EEG-BASED STUDY ON MUSICAL GROOVE AND MOTOR CORTICAL BETA POWER IN THE BRAIN

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Master's Thesis
Musicology
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Culture Studies
University of Jyväskylä
Spring 2023

UNIVERSITY OF JYVÄSKYLÄ

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Title EEG-based study on musical groove and motor cortical beta power in the brain	
Subject Musicology	Level Master's Thesis
Month and year 05/2023	Number of pages 30 + references

Abstract

The phenomenon of people spontaneously moving or dancing in response to music is a well-known everyday occurrence. However, it has not been thoroughly studied in EEG literature from the perspective of musical groove. Despite the attention given to the connectivity between cortical auditory and motor regions of the brain in music neuroscientific research, few studies have addressed groove utilizing EEG, although it has a reputation for evoking a strong desire to move among music listeners. This thesis aims to investigate how motor cortical beta power during listening to groovy music (high groove condition) differs from less groovy music (low groove condition). The primary focus was directed at the beta-band frequency range of 16-24 Hz since beta activity around 20 Hz has been linked to various movement-related processes, such as motor performance, motor imagery, and movement inhibition.

The current study employed a music listening experiment in which participants were presented with music samples that varied in groove. EEG data were recorded from research participants during the music-listening experiment, and they filled out a questionnaire after the listening procedure. The results suggest that the mean motor cortical power in the specified beta range does not differ significantly in the high groove condition compared to the low groove condition. However, a finding on channel FC1 indicating beta power suppression in high groove conditions at 20 Hz requires further investigation to confirm whether groove plays a role in motor-related beta peak activity or mu-rhythms. This thesis contributes to the existing groove literature by introducing a novel approach that utilizes commercially available music to study movement-related oscillatory activity in the brain.

Keywords EEG, groove, beta waves, motor cortex, music and movement

Depository University of Jyväskylä

Additional information

JYVÄSKYLÄN YLIOPISTO

Tiedekunta Humanistis-yhteiskuntatieteellinen	Laitos Musiikin, taiteen ja kulttuurin tutkimuksen laitos
Tekijä Tommi Kuivamäki	
Työn nimi EEG-pohjainen tutkimus musiikillisen grooven yhteydestä beta-aaltojen voimakkuuteen motorisella aivokuorella	
Oppiaine Musiikkitiede	Työn laji Maisterintutkielma
Aika 05/2023	Sivumäärä 30 + lähteet

Tiivistelmä

Ihmisten taipumus liikkua tai tanssia musiikin tahtiin spontaanisti on laajalti tunnettu jokapäiväinen ilmiö. Kyseistä ilmiötä ei kuitenkaan olla perusteellisesti tutkittu EEG-tutkimuksissa musiikillisen grooven näkökulmasta. Vaikka kuuloaivokuoren ja motorisen aivokuoren osien välinen konnektiivisuus on saanut osakseen huomiota neurotieteiden saralla, vain harvat tutkimukset ovat käsitelleet groovea EEG-pohjaisilla menetelmillä. Käsite liitetään kuitenkin vahvasti musiikin aikaansaaman liikkeen sekä tanssittavuuden kokemuksiin musiikinkuuntelijoiden keskuudessa. Tämän tutkielman tavoitteena on selvittää, miten beta-aaltojen voimakkuus motorisella aivokuorella eroaa koehenkilöiden kuunnellessa paljon groovea sisältävää musiikkia (high groove condition) verrattuna vähän groovea sisältävään musiikkiin (low groove condition). Huomio keskitettiin 16-24 hertsin (Hz) beta-taajuusalueelle, sillä aktiivisuus noin 20 hertsin taajuudella on yhdistetty tutkimuksissa erilaisiin motorisiin prosesseihin, kuten liikkeen suorittamiseen, liikkeen mielensisäiseen kuvitteluun sekä liikkeen inhibitioon.

Tutkimus koostui musiikinkuuntelukokeesta, jonka aikana koehenkilöt kuuntelivat grooven suhteen vaihtelevia musiikkinäytteitä. Musiikinkuuntelukokeen aikana koehenkilöiden aivosähkökäyrää (EEG) mitattiin ja he vastasivat kyselytutkimukseen kokeen päätteeksi. Tulosten perusteella keskimääräinen beta-taajuusalueen (16-24 Hz) voimakkuus motorisella aivokuorella ei eroa merkittävästi riippuen siitä, kuuntelevatko koehenkilöt paljon vai vähän groovea sisältävää musiikkia. FC1-elektrodissa havaittiin beta-aaltojen vaimenemista 20 hertsin taajuudella paljon groovea sisältävän musiikin kuuntelun aikana. Jatkotutkimukset ovat tarpeellisia sen selvittämiseksi, onko groove mahdollisesti yhteydessä motorisiin toimintoihin liittyvien beta-aaltojen voimakkuuden huippukohtiin ja mu-rytmeihin. Tämä tutkielma käsittelee groovea uudesta näkökulmasta hyödyntäen kaupallista musiikkia motorisiin toimintoihin ja liikkeeseen liittyvien aivojen oskillaatioiden tutkimisessa.

Asiasanat EEG, groove, beta-aallot, motorinen aivokuori, musiikki ja liike
Säilytyspaikka Jyväskylän yliopisto
Muita tietoja

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1 INTRODUCTION

The ability of music to induce movement in listeners is a well-known phenomenon that has likely been observed by most people to some extent. It is common to move one's legs, nod one's head or even dance to music that is energizing, arousing, and enjoyable. The embodied nature of music becomes apparent not only when performing or playing an instrument but also when listening to it. In particular, low-frequency soundwaves can be distinctively felt in the body when attending a concert, and this auditory-tactile modality seems to enhance the movement-inducing aspect of music (Hove, Martinez, & Stupacher, 2019). The tendency to move in response to music appears to be universal, as evidenced by the integration of music and dance across various cultures. For example, dancing while singing is common practice in African cultures (Himberg & Thompson, 2011). Infant studies suggest that predisposition may play a greater role in forming the music-movement relationship than learning from the environment. Sensitivity to movement in response to periodic sounds has been observed in babies who produced rhythmical motor movements while listening to music (Zentner & Eerola, 2010).

Although the embodied experience of music is relatable to almost everyone, its underlying neural mechanisms are not clearly understood. One of the key factors contributing to the link between music and movement is the coupling between the auditory and motor areas of the brain. Sensory and motor processes interact with each other when people synchronize their movements to the beat (Nozaradan, Zerouali, Peretz, & Mouraux, 2015). Studies have demonstrated that some cortical motor regions in the brain are activated even if participants do not produce any overt movement while listening to musical rhythms (Grahn & Brett, 2007; Chen, Penhune, & Zatorre, 2008; Teki, Grube, Kumar, & Griffiths, 2011). Furthermore, tactile sensations experienced when listening to music with low-frequency spectral content may be closely associated with motor systems (Hove et al., 2019).

The relationship between music and movement has been extensively explored in music neuroscience. However, the concept of musical groove, despite its significance in rhythmic music, has not received much attention in the field until recently. Although research concerning the neural correlates of music and movement has not addressed musical groove specifically, substantial research has focused on rhythm-related phenomena such as musical beat processing. Investigating the neural correlates of groove in music processing may facilitate a better understanding of music and its tendency to induce bodily movement in everyday music listening. Since auditory-motor coupling involves cortical brain regions and is crucial for processing musical rhythm, electroencephalography (EEG) presents a suitable method for studying the motor cortical correlates of groove.

This study consists of a music-listening experiment in which research participants listened to commercially available music samples that varied in groove, while their EEG was recorded. Participants also completed a questionnaire following the music-listening experiment. This project's main goal was to determine how motor cortical beta power in the brain in a frequency band of 16-24 Hz differs between high- and low-groove conditions during passive music listening. The hypothesis is that beta-band power in the brain's motor cortical regions is either increased or decreased in high groove compared to low groove conditions.

This study focuses on studying groove with an emphasis on motor- and movement-related aspects of the phenomenon, comprising a basis from a theoretical background through to analysis and result implications. The decision to further analyse beta-band motor cortical power derives from its role in the brain's auditory-motor coupling, a fundamental element in groove perception and experience. Motor cortical beta suppression around 20 Hz seems to play a role in motor imagery (Schnitzler, Salenius, Salmelin, Jousmäki, & Hari, 1997) and motor-related mu-rhythm activity (Ross, Comstock, Iversen, Makeig, & Balasubramaniam, 2022), both of which might be related to groove.

EEG-based studies regarding groove are scant despite the technology being well-suited for studying cortical activity in the brain during music listening. Applying commercially available music stimuli in the music-listening experiment further adds to this study's novelty: groove has typically been studied via plain drumbeats or computerized rhythms as stimuli instead of using more naturalistic music stimuli. Applying commercially available music as a representation of what people tend to listen to outside laboratory-like research environments may better capture the complex nature of groove. In addition to rhythm-related features (Matthews, Witek, Heggli, Penhune, & Vuust, 2019; Pressing, 2002), research suggests that musical features such as harmony (Matthews et al., 2019; Stupacher, Wrede, & Vuust, 2022) and instrumentation

(Hurley, Martens, & Janata, 2014) also contribute to the overall sense of groove. To the author's knowledge, this study is the first to investigate motor cortical beta power on a specified frequency band of 16-24 Hz while listening to different music samples that vary in groove. This novel approach may shed light on the auditory-motor coupling and movement-related characteristics of groove in everyday passive music listening situations.

2 STUDIES ON GROOVE AND THE NEURAL BASIS OF RHYTHMIC MUSIC PROCESSING

Neuroscientific research on groove, especially EEG-based methods, is scant. However, other research methods have been employed to explore groove. For example, survey studies have been used for collecting data by addressing groove's perceptions and experiences, helping researchers define a music psychology-oriented concept of groove. Furthermore, some studies have collected neurophysiological, physiological, or movement-related data in addition to survey data, focusing on groove or closely related phenomena such as musical movement. While certain musical features have been identified as playing a key role in groove, others appear to have no significance or have a more nuanced and context-dependent relationship with groove.

Possibly an essential neuronal mechanism for groove, the coupling between the brain's auditory and motor cortical areas has been studied extensively in the neuroscientific research literature. Investigating the interaction between these functionally interconnected but spatially separate brain regions may also offer insights into musical groove. Findings about the brain's oscillatory activity during musical beat processing in passive listening conditions may be relevant for the current study even though most studies have not assessed groove. While using an EEG-based approach offers many possibilities in studying this phenomenon, the complex nature of music, groove, and the brain presents certain limitations for the study.

2.1 Defining musical groove

The term 'groovy' is commonly used in various musical styles by both musicians and music enthusiasts to describe the movement-inducing aspects of music, although the term seems to have been originally established in the jazz tradition. For example, musicians often use the phrase "getting into a groove" to describe their experience during musical performances. This state has been reported by musicians to enhance ensemble playing, making it more effortless and satisfactory (Janata, Tomic, & Haberman, 2012). Additionally, the experience of groove may even share similarities with religious or spiritual states and other altered states of consciousness (Zagorski-Thomas, 2007).

Using complex musical definitions and musicians' perspectives of groove can be problematic when applied to research aimed at capturing its essence and how it affects the general population, most of whom are nonmusicians. An individual's musical experience with a specific genre or musical style can influence music processing at perceptional and even neuronal levels (Tervaniemi, Janhunen, Kruck, Putkinen, &

Huotilainen, 2016). Furthermore, individual differences and subjectivity seem to play a significant role in how musicians and music listeners describe groove (Hosken, 2020). However, these different standpoints typically share an understanding of the importance of bodily movement and pleasure in groove.

In Madison's study (2006), although not delving deeply into music theory, a bit more elaborate definition of groove was provided as "wanting to move some part of the body in relation to some aspect of the sound pattern" (Madison, 2006). However, this definition views groove from a general standpoint, mentioning the urge to move to sound, and it lacks other noteworthy elements of groove. Other studies have shown that in addition to the desire to move to sound, people find groove pleasurable (Hurley et al., 2014; Janata et al., 2012; Matthews, Witek, Lund, Vuust, & Penhune, 2020). The groovy elements perceived in music seem to activate reward networks in the brain in addition to sensorimotor networks (Matthews et al., 2020), supporting the important role of both movement and pleasure in groove. Experiencing groove as a pleasurable urge to move seems to be modulated more by a general preference for dancing or movement, rather than musical training (Witek, Clarke, Wallentin, Kringelbach, & Vuust, 2014). Thus, studies suggest that groove as a musical psychological phenomenon is strongly related to both movement and rewarding aspects of music regardless of musical expertise.

2.2 Musical features linked to groove

The growing body of scientific evidence suggests that certain musical characteristics play a role in groove perception. Probably the most significant factor in determining the level of groove is the rhythmical structure of a musical piece. Studies consistently show that syncopated rhythms are generally perceived as more groovy than steady rhythms (Matthews, Witek, Heggli, Penhune, & Vuust, 2019; Pressing, 2002). Moreover, syncopated rhythms closely related to groove sensations seem to elicit physiological arousal more than steady rhythms (Bowling, Ancochea, Hove, & Tecumseh Fitch, 2019), providing support for the activating nature of rhythmic music and groove. The level of rhythmic complexity also plays an important role in groove: highly complex and very simple rhythms are perceived as less groovy than rhythms with medium complexity. Notably, the degree of syncopation, which serves as a measure of rhythmic complexity, appears to form an inverted u-shape when correlated with the pleasurable drive to move one's body (Matthews et al., 2019; Stupacher, Wrede, et al., 2022; Witek et al., 2014).

Although unlikely to be as important as rhythmic factors in defining groove (Matthews et al., 2019; Stupacher, Wrede, et al., 2022), harmony and various other musical features do play a role. In contrast to syncopated rhythms, medium and low-complexity harmony seems to enhance perceived groove more than highly complex harmony (Matthews et al., 2019; Stupacher, Wrede, et al., 2022). The lower notes typically played by bass instruments also seem to be important for groove (Hove et al., 2019; Stupacher, Hove, & Janata, 2016), although it is important to note that overall lower musical frequencies do not necessarily correlate with higher groove ratings (Bowling et al., 2019). It has been suggested that lower frequencies may be important for auditory-motor entrainment. Conversely, higher frequencies likely contribute to music's identifiable characteristics and arousing elements (Bowling et al., 2019). Other musical features such as event density and beat salience may also explain higher perceived groove (Madison, Gouyon, Ullén, & Hörnström, 2011). However, the latter of these two has not shown an effect when using only drumbeats (Senn, Kilchenmann, Bechtold, & Hoesl, 2018). In addition, music's audio signal variability may also be related to groove: lesser variability in dynamics is linked to lesser perceived groove (Stupacher et al., 2016).

Music with a slightly quicker tempo is often considered groovier than slower music, but excessively quick tempos may decrease the sensation of groove. One study estimated that an approximate tempo of 100–120 BPM (beats per minute) represents groove's optimal tempo (Etani, Marui, Kawase, & Keller, 2018). However, tempo's role in producing groove is not clear, and some studies have not found a consistent relationship between tempo and perceived groove (e.g. Madison, Gouyon, Ullén, & Hörnström, 2011). In addition to tempo, microtiming, which refers to small timing deviations from the exact rhythmical structure in music, has been linked to groove. Despite the association, studies have been unable to find a robust link between microtiming and groove (Madison et al., 2011; Skaansar, J., Laeng, B. & Danielsen, 2019). Senn, Kilchenmann, von Georgi, & Bullerjahn (2016) tested two contrasting hypotheses about whether microtiming deviations are essential for groove or if they diminish it instead, and they found neither of the hypotheses to be strictly true. It was concluded that both temporally exact rhythms and microtiming in music were rated similarly high regarding groove when microtiming was performed by an expert musician (Senn et al., 2016).

The temporal characteristics and repetition of concurrent rhythmic patterns in music are most likely to contribute to the experience of groove (Pressing, 2002). Repetition plays a key role in one's ability to predict events. However, high predictability alone may not guarantee groove. While groovy music is typically steady in tempo, unlike classical music with rubato, for example (Pressing, 2002), it is not stable in rhythm due to the high degree of syncopation. It seems that a moderate degree of predictability in music is associated with higher ratings of groove, as previously mentioned studies about rhythmic and harmonic complexity suggest. Vuust & Witek (2014) describe how the neural processing of complex rhythms exemplifies the theory of predictive coding in action. According to this view, repeatedly playing moderately complex rhythms elicit prediction errors in listeners and lead to pleasure, possibly indicating learning in the process (Vuust & Witek, 2014). The complexity of music may explain difficulties in describing the relationship between predictability and reward. Since music consists of several simultaneously occurring dynamic features, moderate variance in some features may typically result in positive prediction errors and reward (Salimpoor, Zald, Zatorre, Dagher, & McIntosh, 2015). An example of the complex interplay between musical features is how harmony may indirectly relate to groove by modulating the effects of rhythm and inducing pleasure, which influences the desire to move (Matthews et al., 2019).

It is important to note that groove is not solely dependent on various musical features that either increase or diminish it. For example, the preferred musical style and familiarity of the music appear to significantly influence the perceived groove (Senn et al., 2018). When considering the overall processing of musical beats and the vital role of the ability to temporally predict the sound plays in it, the importance of familiarity regarding genre or musical style in making music 'groove' seems plausible. Although certain musical features (e.g., temporal regularity, syncopation) have been shown to influence groove ratings across studies, it would be reasonable to avoid making strict statements or generalizations about them (see Senn et al., 2018). It is likely that the roles and functions of specific musical features may vary depending on the musical context, such as music genre, degree of instrumentation, familiarity, and other factors.

2.3 EEG and the role of motor beta oscillations in the brain

Researchers widely agree that the source of the EEG signal lies in the synchronized activity of cortical neurons, specifically pyramidal cells (Jackson & Bolger, 2014). These cortical neurons, which consist of positive and negative charges separated by a distance, are called dipoles (Jackson & Bolger, 2014). When multiple neurons and their dipoles are synchronized in activity and arranged in parallel, the summed activity of the dipoles is large enough to measure the signal (Jackson & Bolger, 2014). Electrodes attached to the scalp can detect changes in electrical activity (voltage) resulting from the dipoles positive and negative charges. This is the basis for observing excitatory (positive charge) or inhibitory (negative charge) activity in EEG data. These electrodes that measure cortical activity are typically called channels in EEG literature. Due to the weak nature of the EEG signal, electrodes must be positioned carefully on the scalp by clearing hair out of the way and using conductive gel to increase the signal strength and reduce the noise-to-signal ratio.

Pure EEG data comprises electrical brain activity on different frequencies, corresponding to different brain waves and their oscillatory activity. The EEG power spectrum typically follows a 1/f curve, where power decreases as frequency increases (Demanuele, James, & Sonuga-Barke, 2007). Beta waves are typically defined as appearing in the 13-30 Hz frequency range. However, definitions may vary according to the specified study goals. Beta oscillations are known to play a role in motor functions and movement: beta desynchronization or decrease in power occurs when preparing for movement, performing the movement, or imagining the movement, followed by beta synchronization or increases in power shortly afterwards (Neuper, Wortz, & Pfurtscheller, 2006). Motor-related beta power typically peaks around 20 Hz but may vary depending on the person and cortical region being inspected (Davis, Tomlinson, & Morgan, 2012). In addition to overt movement, 20 Hz beta suppression has been observed during motor imagery over the primary motor cortex (Schnitzler et al., 1997). Additionally, 20 Hz beta suppression over sensorimotor areas also represents a harmonic of the alpha-band mu- rhythm, which plays a role in movement inhibition and has become apparent during passive music listening (Ross et al., 2022).

2.4 Groove-related neuroscientific research

Substantial neuroscientific research literature exists that is possibly relevant for the topic; however, most studies have not assessed groove directly. Musical features that have been shown to play an important role in groove have been studied using various neuroscientific methods, which may shed light on the relationship between groove and the brain. For example, musical beat processing seems to be enhanced in the brain more by lower frequencies than higher frequencies (Lenc, Keller, Varlet, & Nozaradan, 2018). Tempo may modulate the strength of the auditory-motor coupling in the brain (Nicolaou et al., 2017). In addition to the auditory-motor coupling, tempo may modulate movement-related activity in motor areas (Daly et al., 2014).

The connection between sensory and motor areas of the brain has been extensively studied in music neuroscience. The connectivity between auditory and motor regions could be considered significant concerning music-induced movement or the urge to move. Musical beat and rhythm, as key factors contributing to the sensation of groove, are processed in several brain regions, including the cortical auditory (Fujioka, Trainor, Large, & Ross, 2009) and motor areas (Grahn & Brett, 2007). The brain's motor areas have been shown to be functionally connected to its sensory regions and play a key role in predictive temporal processing, which is enhanced when tapping along to auditory stimuli (Morillon & Baillet, 2017). Sensory and movement-related areas are strongly coupled and interactive when participants are engaged in some form of motor activity in synchronization with the beat (Nozaradan et al., 2015).

While motor activity during auditory listening tasks enhances the connectivity between sensory and motor areas, there is also evidence of motor cortex activation during passive listening despite the absence of overt movement. For instance, processing the timing of the beat activates motor areas such as the supplementary motor area (SMA) and premotor cortex (PMC) in participants who passively listen to musical beats (Grahn & Brett, 2007; Chen et al., 2008; Teki et al., 2011). Additionally, listening to samba percussion that participants rated high for groove was found to increase activity in SMA, PMC, and middle frontal gyrus (Engel, Hoefle, Monteiro, Moll, & Keller, 2022). Furthermore, the processing of complex and syncopated rhythms may rely more on cortical than subcortical activity, possibly due to the greater need to produce the beat internally when listening to such rhythms (Nozaradan, Schönwiesner, Keller, Lenc, & Lehmann, 2018).

Rhythmic auditory stimuli and motor processes may influence beta-band oscillatory activity in the brain. For example, beta power has been observed to increase in motor cortical areas during finger tapping to a beat (Stegemöller, Izbicki, & Hibbing, 2018). It has been suggested that beta oscillations in the auditory cortex also play a role in auditory-motor coupling (Fujioka et al., 2009). Moreover, enhanced beta activity has been observed after participants listened to music they perceived as activating (Höller et al., 2012) and after increasing the music tempo (Hurless et al., 2013). In tasks that require auditory attention, beta oscillations in sensorimotor regions appear to reflect predictive temporal processing (Morillon & Baillet, 2017). The beat seems to modulate beta-band activity: there is a decrease in amplitude after hearing the beat and an increase in amplitude when predicting the next beat (Fujioka, Ross, & Trainor, 2015).

While listening to musical rhythms without moving can activate motor-related brain activity, it seems even more intriguing that merely imagining the auditory stimuli may have a similar effect. Beta-band amplitude has been shown to decrease not only after hearing a beat but also after imagining the downbeat of a measure (Fujioka et al., 2015). Considering that rhythmic music listening engages the motor system, and that motor imagery modulates beta power, it is possible that motor imagery could play a role in passive music listening and modulate beta activity differently depending on the groove. For example, participants might imagine moving their bodies more when hearing high groove music and modulating motor cortical beta power in the process.

In a recent study, Ross et al. (2022) found that cortical mu-rhythms were enhanced during passive music listening, indicating inhibition of motor systems. However, Stupacher et al. (2013) observed inhibitory activity over motor areas only in nonmusician participants who listened to high groove music, whereas musicians showed excitatory activity in the same situation. These studies pave the way for the current study, which explores motor-related beta power around 20 Hz and aspires to shed light on excitatory and inhibitory processes that occur in motor cortical areas during passive music listening while controlling for groove.

2.5 Studying groove with EEG: possibilities and limitations

Considering that pleasure and wanting to move contribute to an overall sense of groove, it would seem reasonable to take both factors into account when conducting an EEG-based study. However, cortical regions showing increased activity during pleasurable experiences with music do so through enhanced connectivity with the nucleus accumbens (NAcc; Salimpoor et al., 2013). Therefore, solely inspecting cortical activity may not be sufficient. Furthermore, the medial orbitofrontal cortex, which is considered a part of this network, does not appear to play a distinct role in pleasure itself but rather in movement-related aspects of groove (Matthews et al., 2020). Since music-induced pleasure seems to activate primarily subcortical brain regions, such as the NAcc (Matthews et al., 2020; Salimpoor et al., 2015), while its cortical counterparts are less distinct, studying the rewarding aspects of groove using EEG is outside the scope of the current study.

EEG presents as a suitable technique for studying cortical activity during music listening due to its good temporal resolution. This is particularly important since music listening is not a static process. Instead, many temporal elements in music, such as beat placement in rhythm (Fujioka et al., 2015) or introducing new instruments to the auditory stimulus (Hurley et al., 2014) seem to modulate brain activity. EEG is also suitable for studying complex stimuli, such as music, due to its record durations, which are longer compared to event-related potentials (ERP) as an alternative EEG-based method (Hurless et al., 2013). While it may seem counterintuitive to record movement-related brain activity with EEG since the recorded data is easily disrupted by movement, studies show intriguing findings about cortical motor activity even in passive music listening conditions (e.g. Grahn & Brett, 2007; Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller, 2013; Teki et al., 2011), making EEG suitable for studying motor-related brain activity despite the lack of movement.

Selecting appropriate auditory stimuli is challenging in neuroscientific studies of music, including when examining music that varies in groove. Many of the studies exploring musical beat processing have applied stimuli consisting of only the auditory beat or rhythm rather than commercially available music (e.g. Fujioka et al., 2009; Grahn & Brett, 2007; Nozaradan et al., 2018). In this approach, the validity of stimuli is high regarding the variable of interest (such as beat) due to the lack of other factors in the audio that might influence auditory processing. However, measuring the effects of groove will probably require more complex stimuli since several musical components are thought to play a role in groove perception. For example, perceived groove may be positively correlated with the degree of instrumentation and gradually adding new instruments into the musical stimuli (Hurley et al., 2014). Thus, it could be argued that commercially available music stimuli that represent the everyday music listening choices of the average person should be applied in studies to gain a true understanding of groove.

The use of music in an experiment and focusing on groove poses several challenges. Firstly, identifying which musical features systemically contribute to groove is difficult. For example, some studies suggest that tempo and microtiming in music are related to groove, but they have not shown a consistent relationship with groove when assessed in research settings (see Madison et al., 2011). Despite the inability of studies to find a robust relationship between groove and microtiming, a substantial group of expert musicians advocate for the importance of minor rhythmic deviations in producing groove (Senn et al., 2016). Different music genres can create contextual factors that are related to some musical features, and microtiming may enhance perceived groove in specific songs (Skaansar, J., Laeng, B. & Danielsen, 2019). In addition to musical features, individual factors such as music preference or familiarity (Hurless et al., 2013) and attentional or imagery-related processes (Fujioka et al., 2015; Leslie, Ojeda, & Makeig, 2014) may also influence cortical activity in research settings. Nonetheless, despite the challenges associated with applying music stimuli, the overall groove ratings of certain songs can aid researchers in selecting more valid stimuli, especially when similar results are replicated across different studies.

Although musical groove has received limited recognition in the field of music neuroscience, a broad range of research literature on music processing suggests that there remains more to discover regarding the neural correlates of movement-inducing music. By studying groove, it may be possible to gain further insight into the neurological basis of a universal phenomenon and the nature of music as an embodied activity. Furthermore, auditory-motor coupling enhanced by groovy music can be studied even in passive music listening conditions, rendering observations more applicable to everyday music listening situations. However, it is important to acknowledge the limitations of neuroscientific methods in groove research and using the concept of groove. All in all, groove as an experience is a highly subjective and context-dependent phenomenon (Hosken, 2020). It is unlikely that a generalization about perceived or experienced groove, considering all possible aspects, can be made based on neuroscientific data. However, researchers can still make reliable observations about certain aspects of groove, such as its role in the brain's motor-related cortical activity.

3 METHODOLOGY

The current study focuses on the motor-related aspects of musical groove, specifically on beta-band power around 20 Hz in the brain's motor cortical region, while acknowledging the psychological dimension of groove as a pleasurable drive toward moving in sync with music. Prior research has shown that beta waves are linked to motor activity (Schnitzler et al., 1997; Neuper et al., 2006), auditory-motor coupling in the brain (Fujioka et al., 2009), and processing musical beats (Fujioka et al., 2015). It is reasonable to postulate that the rhythmic and movement-inducing properties of groovy music may influence beta power, given that musical beat processing and movement have been shown to modulate beta power. Frequencies at ~20 Hz are of main interest in this study due to motor performance, motor imagery, and mu-rhythm-related motor inhibition exhibiting the most prominent activity around this frequency. This thesis aims to answer the following research question:

How does motor cortical beta power in the brain on a 16–24 Hz frequency band differ between high- and low-groove conditions during passive music listening?

This study is based on a hypothesis that beta-band power in the motor cortical region of the brain either increases or decreases in high groove conditions compared to low groove conditions. The hypothesis is non-directional due to evidence suggesting both motor excitability and motor suppression during listening to groovy music. Specifically, research has shown that musicians exhibit increased motor cortex excitability during high groove music listening, while nonmusicians show motor cortex suppression (Stupacher et al., 2013). It is unclear whether these effects stem directly from musical training and its impact on auditory processing due to functional changes in the brain or other attention-related processes typical for musicians (but not restricted to them). For example, nonmusicians may be more inclined to concentrate on inhibiting their motor responses while listening to music in passive music listening conditions compared to musicians (see Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller, 2013). When interpreting the results, certain factors, such as song familiarity, preference of moving to music, and attentional or other cognitive processes, could possibly play a role. The term "passive music listening" refers here to listening without overtly moving at the same time, such as dancing or nodding the head in response to music.

3.1 Participants

Ten healthy Finnish individuals participated in the study. All participants reported being right-handed and having normal hearing. Two participants were excluded from the analysis due to excessive movement and/or high electrode impedance levels. Consequently, eight participants (six females) aged between 24–28 years (mean 25.38, SD ± 1.30) were included for further analysis. The participants were informed about the study and their rights by reading the research notification and privacy notice concerning the study, and they signed a consent form before starting the experiment.

3.2 Stimuli

From a list of 30 music samples previously evaluated in terms of groove criteria, nine music samples were chosen for this study (Duman, Toiviainen, & Luck (in press)). The criteria aligned with the current study: pleasure and wanting to move. The chosen music samples represented three genres: pop, funk, and electronic dance music (EDM). These genres were chosen since they are generally popular, and the songs within these genres were relatively stable in terms of tempo compared to other genres in the list, such as rock. Since variations in tempo have been shown to modulate beta wave activity (Hurless et al., 2013; Nicolaou et al., 2017), an area of interest in this study, all selected music samples were roughly similar in terms of tempo (between 112–138 BPM). The effect of tempo variation is also worth noting since groovy music is typically associated with a stable tempo (Pressing, 2002).

Music samples were approximately 25 seconds long and divided into separate groove categories as follows: three high groove, three medium groove, and three low groove music samples (see TABLE 1). Each category included music samples from each genre. Groove categories were based on the order of groove rating scores and not any absolute numerical values. Music samples were presented to participants in five blocks, with each block containing all the music samples (9) used in the experiment. In each block, the music samples were presented randomly to avoid possible bias regarding the presentation order.

TABLE 1 Music samples and respective groove categories according to survey study by Duman et al. (in press).

Song	Artist	Genre	Tempo	Groove category
Cool	Gwen Stefani	Pop	112 BPM	Low groove
Somebody that I used to know	Gotye	Pop	129 BPM	Medium groove
Uptown Funk	Bruno Mars	Pop	115 BPM	High groove
I Just Called to Say I Love You	Stevie Wonder	Funk	114 BPM	Low groove
Think About It	Lyn Collins	Funk	113 BPM	Medium groove
September	Earth, Wind & Fire	Funk	126 BPM	High groove
Think	Kaleida	EDM	138 BPM	Low groove
Say My Name	Florence the Machine + Calvin Harris	EDM	126 BPM	Medium groove
Get Lucky	Daft Punk	EDM	116 BPM	High groove

3.3 Questionnaire

The first part of the questionnaire consisted of a section where subjects evaluated all nine music samples. The subjects were asked to indicate how much they agreed with the following claims regarding each music sample (questions 1–9):

A. I find the song familiar.
B. I find the song enjoyable to listen to.
C. The song makes me want to move/dance.

The participants evaluated the music samples on a Likert scale from one to five points (1 = strongly disagree, 2 = somewhat disagree, 3 = don't agree or disagree, 4 = somewhat agree, 5 = strongly agree). The groove rating for each music sample was obtained by calculating the sum of the scores for pleasure (B) and wanting to move (C), and then taking the mean. The music samples were presented in alphabetical order based on the song names. Thus, information about music genres or different groove categories could not be implied from the song order (e.g., all high groove songs were presented first). In questions 10–13, the subjects were asked to answer more general music-related questions and state basic demographic information about themselves.

Subjects were asked the following questions accompanied by the following answer options:

10. How easy do you find it to move or dance to music in general?
- Very difficult
- Somewhat difficult
- Not easy or difficult
- Somewhat easy
- Very easy

11. How much do you spend time on music listening on average (hours per day)?
- Less than 1 h/day
- 1-2 h/day
- 3-5 h/day
- 6-8 h/day
- More than 8 h/day

12. Evaluate your musical training experience (years spent on formal musical training).
- Less than one year
- 1-3 years
- 4-6 years
- 7-9 years
- 10 years or more

Participants were asked to provide their age, gender, and nationality in question 13. They were also given the option to provide feedback and/or comment on any aspect of the study in a free manner at the end of the questionnaire (question 14). All participants filled out the questionnaire after the EEG experiment procedure. Participants had the possibility to hear the music samples again when filling out the questionnaire to avoid any possible memory bias during evaluation.

3.4 EEG experiment procedure

The experiment was conducted at the Motion Capture Laboratory in the Department of Music, Art and Culture Studies at the University of Jyväskylä, Finland. Prior to the experiment, participants were seated, and the electrodes were placed on their scalp using the international 10/20 system, utilizing a Biosemi Active Two 64-channel EEG device (Biosemi, Amsterdam, Netherlands). The sampling rate was set to 512 Hz.

Electrode impedances were kept below 20 kΩ during all recordings, with only six electrodes slightly exceeding this threshold. Two electrodes, Common Mode Sense (CMS) and Driven Right Leg (DRL), were placed on the posterior brain region prior to recording to replace ground electrodes in the applied Biosemi system.

After setting up the EEG, participants were instructed to listen to the music samples while sitting calmly and trying not to produce any body movement during the experiment. To minimize eye movement during the experiment, participants were instructed to keep their eyes fixated on a self-chosen spot in front of them. Additionally, participants were instructed to avoid excessive eye blinking during the music presentation, although they were allowed to blink their eyes more freely during the eight-second-long silent periods between each music sample. The music samples were played through speakers, and for two of the participants, the audio volume was adjusted down from 100 % to 70 % when asked if the presentation volume of the audio was pleasant. The stimuli were presented in five blocks using E-Prime software linked to the Biosemi system, with each music sample repeated five times in total. The presentation order of the music samples was fully randomized for each block. The total duration of the listening experiment was roughly 30 minutes.

3.5 EEG data pre-processing

EEG data pre-processing was made offline using the EEGLAB toolbox (Delorme & Makeig, 2004) in MATLAB R2020b (Mathworks). Several pre-processing steps were needed to transform the raw EEG data into a cleaner form for the analysis. The following pipeline was used for all the data in the following order:

1. Data were imported and referenced to channel Pz upon import.
2. Data were inspected by eye and made sure that there were no missing or excessively noisy channels in the data.
3. Channel locations were loaded.
4. Sampling rate was set from 512 Hz to 256 Hz.
5. Data was filtered by setting the lower edge of the filtering pass band (Hz) to 1 and the higher edge to 50. DC offset, and epoch baseline was removed prior to filtering.
6. Common average reference was computed offline for all channels.

7. Independent component analysis (ICA) was performed by using the 'runica' algorithm. With the help of the IC label -function, EEG artifacts were identified and removed from the data.
8. Data were segmented into 16-second-long epochs starting from 1 second before and lasting to 15 seconds after the stimulus onset of each event.
9. Channel lz was removed from all datasets due to excessive noise in several datasets, resulting in an equal number of channels (n = 63) per dataset.
10. Common average reference was recomputed after channel removal.

In EEG, the voltage measurements of the electrodes are always related to other electrodes, which act as reference electrodes. The common average reference means that the average of all the electrodes is used as a reference point. It is important to explicitly state both the online reference used during the experiment and the offline reference computed afterwards during the analysis stage, since different referencing methods can affect the data (Keil et al., 2014). ICA decomposition is a crucial step in EEG pre-processing, as it enables automated detection of various non-brain components in the data, including eye-, muscle-, and signal noise-related artifacts, which must be removed to increase the signal-to-noise ratio. The IC label function in EEGLAB is a classifier for brain and non-brain components based on extensive previous evaluations of EEG data regarding the components' probability rates. A minimalist approach was adopted when excluding the components, excluding only those containing less than a 1 % probability rate of originating from the brain. This was done to avoid removing real brain signals from the data. Despite the conservative criteria, a substantial number of components were removed. Upon inspecting the first 35 components of each participant, 9.5 components on average were removed per participant.

3.6 Data analysis

The questionnaire data was subjected to descriptive statistical analysis. The mean, standard deviation, and range were calculated for groove- and familiarity ratings of the music samples (questions 1-9) in each groove category and for the remaining questions on the Likert scale (questions 10-12). Furthermore, a two-way ANOVA was conducted using IBM SPSS Statistics (Version 28) to analyze whether groove category and music genre had a statistically significant effect on groove ratings.

Fifteen channels representing motor cortex (Cz, C1, C2, C3, C4, FCz, FC1, FC2, FC3, FC4, CPz, CP1, CP2, CP3, CP4) were selected for EEG data analysis. Specifically, five channels each were associated with the estimated SMA/premotor area, primary motor area, and primary somatosensory area, respectively. *Figure 1* illustrates a scalp topography of electrode locations and the channels of interest.

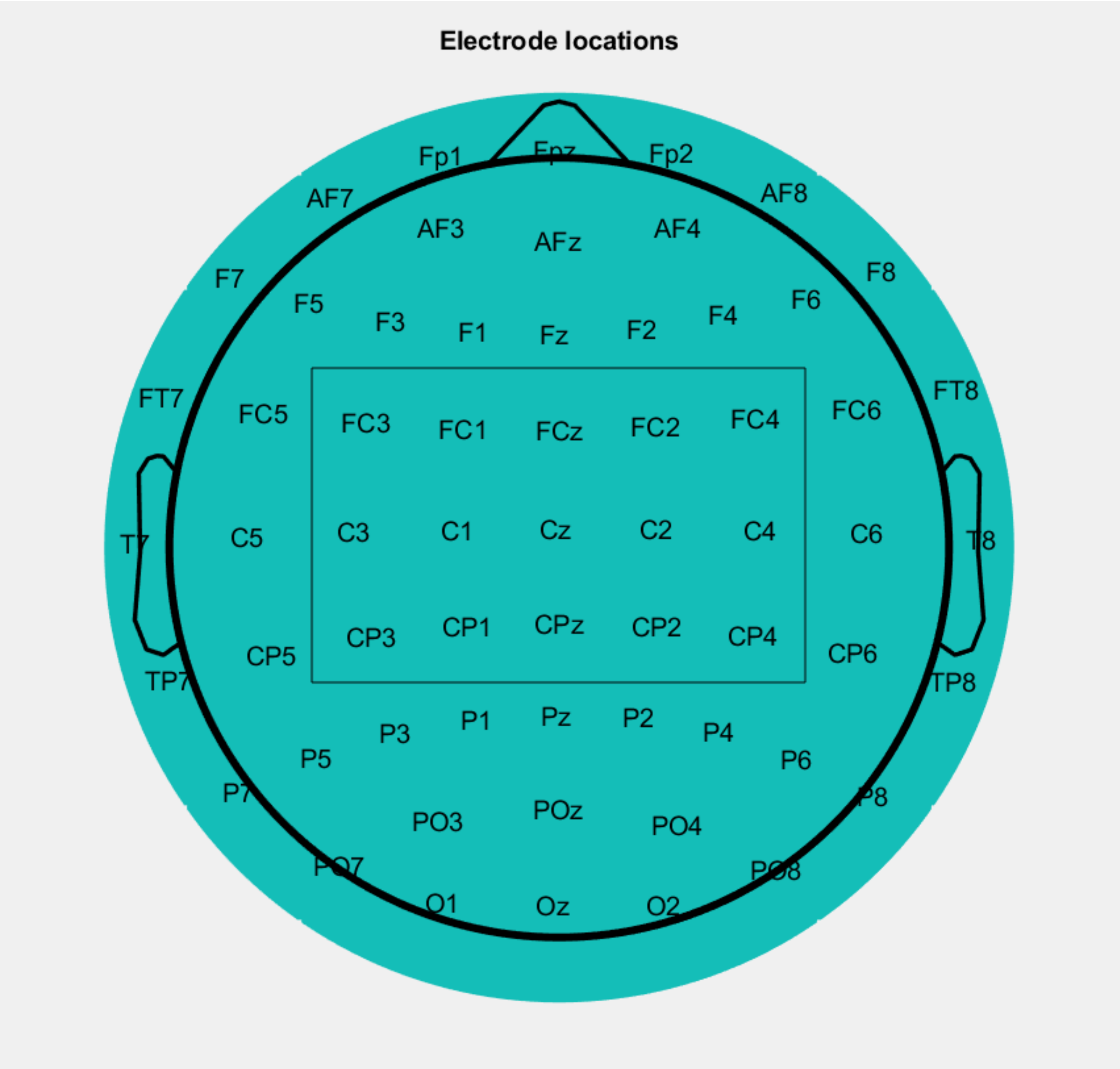

FIGURE 1 Scalp topography of 63 channels (lz removed during preprocessing stage). SMA/premotor (FCz, FC1, FC2, FC3, FC4), primary motor (Cz, C1, C2, C3, C4), and primary somatosensory (CPz, CP1, CP2, CP3, CP4) channels selected for analysis (n = 15) are highlighted by a rectangle.

The data of all subjects underwent power spectral analysis, computed in MATLAB (R2020b) by applying fast Fourier transform (FFT) to transform temporal information into frequency domain. First, power spectra were analyzed qualitatively through data visualization. Second, the mean power spectra were computed across all trials for each separate channel representing the motor cortex. There were 15 trials in each groove category consisting of three music samples that were presented five times in total per subject. The data were analyzed to determine whether there were differences in beta-band power (16-24 Hz) between high- and low-groove conditions.

All statistical tests for EEG data were performed in EEGLAB using EEGLAB STUDY statistics. Paired t-tests were computed separately for each channel across all trials to compare the mean beta power between high- and low-groove conditions at a group level. Additionally, a two-way ANOVA was computed for each channel across all trials at group level by applying non-parametric bootstrap statistics with the default number of randomizations (n = 2000) to compare the mean beta power between high- and low-groove conditions in two distinct groups: those with substantial musical training (10 years or more) and those with some musical training (0–9 years). Holms-Bonferroni correction for multiple comparisons was applied for all statistical tests to avoid obtaining false statistical significance.

4 RESULTS

4.1 Questionnaire data

The whole group groove ratings over all music genres showed a distinction between groove categories: high groove (mean: 4.73, std: 0.49, range: 2), medium groove (mean: 3.71, std: 1.34, range: 4), and low groove (mean: 3.31, std: 1.26, range: 4). Groove ratings of six participants aligned with the group average for different groove categories, while the ratings of two participants did not match the group average. According to the results, the high groove category was the most distinct and robustly rated of the three, as the relatively small standard deviation (0.49) and range (2) suggest. Only the high and low groove conditions were further analysed as they represented the greatest difference in perceived groove. Groove ratings for individual music samples generally aligned with expectations. However, the low- and medium-groove categories in the funk genre were rated the other way around in relation to a study by Duman et al. (in press). Results from the two-way ANOVA showed that there was no statistically significant interaction between the effects of music genre and groove category ($F(4, 135) = .42$, $p = .80$). However, both music genre ($p = .02$) and groove category ($p = <.001$) had a statistically significant effect on groove rating. The updated list of music samples can be found in TABLE 2, and *Figure 2* provides a visualization of their associated groove ratings. Additionally, ratings for familiarity were higher for high groove conditions (mean: 4.79, std: 0.66, range: 3) than for low groove conditions (mean: 2.83, std: 1.43, range: 4), corroborating the previous findings about the familiarity of music and its positive correlation with groove (Duman et al., (in press); Senn et al., 2018).

Question 10 assessed how easy participants generally find it to move or dance to music (mean: 4.50, std: 1.07, range: 3) and question 11 reviewed their average daily time spent on music listening (mean: 2, std: 0.76, range: 2). However, these questions were not analysed further due to the small differences in participants' responses. Conversely, results from question 12, investigating formal musical training experience (mean: 4, std: 1.41, range: 4), were used to divide participants into two separate groups of equal size for further statistical analysis as previously mentioned when describing EEGLAB STUDY statistics.

TABLE 2 Music samples and respective groove categories based on the results from the current study. Songs that differed in terms of groove category compared to TABLE 1 are highlighted in yellow.

Song	Artist	Genre	Tempo	Groove category
Cool	Gwen Stefani	Pop	112 BPM	Low groove
Somebody that I used to know	Gotye	Pop	129 BPM	Medium groove
Uptown Funk	Bruno Mars	Pop	115 BPM	High groove
Think About It	Lyn Collins	Funk	113 BPM	Low groove
I Just Called to Say I Love You	Stevie Wonder	Funk	114 BPM	Medium groove
September	Earth, Wind & Fire	Funk	126 BPM	High groove
Think	Kaleida	EDM	138 BPM	Low groove
Say My Name	Florence the Machine + Calvin Harris	EDM	126 BPM	Medium groove
Get Lucky	Daft Punk	EDM	116 BPM	High groove

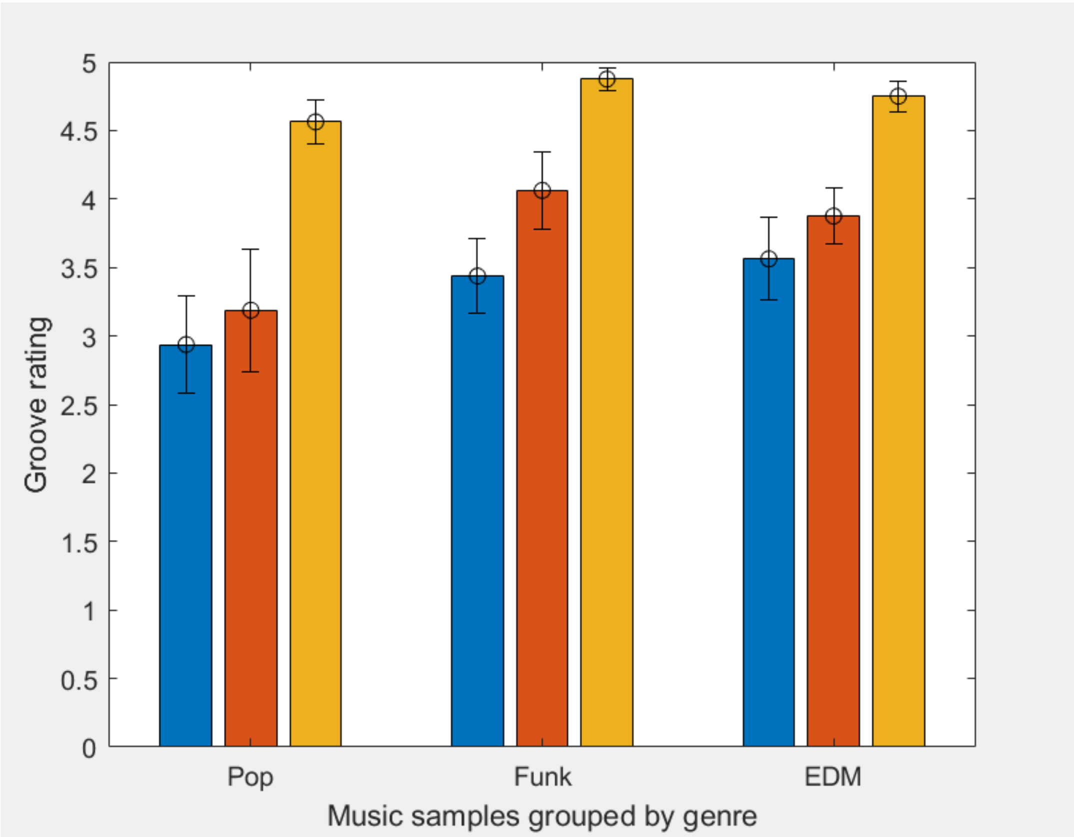

FIGURE 2 A bar graph with standard errors illustrating groove ratings from 1 to 5 in three groove categories (high groove = yellow, medium groove = red, low groove = blue) grouped by music genre (funk, pop, EDM).

4.2 EEG data

Qualitative analysis of mean power spectra showed a general decrease in power from higher to lower frequencies. However, there was a distinct increase in alpha-band power around 10 Hz and a slight increase in beta-band power around 20 Hz (see *Figure 3*). The peaks in alpha and beta were more visually distinct on the left hemispheric motor cortical channels than on the right hemisphere, possibly indicating that participants were right-handed. The whole scalp topographies revealed beta power suppression involving central and bilateral motor cortical areas in relation to surrounding regions (*Figure 4*). Groove did not have a prominent effect on power spectral data when inspecting averaged power over wide alpha- and beta-band frequency ranges purely via data visualization.

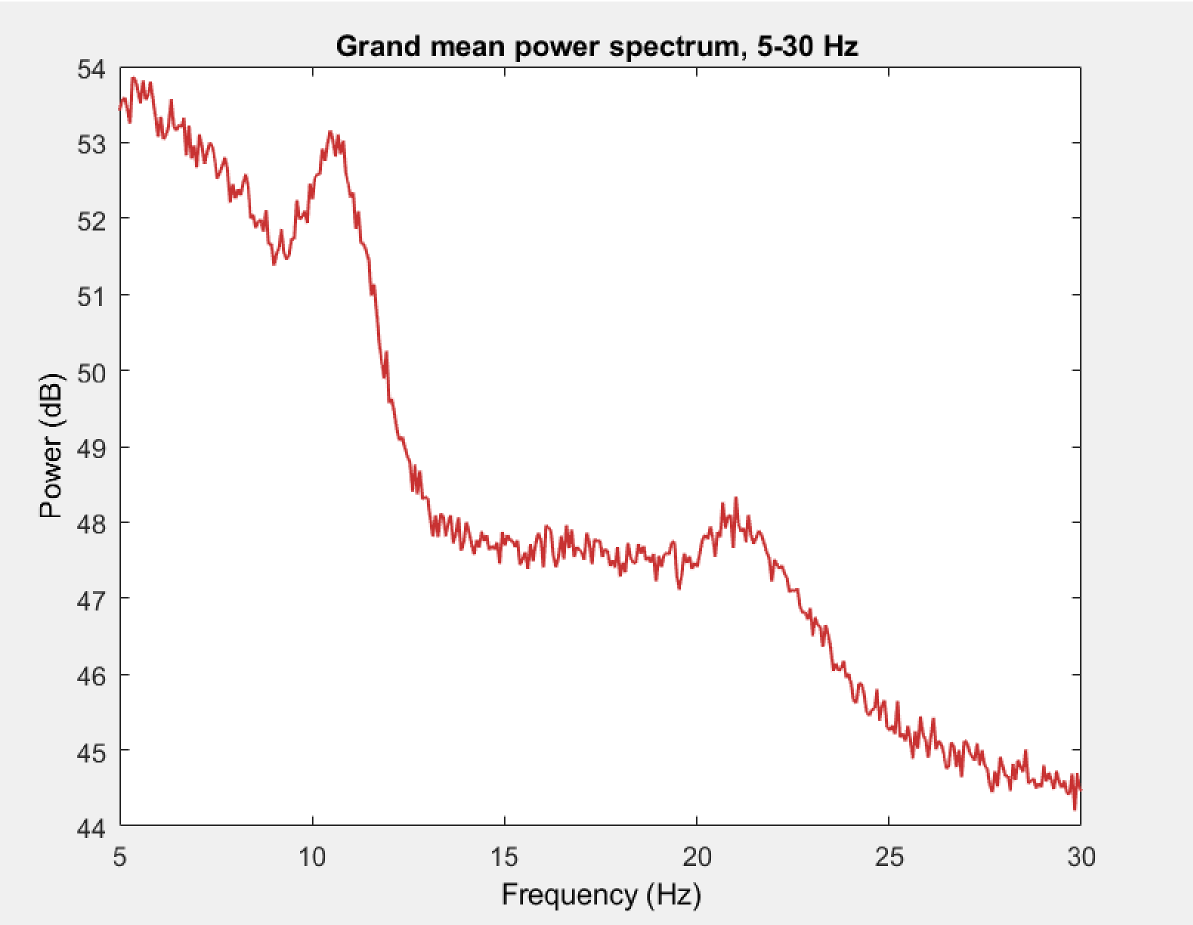

FIGURE 3 Grand mean power (dB) spectrum including all conditions (high groove – low groove) and trials (n = 240), all participants (n = 8), and all channels (n = 15). A distinct increase in alpha-band power around 10 Hz and a slight increase in beta-band power around 20 Hz can be seen.

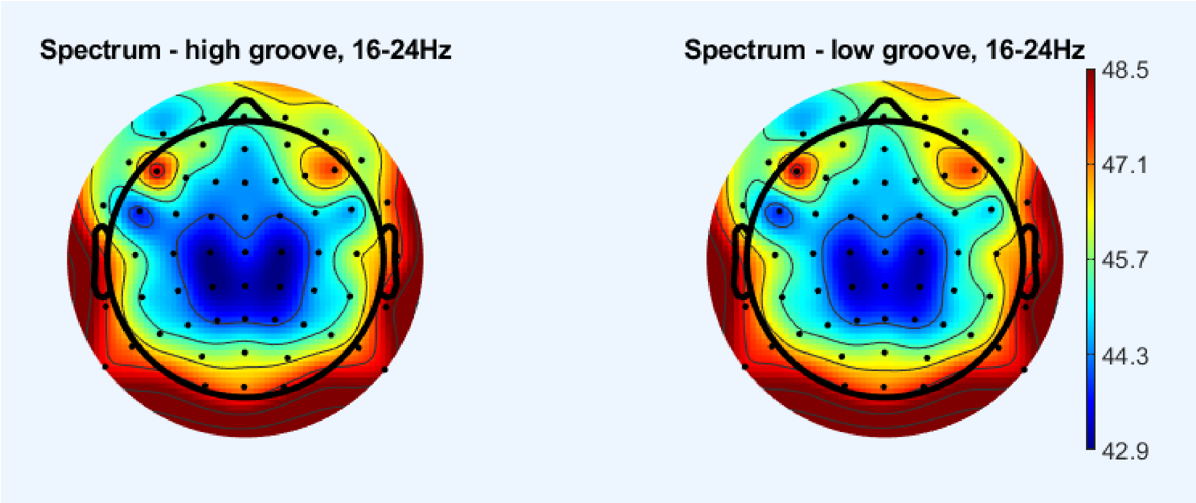

FIGURE 4 Mean group-level power ($10*\log_{10}$ (μV^2)) scalp topographies in high groove (left plot) and low groove (right plot) conditions in a frequency band of 16-24 Hz. While barely showing any differences, both conditions are characterized by power suppression involving central and bilateral motor cortical areas in relation to surrounding regions.

Paired t-tests revealed a significant difference ($p < .05$) in power between the high groove (M= 43.61, SD = 1.99) and low groove (M= 45.24, SD = 1.82) conditions in channel FC1 at 20 Hz frequency ($t(7) = -6.83$, $p = .03$). This result indicates a decrease in power in high groove condition relative to the low groove condition. *Figure 5* illustrates this effect on a whole scalp topographical map.

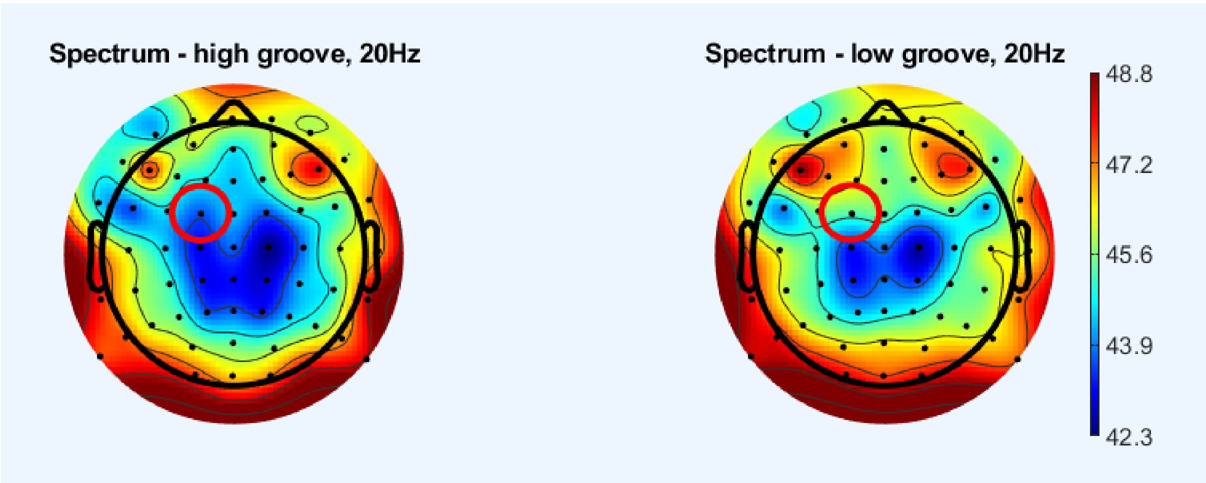

FIGURE 5 Mean group-level power ($10*\log_{10}$ (μV^2)) scalp topographies in high groove (left plot) and low groove (right plot) conditions at 20 Hz frequency. Electrode 'FC1' found to show a statistically significant difference ($p = .03$) between the two conditions is highlighted with a red marker.

A two-way ANOVA for unpaired data showed no statistically significant interaction between the effects of groove category and musical training ($p > .05$). Analysis of the main effects showed that neither groove category nor musical training had a statistically significant effect on mean beta power ($p > .05$).

5 DISCUSSION

The main goal of this thesis was to discover how motor cortical beta power in the brain on a frequency band of 16-24 Hz differs between high- and low-groove conditions during passive music listening. The results suggest that 16–24 Hz beta power on motor cortical channels does not differ between the two conditions, indicating that groove does not play a role in motor cortical beta power within this frequency range.

The current study does not provide adequate evidence to reject the null hypothesis and state that motor cortical beta power is either increased or decreased in high groove condition compared to low groove condition. Furthermore, the statistical significance between the mean beta power in high and low groove conditions in channel FC1 at 20 Hz frequency ($p = .0314$) was not very robust, as the p-value was only slightly below .05. However, considering the theoretic background on motor-related beta peak activity and mu-rhythm beta harmonic typically appearing around this frequency, further investigation may be helpful to fully understand these findings. The possibility that groove plays a role in more precisely defined motor cortical beta characteristics, such as motor-related beta peak or mu-rhythm beta harmonic around 20 Hz cannot be ruled out. While the statistically significant finding in channel FC1 is intriguing, it should be noted that a study by Stupacher et al. (2013) found that musicians showed higher motor cortex excitability when listening to music with high groove compared to music with low groove. While participants in the current study generally had a relatively high degree of musical training experience (10 or more years = 4 participants, 7–9 years = 2 participants, 4–6 years = 1 participant, less than one year = 1 participant), decreased beta power during high groove music listening in channel FC1 at 20 Hz might reflect increased motor-related cortical activity, such as motor imagery. However, it is likely that the current study could not point out any possible differences between participants with varying degrees of musical training experience due to the small sample size and a relatively high degree of musical training experience in most participants.

5.1 Questionnaire

The current study found that groove ratings obtained were generally consistent with expectations, indicating a clear difference between the values in high- and low-groove categories. However, the low- and medium-groove categories in the funk genre showed the opposite pattern in relation to a study by Duman et al. (in press). Thus, “Think About It” by Lyn Collins was rated the lowest in groove, and “I Just Called to

Say I Love You" by Stevie Wonder was rated medium. The difference concerning song order regarding groove was acknowledged during further analysis so that EEG data was reflected upon survey results from the current study, rather than those of Duman et al. (in press) involving a different sample of participants. Considering the relatively small sample size in the current experiment and that funk genre songs were rated relatively high in general (see *Figure 2*), the inconsistency between the medium- and low-groove songs between the studies may not be surprising. The common association between groove and funk might explain why none of the funk songs received a particularly low groove rating. Moreover, the song "Uptown Funk" by Bruno Mars, featuring prominent funk influences, was rated the highest in terms of groove in the pop category.

While groove ratings effectively differentiated between high and low groove conditions, the ratings for low groove remained relatively high (mean = 3.31). One reason for this result may lie in the consistency of the chosen music genres, with each genre including a music sample representing each groove category. Moving and dancing are often fundamental elements in genres such as funk and EDM, and finding low groove songs within these genres may be more difficult than, for example, ambient music. Here, special care was taken to keep musical style and tempo roughly similar across music samples, which may have compromised the ability to catch the full spectrum of groove as defined in the current study.

The desire to move or dance in response to music and music-induced pleasure have been widely accepted in music psychological groove research as indicators for groove. Even if researchers agreed upon the validity of these two terms in describing groove, questionnaires and self-report methods may be problematic due to their subjectivity (Senn et al., 2020). The current study aimed to increase the findings' validity by applying both self-report- and EEG methods for gathering data. Based on the current methodology, conclusions about the data are only related to participants' perception of groove rather than their actual experience. Addressing the experience of groove would be challenging and require additional techniques to support the current methodology, such as measuring the physiological arousal of participants by recording non-brain physiological responses (e.g., Bowling et al., 2019).

The questionnaire utilized a five-point Likert scale due to it being equivalent to the study by Duman et al. (in press), making it easy to compare the groove ratings obtained from the current study with groove ratings previously obtained. However, there are some problems associated with Likert scales: applying ordinal data such as Likert scales can lead to misinterpretations when analyzed with parametric statistics (Allen & Seaman, 2007). Moreover, Likert scales are likely not the most optimal method for assessing the degree of musical training in years due to the wide range of participants' musical training. Consequently, using a Likert scale may result in vagueness of the results, especially regarding the more experienced musicians whose musical experience may exceed the given scalar value.

5.2 EEG experiment

The research design of the current study differs from many other EEG-based studies that have focused on the neuronal processing of auditory stimuli, including music. Many EEG-based studies, especially ERP (event-related potential) studies, focus on small time windows and oscillatory activity at a millisecond level when inspecting brain responses to musical stimuli. In such studies, it is typical to analyse data epochs that last only a few seconds. In contrast, the current study analysed whole 16-second-long data epochs to capture the average brain activity during listening to different music samples, rather than brain responses to temporally specific musical events, such as the downbeat of a rhythm or the beginning of a chorus. Although the experience of groove may not be measurable at a millisecond level, studying shorter EEG data epochs could be beneficial considering the temporal characteristics of music and brain oscillatory activity. For example, musicians' motor cortex excitability during high groove music listening has been shown to be higher when they received transcranial magnetic stimulation (TMS) during on-beats rather than off-beats (Stupacher et al., 2013). Beta-band suppression during movement-related activity and the subsequent increase in power occurs in less than one second (Neuper et al., 2006). By computing only the mean power of long EEG data epochs, the sensitivity to detect temporal dynamics in beta activity may be compromised. Additionally, using 25-second-long music samples in the current study resulted in fewer trials than what is typically expected from EEG-based studies, where subjects are exposed to hundreds of short trials lasting only a few seconds or less. Therefore, the relatively small sample of participants and small quantity of trials in the current study make it rather exploratory, which must be acknowledged when interpreting the results.

Non-parametric statistical tests, such as permutation tests and bootstrapping, have been recommended for EEG data analysis as an alternative for traditional parametric statistical tests. The advantage of non-parametric tests is that they do not assume a specific data distribution, making them a safer choice compared to parametric tests, which assume Gaussian data distribution. Traditional parametric paired t-tests were used in the main analysis since running permutation tests multiple times on the same data seemed to return different p-values, making the results unstable. However, non-parametric bootstrapping was applied in the secondary analysis involving participants' musical training experience, as it was the only statistical method in EEGLAB providing for a two-way ANOVA design. Holms-Bonferroni correction was used to tackle the multiple comparisons problem since it represents a slightly more powerful method than Bonferroni correction, which can be overly conservative.

Impedance levels were generally kept below 20 kΩ, though a few electrodes slightly exceeded this threshold. Relatively high impedance levels in the current study increased the risk of excessive noise in the data. While motor-cortical electrodes were of main interest in the current study, precise claims about how various motor cortical regions or subregions contributed to the results cannot be made. EEG is known for its relatively low spatial resolution compared to some other brain imaging methods, such as MRI and DTI. Furthermore, the standardized electrode caps used in this study are not sensitive to possible individual differences, such as head shape, which may influence how the electrodes are located on the scalp.

5.3 Relevant musical and non-musical factors

The analysis in the current study primarily focused on differences between the music samples based on condition (groove categories) rather than specific sound-related properties. Musical structures, musical features, and other sound-related factors within the auditory signal of each individual music sample were not analyzed. Although several studies have investigated the link between musical features and groove, analyzing such factors serves an important function, especially when novel music samples that have not been previously used across several studies are being applied in groove research. For instance, musical features such as tempo might have influenced beta-band activity despite efforts to keep tempo fluctuations minimal between the music samples. For example, "Think" by Kaleida had a relatively high tempo (138 BPM) compared to the other music samples, which may have contributed to the findings.

Listening to music and experiencing movement-inducing sensations typically occurs in a different environment and situation than that of a standard research setting. Music listening in a traditional EEG study may differ from a real-life event in various ways: participants listen to music alone while being observed, participants' movements are restricted, and the songs are predetermined and not chosen by participants. Notably, the significance of movement in groove raises questions about whether it is reasonable to study the phenomenon in passive music listening conditions where movement is restricted. Fitch (2016) has stated that rhythmic elements in music including groove cannot be truly understood without the study of dance, which has traditionally served a fundamental purpose as an accompaniment to music in most cultures. Even if participants were instructed to do nothing other than listen to music (like in the current study), their attentional processes during the experiment may differ from typical music-listening situations. For example, participants may try to guess the aim of the experiment and critically evaluate the music samples from this standpoint, which may influence behavioral and neuronal processes. Certain studies focusing on music-induced movement have addressed this issue by making the research setting resemble a real-life environment as much as possible (e.g., Hove et al., 2019; Solberg & Jensenius, 2019; Swarbrick et al., 2019). Although it is well known that EEG is sensitive to movement-induced artifacts and noise in the signal, dance experience should be studied more directly (see Stupacher, Matthews, Pando-Naude, Foster Vander Elst, & Vuust, 2022), and more naturalistic environments should be considered in future groove studies.

Individual differences in participants are often unexplored, even if they are very similar in terms of demographic information and musical training experience and undergo exactly the same experimental procedures. For example, personality may play a role in musical movement and its characteristics, with extroverted participants being more prone to produce more spontaneous movement during music listening than neurotic ones (Luck, Saarikallio, Burger, Thompson, & Toiviainen, 2010). Attentional factors related to the cognitive processing of auditory stimuli also vary among individuals. According to Fukuie et al.'s study (2022), some people benefit from listening to groove rhythms as indicated by better executive function performance, while others do not show this effect or might perform even worse. Listening to high groove stimuli could possibly improve executive function by increasing arousal, boosting positive mood. Alternatively, the opposite may happen, draining cognitive capacity, leading to poorer executive function (Fukuie et al., 2022). Different factors, such as whether participants perceived the music as ‘groovy’ and were positively affected by it or if they needed to pay extra attention to beat processing during the listening might have influenced the results (Fukuie et al., 2022). Returning to the current study, it may not be clear whether people suppressing their motor functions or imagining movement while listening to groovy music is dependent on factors such as musical training, musical preferences, or song familiarity. Individual differences in various cognitive properties, such as attentional processes taking place during the experiment, may also influence differences in beta power.

5.4 Conclusion

This thesis explored how motor cortical beta power in the brain, within a frequency band of 16–24 Hz, differs between high- and low-groove conditions during passive music listening. According to the results, the mean motor cortical power in this specified beta range does not differ significantly based on whether people listen to music they perceive as more or less groovy. However, further research is needed to confirm whether groove plays a role in motor-related beta peak activity or mu-rhythm suppression at ~20 Hz frequency. Future studies should employ a larger and more diverse sample of participants and evaluate them in terms of musical and dance training, preference of moving to music, personality traits, and other possible groove-related factors. Analysing shorter EEG data epochs could provide a better understanding of the temporal characteristics during neuronal processing of groove. Additionally, studying various musical features related to groove should be continued due to the complex relationship between music listening and associated brain processes. Applying more naturalistic research settings that involve socializing and dancing could improve researchers' ability to capture the essence of groove better, although it may compromise the recording quality of EEG-based systems.

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