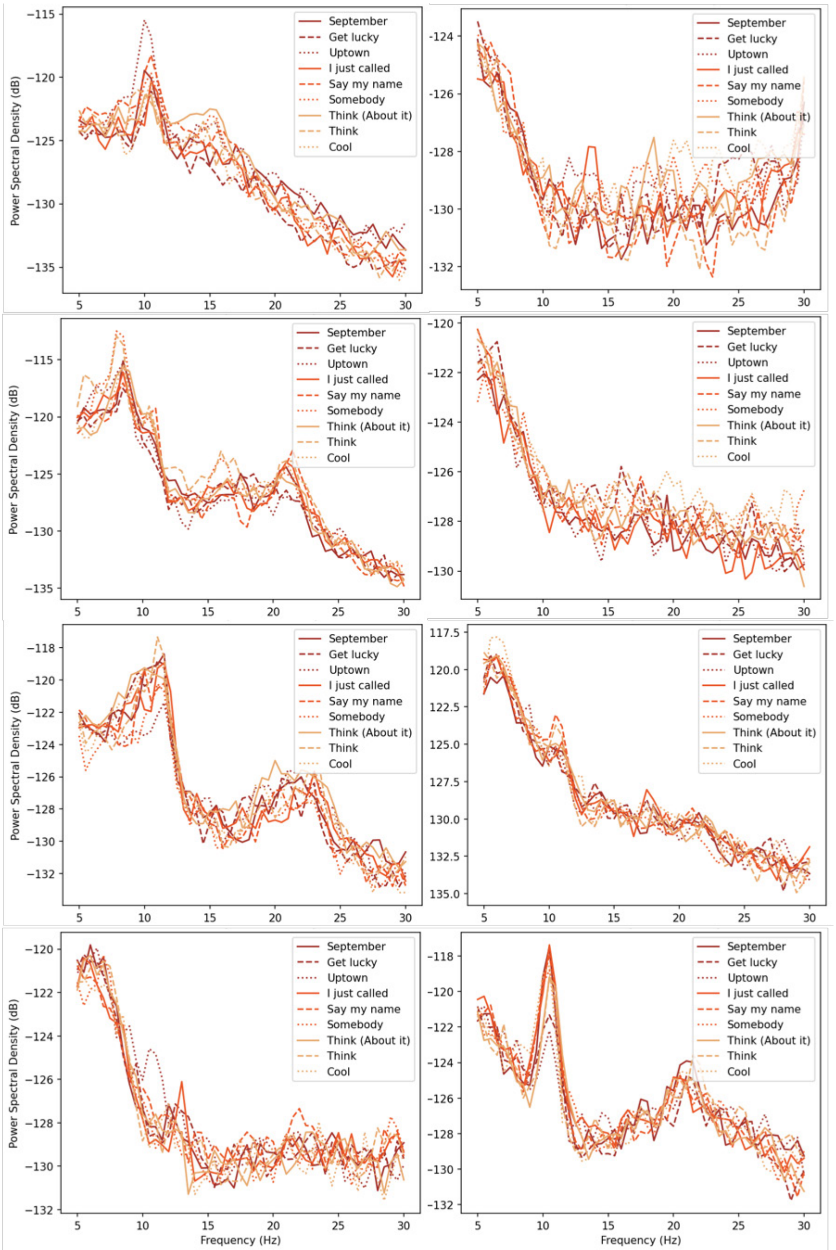

Figure 3. Power spectral density representation of the stimuli of individual participants.

(Croce et al., 2020), the data were also inspected on an individual level. The individual spectral decompositions demonstrated various patterns, as presented in Figure 3. Still, no relationship between subjective groove ratings and Mu activity was detected.

Discussion

Overall, the current study's results might be similar to the null findings of Nijhuis et al.'s research (2022), indicating no influence of different levels of groove stimuli on Mu oscillations. However, additional data and other analytical investigations might be required before pursuing such a conclusion. Therefore, we propose the following limitations and potential adjustments to be considered for future research.

First, the lack of evidence for the hypothesis could be due to stimuli selection. As seen in Figure 1, some participants also gave high ratings to low-groove stimuli. A set of stimuli that differ clearly in terms of groove ratings might be crucial. Second, previous literature revealed that high-groove music influences postural sway (Ross et al., 2016). Thus, quantifying body movements during a passive listening task (such as via simultaneous motion capture measurement) might be necessary to control the movement of participants. Third, similar to the study by Ross et al. (2022), a localizing analysis could be carried out in order to ensure the source of Mu oscillations is auditory and motor-related brain regions. For this, a change in experimental design might be needed to detect each participant's motor and auditory brain regions.

Furthermore, it is known that there are individual differences in neuronal responses across participants (Croce et al., 2020) as well as in terms of the music that participants want to move to (Duman et al., 2022). Therefore, future research could consider carrying out the analysis individually rather than a grand averaged group analysis. Finally, a groove is described as a personal experience (Duman et al., 2021) related to several factors (Senn, Bechtold, et al., 2019). In addition, there is a consideration of different kinds of groove experiences in the groove literature (Duman et al., 2021; Keil, 1995). Thus, future research could consider the possibility of different groove experiences across participants depending on selected stimuli. In conclusion, careful experimental designs are crucial while investigating the brain's processing of naturalistic groove stimuli.

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