Effect of tDCS of the SMA on Groove Perception for High and Low Groove Music

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Abstract

Groove is said to be the quality of music related to the psychological and physiological reactions of listening to music, such as feelings of pleasure and the urge to move. This study assessed the effects of Transcranial Direct Current Stimulation (tDCS) manipulation of the Supplementary Motor Area (SMA) on ratings of the urge to move, pleasure and familiarity in the presence of low or high-groove music. The study compared the mean ratings of the urge to move, pleasure and familiarity related to low and high-groove songs, either during tDCS anodal stimulation or without stimulation. The results showed a main effect of mean ratings of the urge to move and pleasure for low compared to high groove music. However, the results showed significant differences between the mean ratings of the urge to move and pleasure for the high groove anodal/stimulation and high groove sham/no-stimulation conditions. The findings highlighted the effect of tDCS on the SMA but only for high-groove songs, supporting the SMA's role in groove perception and its influence to some extent over the reward network associated with feelings of pleasure.

Effect of tDCS of the SMA on Groove Perception for High and Low Groove Music

Music is a cultural universal; it can alter our mood, elicit feelings of pleasure, and make us want to move along to the beat (Basaglia-Pappas et al., 2013). The desire to move along to the beat is a common experience that most individuals have encountered while listening to music they enjoy. These feelings of pleasure, coupled with the desire to move, have become known as groove (Pressing, 2002). Groove is a versatile term; one can describe music as groovy or being in the groove; many studies have assessed the different characteristics of music that contribute to groove. However, relatively few have assessed the subjective qualities that underlie the individual perception of groove (Brattico & Jacobsen, 2009).

Additionally, the processes by which music processing occurs and the specific brain regions involved in its interpretation are still not well understood. Furthermore, the relationship between groove and feelings of pleasure is mediated by subjective factors such as familiarity to an unknown degree (Senn et al., 2021). This relationship motivated the present research, which will attempt to ascertain the nature of the relationship between familiarity and pleasure elicited by groovy music using cortical modulation of the Supplementary Motor Area (SMA).

Groove

Groove is a central concept in music psychology, having been used to describe music since the beginning of the 20th century. Originally, groove referred to music such as jazz or funk and its quality of being readily danceable. Researchers Camara and Danielsen (2018) stated, "a groove is not a groove until it actually grooves; that is, it is experienced as groovy." This statement highlighted how groove could be used in a normative manner to judge music and to say that music can put individuals in a state of being in the groove. Pressing (2002) defined groove as a temporal cognitive phenomenon characterised by the perception of a consistent beat,

recurring rhythmic patterns, and a tendency to elicit movements such as foot tapping or dancing. As its use in music psychology increased, it became operationally defined as "wanting to move some part of the body in relation to some aspect of the sound pattern" (Madison, 2006, p. 201). This definition focuses on groove as movement, either of some body part or the intention to move shown by activity in the motor network. Janata et al. (2012) added a dimension of musically-elicited emotions by defining groove as "the pleasant sense of wanting to move along to the music." Groove was thus divided into two main dimensions: feelings of pleasure and the urge to move (Senn et al., 2020).

Groove and pleasure

Multiple studies have confirmed music's association with emotion and affect; for example, Saarikallio and Erkkilä (2007) showed a correlation between music preference and mood regulation in adolescents. The study went on to demonstrate how adolescents' music choices were correlated with both their present and desired emotional state. The study concluded that music created intense affective experiences, primarily through its influence on emotional valence by shifting it towards positive emotions. Groove has been proposed as one of the most potent sources of music-derived pleasure (Janata et al., 2012). Pleasure is better described as a broadly positive affect; Blackburn (2008) described pleasure as "a quality of consciousness, intimately connected to contentment or happiness". Pleasure reactions can be psychological, such as happiness, or physiological, such as chills; both constitute a positive affective response to music. A study by Madison (2006) showed via self-report measures that are experiencing rhythmic music, or music with moderately complex rhythms associated with groove, is associated with increased pleasure and correlates with activity in the brain's reward system. The physiological expression of pleasure in response to music with groove is shown by the sensation

of chills, a phenomenon characterised by transient pleasurable somatosensory responses associated with intensely positive emotions (Grewe et al., 2007). Grewe et al. (2007) assessed the correlation between the physiological reaction of chills and its psychological component of intense emotions via Skin Conductance Responses (SCRs) and self-reports of chills by participants. The results showed that 21 of the 38 participants experienced chills in response to a selection of classical music representing 399 self-reported chill events, of which 291 corresponded to a visible SCR. These two studies further demonstrate how music with groove can elicit feelings of pleasure and how these feelings can be expressed in multiple ways. While there is some research on groove and pleasure, most of the research has focused on understanding its association with the urge to move and not its relationship with pleasure or the factors that influence this relationship.

Groove and the urge to move

Groove is defined by its combined effects of eliciting feelings of pleasure and the urge to move; however, the connection between these psychological and physiological effects continues to pose questions. The lack of understanding of the overlap of these two types of effects led researchers to propose a hybrid model in which instead of two effects co-occurring, they are part of the same effect, Sensorimotor Coupling (Janata et al., 2012). Researchers Janata et al. (2012) posited that the feeling of being in the groove, a pleasing state in which creating music becomes effortless, was the outcome of the coupling of sensory and motor systems. This model posits that the combined effects of sensory systems' perception of groove in music and the urge to move associated with the motor systems strongly correlate with the resulting feelings of pleasure. The nature of the relationship between the perception of groove in music activating the motor

systems, specifically the SMA and pleasure activating the reward systems is poorly understood. However, what qualities of music with groove induce this urge to move?

Groove's association with the urge to move and bodily movements necessitates the presence of a regular beat to guide these movements (Camara & Danielsen, 2018; Witek, 2013). Madison et al. (2011) assessed the mean tempo of a wide range of music and concluded that dance music, such as EDM or hip-hop, ranged in tempi from 60 to 200 beats per minute (bpm). Janata et al. (2012) found that the mean tempo for selecting high-groove music was 115 beats per minute.

Another characteristic of groove is its metrical structure, its rhythmic aspects such as complexity and repetition, and the subdivisions of the beat (Madison et al., 2011). Music rated as having a high groove regularly has either one or more repetitive rhythms (Pressing, 2002; Madison et al., 2011; Iyer, 2002). The addition of sound events occurring at faster rates than the beat of the music, otherwise known as subdivisions of the beat, are another common feature of groove (Pressing, 2002; Camara & Danielsen, 2018). These subdivisions of the beat impart a rhythmic drive or motivational energy, or the urge to move, to groove (Danielsen et al., 2015).

The most researched characteristic of groove is syncopation, or local contradictions of meter (Stupacher et al., 2016; Witek, 2013; Madison & Sioros, 2014). Syncopation is best described as a displacement of the metrical structure's regular or on-beat accent by purposefully stressing the offbeat to surprise the listener by violating metrical expectations. The degree of syncopation is significant in perceptions of groove; overuse will result in lower ratings of pleasure and groove. Multiple studies have found that moderate levels of syncopation are optimal for groove, while high levels of syncopation decreased ratings of groove (Witek, 2013; Stupacher et al., 2016; Janata et al., 2012; Camara & Danielsen, 2018). The researchers posed that

syncopation may mediate the relationship between pleasure and the urge to move. The urge to move elicited by groove shows itself through the motor's activation, and feelings of pleasure activate the reward systems (Matthews et al., 2020). While research showed the correlation between the urge to move and the SMA, there is no consensus on how feelings of pleasure relate to the activity in the SMA while listening to music with groove.

SMA

The SMA is a part of the motor network and is hypothesised to be one of the areas involved in producing voluntary movement (Cunnington et al., 1996). A study conducted by Rao et al. (1997) investigated which brain regions were involved in timing or time perception using a rhythmic tapping task. The researchers first had participants tap in synchrony with tones at consistent intervals; next, participants had to continue tapping without the auditory cue. The results of the second task showed activation of the medial premotor system, including the SMA and left putamen, paving the way for further research on the SMA's role in timing. A similar study conducted by Dhamala et al. (2003) measured participants' brain activity as they performed two tasks involving rhythmic tapping during an fMRI scan. The first task was a rhythm production task involving tapping at a consistent rate. In contrast, the second task was a rhythm perception task involving tapping rhythms of varying complexities from memory. The results of the second task showed activity in the primary motor cortex, pre-SMA/SMA, basal ganglia, and cerebellum, furthering its implication in time perception. Coull et al. (2004) studied time perception. They found that the motor areas, namely the SMA and premotor cortex, the basal ganglia, and the cerebellum, were consistently active during attention-to-time tasks. These three studies consistently implicate various motor areas, namely the SMA, in time perception tasks

even without an auditory stimulus, meaning timing must occur internally and suggesting the presence of an internal beat.

Furthering this research, a study by Grahn and Brett (2007) investigated whether specific motor regions, the basal ganglia and pre-SMA/SMA would respond during a rhythm reproduction task if there were regular perceptual accents, the same interval between each accent, present or not. The study had three conditions: a simple metric rhythm with regular perceptual accents, a complex metric rhythm with irregular perceptual accents, and a nonmetric rhythm with non-integer intervals of irregular perceptual accents. The results supported the hypothesis that significantly more simple metric rhythms would be accurately reproduced than the other rhythms. These results suggest that a regular beat may have been induced in participants by the simple metric condition, specifically the presence of regular perceptual accents. The fMRI scans showed that listening to simple metric rhythms significantly increased bilateral activity in the basal ganglia, anterior superior temporal gyri, and the pre-SMA/SMA compared to the metric complex and nonmetric conditions. Musicians showed significantly greater activation in the pre-SMA/SMA and bilateral cerebellum than non-musicians.

These four studies support the theory that the pre-SMA/SMA and basal ganglia may be involved in detecting or generating an internal beat. The SMA is involved in internal beat perception and production, but its role in music perception is unknown. Additionally, research has yet to study the SMA's role in groove. Its role in beat perception as part of the motor system and its recent involvement in auditory processing, as shown in a study by Lima et al. (2016), suggests its role in music perception and a potential role in groove perception. As the SMA activates when listening to music with groove, as does the reward system. Thus the question

becomes whether modulation of the SMA would result in a change in ratings of pleasure associated with groove.

Familiarity

Familiarity is a very subjective concept; concerning music, some researchers have defined it as a matter of frequency. For example, Ruozao (2018) defined familiar songs as those an individual has listened to more than 15 times. For this study, familiarity is operationally defined as the ability to recognise a song after listening to no more than 10 seconds of it. Research on familiarity with music is relatively limited in scope, covering primarily its relationship with groove or its influence on the subjective appraisal of music (Senn et al., 2021; Pereira et al., 2011). There is a research gap on how familiarity influences pleasure derived from music and its role in the pleasure-groove relationship. Past research on familiarity and groove has uncovered a phenomenon known as the mere exposure effect, best described as a positive bias towards music an individual has heard before (Peretz et al., 1998). Familiarity mediates participants' ratings of groove; musicians rate familiar songs with more syncopation or a more complex metrical structure as higher in groove (Senn et al., 2021; Davies et al., 2013). A study conducted by Senn et al. (2018) on the influence of different musical and listener-related factors on ratings of groove found that listener-related factors such as familiarity had a significantly stronger effect on ratings of groove. Senn et al. (2021) assessed the effects of familiarity and musical experience on participants' groove ratings. The study showed that the main effect of familiarity was the most potent predictive factor in ratings of groove, accounting for nearly eight percent of the variance. In sum, as participants' familiarity with a piece of music increases, so does their groove rating, but whether that is both their ratings of the urge to move and pleasure or just one of them is unknown. Pereira et al. (2011) investigated the influence of familiarity and

musical preferences in musical enjoyment using mainstream pop/rock songs. They assessed the influence of these two factors by their activation of the limbic, paralimbic, and reward system areas using the BOLD response in those regions. The results showed that most BOLD responses were associated with familiar music rather than music that fit the participants' preferences, thereby showing the crucial role of familiarity in music enjoyment or pleasure derived from music. Past studies have shown familiarity to be a mediating factor for ratings of groove, but whether familiarity plays a role in both the urge to move and pleasure and if groove type plays a role in the perceptions of familiarity is still unknown. It would be beneficial to use cortical modulation methods such as Transcranial Direct Current Stimulation (tDCS) to understand better familiarity's role in groove perception and perceptions of the urge to move and pleasure derived from listening to familiar music.

tDCS

In contrast to fMRI, which provides correlational data through BOLD responses in brain regions, tDCS works to identify brain-behaviour relationships by cortical modulation and thus provides more causational data. tDCS is a cortical modulation tool that uses weak electrical stimulation to alter cortical activation thresholds and produce either facilitatory via anodal stimulation or inhibitory effects via cathodal stimulation (Thair et al., 2017). tDCS provides a non-invasive method to assess brain-behaviour relationships through reversible cortical manipulation. It uses a weak electrical current to stimulate shallow brain structures from a target electrode or montage of electrodes. Electrode placement typically follows the 10:20 EEG system, an internationally recognised method for standardising electrode placement. It maps electrode placement propositional to skull size allowing inter-electrode spacing to be consistent (Rich et al., 2017). Participants' skulls are measured before electrode placement to allow the identification

of the target region. Some studies include an MRI scan of participants for greater accuracy. Others may use Transcranial Magnetic Stimulation (TMS) for identification, especially when the target is the motor region (Thair et al., 2017). tDCS current density is essential; research suggests that a minimum of 0.017 mA/cm^2 is necessary for cortical modulation to occur, and as current density increases, so do its effects (Nitsche & Paulus, 2000). The electrodes used in tDCS vary according to the size and shape of the target region but also depending on the spatial locality desired (Thair et al., 2017). A typical montage employs a smaller target electrode and the larger reference electrode to ensure a more focused current and prevent accidental stimulation of the reference electrode. However, HD-tDCS or ring electrodes have been employed, comprised of five small electrodes in a four-cathode and one anode setup or vice versa (Villamar et al., 2013). This montage has enhanced spatial focus due to the other electrodes suppressing surrounding regions to focus better on the modulated region (DaSilva et al., 2015). tDCS carries risks; cortical modulation's effects last longer as modulation's duration increases, and modulation's safety also depends on current density and electrode size (Poreisz et al., 2007). The present study will use an HD-tDCS montage to provide anodal stimulation to the SMA while participants listen to familiar or unfamiliar music.

Present Study

The present study investigated the effects of tDCS manipulation of the SMA on resulting ratings of the two components of groove and familiarity to control as a control and to help identify outliers. The relationship between the SMA and groove is not well understood; it was shown that the SMA, along with parts of the motor and reward networks, are active while listening to music even if the individual is not moving (Camara & Danielsen, 2018; Witek, 2013; Janata et al., 2012). Furthermore, the present study extended a recent study, using real music

rather than just drum beats to replicate the findings and generalise them to the real-world population. The study also assessed whether groove type was associated with ratings of familiarity. The musical excerpts were all from the top 100 billboards ensuring they had a high chance of familiarity. Familiarity acted as a measure of musical preference for high or low groove. It was also kept constant to prevent the influence of the mere exposure effect from altering ratings of pleasure, specifically for familiar music.

Additionally, research on the SMA and its role in beat perception and generation are limited in scope, with little research on its relationship with the components of groove, the urge to move and pleasure. This present study used tDCS anodal stimulation to uncover the SMA's role in the perception of both aspects of groove and how stimulation changes ratings of the urge to move, pleasure and familiarity in the presence of low and high groove music. tDCS was chosen due to its ability to manipulate shallow brain regions non-invasively by altering action potential thresholds and thereby better understand the hypothesised brain-behaviour relationship. The present study attempted to fill part of the gap in research on groove and the SMA through the central research question. How does stimulation of the Supplementary Motor Area (SMA) with Transcranial Direct-Current Stimulation (tDCS) affect participants' ratings of the urge to move and pleasure and their familiarity with low compared to high groove music?

There are three hypotheses regarding the effects of tDCS stimulation of the SMA on ratings of the urge to move, pleasure and familiarity. Firstly, mean ratings of the urge to move and pleasure will be significantly higher during the high groove conditions than the low groove. Secondly, ratings of the urge to move and pleasure will be significantly higher during the anodal than sham conditions. Lastly, a significant interaction effect between groove and stimulation type will be present and result in significantly higher mean ratings of the urge to move and pleasure

during the high groove anodal as compared to the high groove sham conditions and the low groove anodal as compared to the low groove sham conditions.

Methods

Participants

Fifteen undergraduate students participated in this study (10 female; 5 male), and one participant withdrew during the session due to personal reasons. Participants were all undergraduates from the University of Western Ontario, ranging in age from 18 to 23 years old (M = 19.1; SD = 1.53). Participants were recruited using SONA, the Department of Psychology's research participation pool, and were compensated with two research credits, one per hour of participation. Participants were provided with an LOI (see Appendix A) before beginning the study as part of a preliminary demographics questionnaire. All participants had normal hearing, with only one participant reporting that their ears had been ringing recently. Participants with metallic implants, a history of neurological disorders such as ADHD and Epilepsy, taking prescription psychotropic medication, a history of migraines and skin conditions such as eczema will be excluded. This study was approved by the Western University Research Ethics Board (see Appendix B).

Stimuli

Song Stimuli

All 40 song excerpts were taken from the top 100 billboards over the last five years to control for familiarity and mere exposure effects (see Appendix C). Songs were downloaded from YouTube and then cut into 10-second excerpts using Adobe Audition (Adobe Inc., 2003). Due to the lack of research on the factors underlying the perception of groove, this study used subjective feel to categorise low and high-groove music. On average, the low groove music was

similar in tempo, ranging from 60 to 100 bpm, and the high groove music ranged from 100 to 140 bpm.

Questionnaire and Responses

Participants will complete a Qualtrics questionnaire detailing demographics (age, sex, dominant language) and musical experience. After each song excerpt is played, a set of three statements with a corresponding 10-point Likert will be presented to participants (1 = *completely disagree;* 2 = *strongly disagree;* 3 = *disagree;* 4 = *slightly disagree;* 5 = *neutral/no opinion;* 6 = *slightly agree;* 7 = *somewhat agree;* 8 = *agree;* 9 = *strongly agree*; 10 = *completely agree*). The statements will be "This music makes me want to move some part of my body", "This music is pleasurable", and "I am familiar with this music". After the sham condition's 40-song excerpts have been played, participants will answer a questionnaire on their experience with tDCS throughout the study. The questionnaire asked participants if they knew which stimulation type they had received and if there were anything they would like the researchers to know. Whether participants could accurately identify the stimulation type was a measure of how easily discernable stimulation conditions were and helped control for demand bias. At the end of the second session, participants had to repeat the questionnaire they completed after the first session,

Stimulation

This study will use a tDCS machine to manipulate the cortical excitability of the surface regions of the SMA, delivering 2.0 mA for 20 minutes resulting in a total dosage of 40 mA. The tDCS montage will be set up according to the 10-20 EEG international system and will consist of two electrodes, the Anode placed on the SMA and the Cathode above the right eyebrow.

Procedure

After providing written consent, participants' scalps will be measured to locate the ROI, the SMA, according to the 10-20 EEG international system. Participants will then be fitted with two electrodes, an anode and a cathode; these electrodes will be saline-soaked to increase comfort and ensure proper current conduction through the scalp. The Anode will be placed on the SMA, and the Cathode will act as a reference electrode placed above the right eye on the forehead. The electrodes will then be secured with rubber straps to remain in place. The experiment will consist of two successive sessions, both lasting 20 minutes. The first will be a sham (control) condition in which stimuli will be presented without stimulation. To control for potential participant bias, the participant will not know which session is anodal or a sham. Once the session begins, participants will rate 40 music excerpts one by one according to their urge to move, pleasure and familiarity with the music. After the sham session, participants will answer whether they thought it was the sham or the anodal session to better control for potential participant bias. Next, participants will undergo the anodal session, during which the same 40 musical excerpts will be presented (see Appendix C), and the same procedure will be followed. The anodal session will be conducted with participants receiving a two-milliampere direct current flowing through the anode electrode to the cathode electrode for 20 minutes.

Analyses

After data collection, results were filtered into usable spreadsheets and incomplete datasets were removed using RStudio (Posit PBC, 2011). Next, RStudio was used to calculate the means of the three 10-point Likert scales for each participant based on groove and stimulation types across all 40 song excerpts. Once the means had been calculated, the spread function from RStudio's tidyverse package was used to organise data by the participant and allow for further

analysis (Wickham, 2019). The data were then imported to Jamovi for further analysis (The Jamovi project, 2022). A repeated measures ANOVA was then conducted, and significant effects were further analysed using a Tukey HSD test.

Results

This study involved two sessions, first without stimulation as a sham and second with stimulation, high and low groove music was used. This study used a within-subjects design, and thus the results were calculated using a repeated measures analysis of variance (ANOVA).

Urge to Move

The results of the repeated measure ANOVA for the urge to move variable showed a significant effect for groove type, F (1,13) = 37.24, $p < .001$, $\eta^2_p = .74$. The results showed no significant effect for stimulation type, nor a significant interaction between groove and stimulation type. A paired samples t-test was conducted to verify the findings, which showed that the high groove sham and the high groove anodal conditions were significantly different, $t(13) = -2.62$, $p = .021$. However, the low groove sham and low groove anodal conditions are not significant. Additionally, two participants were found to have more than five years of musical experience. Thus an additional ANOVA was conducted excluding these participants, which yielded similar results. Groove type was still significant F (1,11) = 35.63, $p < .001$, $\eta^2_p = .76$, but stimulation type was shown to be marginally significant, F (1,11) = 3.16, $p = .10$, $\eta^2_p = .22$, there were still no interaction effects present.

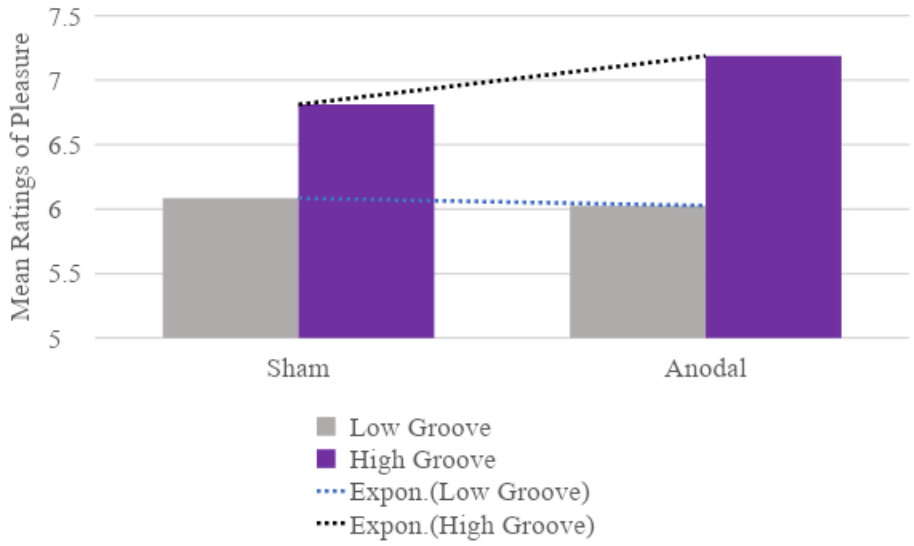
Pleasure

The results of the repeated measures ANOVA for pleasure showed a significant effect for groove type, F (1,13) = 5.50, $p = .04$, $\eta^2_p = .30$. In contrast, no significant effect was found for stimulation type. However, there was a significant interaction between groove and stimulation

type, F (1,13) = 9.57, p = .009, η^2_p = .42. A post hoc Tukey HSD test found that the mean rating of pleasure for the high groove sham condition (M = 6.81; SD = .94) was significantly different from the mean ratings of pleasure for the high groove anodal condition (M = 7.19; SD = 1.15), p = .04. Compared to the differences in mean ratings of pleasure for the low groove sham and low groove anodal conditions which were not significantly different. Lastly, as research has shown the effects of musical experience on ratings of groove, and with pleasure being one of the two aspects of groove, an additionally repeated measures ANOVA was conducted excluding the two participants with more than five years of musical experience (Grahn & Brett, 2007). The results showed that groove type was still significant, F (1,11) = 5.89, p = .03, η^2_p = .35. Additionally, the results modelled the trend towards significance for stimulation type. In contrast, the significant interaction between groove and stimulation types was stronger, F (1,11) = 10.51, p = .008, η^2_p = .49. This trend may reflect the effects of musical experience on musical preference or perceptions of groove in music.

Figure 1

Mean Ratings of Pleasure Across Groove and Stimulation Type



Note. The above figure shows this study's pleasure ratings results across both groove and stimulation-type conditions. The trendlines help visualise the results found, and the upper trendline shows the significant difference between the means of the high groove sham and high groove anodal conditions. Unlike the original 10-point Likert scale, this figure's range is narrowed to help visualise the relationship.

Familiarity

The results of a repeated measures ANOVA for familiarity showed a significant effect for groove type, F (1,13) = 12.41, $p < .05$, $\eta^2_p = .49$, there was no significant effect for stimulation type and no interaction effect between groove and stimulation type for ratings of familiarity. However, stimulation type was close to significance, F (1,13) = 4.26, $p = .06$, $\eta^2_p = .25$. Similarly, the interaction between groove and stimulation type conditions was also close to significance, F (1,13) = 4.41, $p = .06$, $\eta^2_p = .25$. A Tukey HSD post hoc test was conducted due

to both the stimulation type and the interaction between groove and stimulation type being close to significance. The post hoc found that mean familiarity ratings were significantly different for the high groove sham (*M* = 7.15; *SD* = .77) and high groove anodal conditions (*M* = 7.57; *SD* = .97), *p* = .021. However, mean familiarity ratings were not significantly different for the low-groove sham and low-groove anodal conditions.

Table 2

Post Hoc Tukey HSD Results for Familiarity

Comparison							
Groove	Stimulation	Groove	Stimulation	MD	SE	t-value	P-Tukey
Low	Sham	Low	Anodal	-.13	.14	-.93	.79
		High	Sham	-1.02	.34	-2.98	.046*
		High	Anodal	-1.44	.38	-4.32	.004**
	Anodal	High	Anodal	-1.31	.33	-3.92	.008**
High	Sham	High	Anodal	-.42	.16	-2.98	.021*

Note. The above table displays the results of the Tukey HSD post hoc, comparing both groove and stimulation conditions. The above models the post hoc Tukey HSD test conducted on the full sample of 14 participants, excluding the one that withdrew. * $p < .05$; ** $p < .01$; ***$p < .001$.

Discussion

Groove is the pleasurable urge to move felt when listening to music that an individual enjoys; it consists of two components: the urge to move and feelings of pleasure (Janata et al., 2012). This study extended previous research and sought to use excerpts of actual songs to assess the generalizability of the original study's results. This study focused on the role of the SMA in groove perception, using tDCS manipulation of the SMA to analyse further its relationship to the two components of groove and familiarity with the presented music. The results showed that while groove type produced significant effects across all dependent variables, the urge to move, pleasure, and familiarity, none of the dependent variables showed significant effects for stimulation type. Past research has shown the effect of more than five years of musical experience on groove ratings. This led the researcher to conduct a secondary analysis excluding participants with more than five years of musical experience (Grahn & Brett, 2007).

The first dependent variable was the urge to move, believed to be the component of groove associated with activity in the motor network while listening to music (Matthews et al., 2020). The results showed a main effect for groove type on mean ratings of the urge to move, with a very large effect size, $\eta^2_p = .74$. The effect size shows that a large portion of the variance seen in ratings of the urge to move was due to groove type, in line with the expectations as the urge to move is a component of groove (Janata et al., 2012). Stimulation type, and the interaction between groove and stimulation type were not significant. Interestingly, while the ANOVA showed stimulation type not to be significant, a paired samples t-test found that mean ratings of the urge to move for the high groove sham condition as compared to the high groove anodal condition were significantly different, with a small effect size, Cohen's d of .31. However, mean ratings of the urge to move on the low groove sham and low groove anodal conditions were not

significantly different. This finding may reflect the relationship between activity in the SMA and the increased urge to move, or potentially the SMA's role in music perception, in general, being enhanced by tDCS (Grahn & Brett, 2007). The finding of a main effect for groove type was in line with the extant literature, as the urge to move is a groove component associated with the motor network to which the SMA belongs (Matthews et al., 2020). The result that high groove sham and high groove anodal conditions were significantly different indicates an effect of stimulation type. Additionally, a significant difference was present in the initial post hoc test. However, it was absent from the second post hoc test, excluding participants with more than five years of musical experience. The differences in these two results may indicate how differences in groove perception can be brought on through extensive musical experience or may reflect the small sample size of this study, making conclusions hard to draw.

The second dependent variable was ratings of pleasure, believed to be the component of groove associated with activity in the reward network observed while listening to music (Matthews et al., 2020). The results showed a main effect for groove type on mean ratings of pleasure with a large effect size $\eta^2_p = .30$, showing that a large portion of the observed variance in pleasure ratings is attributable to groove type. While stimulation type produced no significant effects, the interaction between groove and stimulation type was significant and had a large effect size $\eta^2_p = .42$. The interaction effects are shown further by the post hoc Tukey HSD test conducted. The result was that mean pleasure ratings for the high groove sham compared to the high groove anodal conditions were significantly different. However, that low groove sham was not significantly different from low groove anodal models in the results for the urge to move and familiarity. This finding may reflect the role played by the SMA in groove perception or a potential role in the pleasure network and response. However, it may also demonstrate the

relationship between higher groove music and increased ratings of pleasure or even be SMA's role in the pleasure response elicited when listening to music with groove (Witek, 2013). As all the music for low and high groove conditions was the same under both stimulation types, it cannot be attributed to personal music preference for higher groove songs alone. However, this effect may be partially explained by the combination of repeated exposure to the song, resulting in a mere exposure effect and a musical preference for higher-groove songs.

The third dependent variable was ratings of familiarity, separate from the concept of groove yet still related to ratings of groove (Senn et al., 2021; Pereira et al., 2011). This variable was primarily included as a constant, as all music came from the top 100 billboards making it all potentially familiar. The main concern of this variable was the mere exposure effect's influence due to repeated exposure to the same music, as the study had both stimulation conditions one after the other using the same music, impacting participants' ratings (Peretz et al., 1998). Additionally, high-groove music was hypothesised to be more familiar to participants, a finding shown in this study with familiarity ratings of high-groove music (M = 7.68; SD = 1.11) compared to low-groove music (M = 5.25; SD = 1.24). The ANOVA results showed a main effect for groove type, high groove music was, on average, more familiar than predicted. Groove type had a very large effect size, η^2_p = .49, indicating a high degree of the variance in familiarity ratings was partly attributable to groove type.

Additionally, the results showed that mean ratings of familiarity for the high groove sham compared to the high groove anodal condition were significantly different,), p = .021. This finding further shows the relationship between ratings of groove and familiarity; it also highlights the potential role of repeated exposure to more preferential high-groove music resulting in higher familiarity than repeated exposure to low-groove music (Senn et al., 2021).

This finding may also demonstrate the effects of tDCS of the SMA on perceptions of musical familiarity, how the memory of music may be influenced by groove type, or how high groove music is perceived to be more alike than low groove music due to factors such as metric expectations. Additionally, while not significant, the results for stimulation type were very close to significance, $p = .06$. This may be attributable to the small sample size and, thus low power of this study not being sufficient to portray the effects of stimulation to the point of significance.

This study had three original hypotheses. Firstly, mean ratings of the urge to move and pleasure will be significantly higher during the high groove than during the low groove conditions. Secondly, ratings of the urge to move and pleasure will be significantly higher during the anodal than sham conditions. Lastly, a significant interaction effect between groove and stimulation type will result in significantly higher mean ratings of the urge to move and pleasure during the high groove anodal compared to the high groove sham conditions and the low groove anodal compared to the low groove sham conditions. The first hypothesis was confirmed through the consistent main effect of groove type across both groove components and familiarity supporting existing research on groove. The second hypothesis was only partially accurate; mean ratings of the urge to move and pleasure were significantly higher for the anodal condition but only under the high groove condition.

Additionally, this was also shown to be proper of familiarity. The last hypothesis was also partially true; the high groove anodal condition had significantly higher ratings of the urge to move and pleasure than the high groove sham condition. However, the low groove anodal condition was not significantly higher in means ratings of the urge to move and pleasure than the low groove sham condition. These findings highlight that while groove type influences our

ratings of the urge to move, pleasure and familiarity, tDCS stimulation of the SMA only seemingly produced a significant effect under the high groove conditions.

This study assessed ratings of the urge to move, pleasure and familiarity with musical excerpts from the top 100 billboards. Groove type, high or low, was determined based on the subjective feel of the song rather than any specific factors. This was mainly done due to the lack of information on core factors influencing groove and its perception in music. Research has shown that factors such as the level of syncopation, metric structure, and a regular/predictable beat impact ratings of groove (Stupacher et al., 2016; Madison et al., 2011; Camara & Danielsen, 2018). However, there is still a lack of research showing how these factors influence groove ratings and whether they are generalisable as universal factors influencing groove.

Furthermore, the influence of musical experience on perceptions of groove in music has yet to be adequately researched, often only mentioned due to self-reports by participants rather than specific research on its effects (Grahn & Brett, 2007; Chen et al., 2008). While Grahn and Brett (2007) showed the influence of more than five years of musical experience on ratings of groove, an explanation of what constitutes sufficient musical experience to influence ratings of groove was not provided. There is also the question of musical preference and groove. Musical preferences differ from person to person, but subjective ratings of high-groove music as high in groove do not. The extent to which an individual's musical preference influences their perception of groove represents a gap in research on music perception.

This study was inherently underpowered due to its small sample size, making generalising any of its findings difficult. Multiple results showed a trend towards significance and may have been significant with a larger sample. Additionally, this study was limited in its participant recruitment to just undergraduate students enrolled in PSYCHOL 1000, resulting in a

relatively homogenous population of young adults. Another limitation of this study was the tDCS montage, with only two large electrodes placed on the SMA and above the right eyebrow based on the 10:20 EEG system. This may have resulted in a lack of sufficient coverage of the SMA by the electrode, a dispersion of charge on the scalp due to the saline solution spreading, and may have led to inadequate stimulation of the SMA. The tDCS machine itself presented multiple problems, being relatively unreliable and outdated.

Additionally, the tDCS setup and stimulation are somewhat uncomfortable; this may have resulted in participants rating the low groove songs as lower on the urge to move and pleasure due to discomfort, helping to explain the lack of significance in low groove sham as compared to low groove anodal conditions. However, this would not explain the significance of ratings of the urge to move, pleasure, and familiarity on high groove sham compared to high groove anodal conditions, leading to the conclusion that the interaction between both high groove and anodal stimulation is responsible for these results.

This study showed the present problems faced by music researchers, the lack of universal factors for classifying groove type. Additionally, a lack of understanding of the interaction between familiarity and ratings of groove and a lack of research on the connections between the motor and reward networks active while listening to music, with specific reference to the SMA's role in both networks. This study, while underpowered, demonstrated the relationships between high-groove music and the SMA and this relationship's influence on ratings of the urge to move, pleasure, and familiarity. Future studies should replicate this study with a larger sample, potentially with a different tDCS montage or cortical manipulation instrument, to confirm and expand the results. More research is needed to understand the network of brain regions responsible for music perception, specifically, groove perception. Additional research is also

needed to ascertain the key factors influencing whether music is perceived as the high or low groove and the role of individual preference in determining groove ratings. The SMA is involved in beat and music perception tasks, but its role in groove perception and relationship with the reward network is still unclear. Future research should assess whether groove ratings are influenced by factors such as the presence of vocals, the ability to understand spoken language, or cultural perceptions such as those associated with Inuit throat singing.

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Appendix A

Letter of Information for Participants

This appendix section consists of two items related to this study, the letter of information (first four pages) given to participants at the beginning of the study to ensure they can provide informed consent and the Western Research Ethics Board approval to conduct this study.

Western The Brain and Mind Institute | Department of Psychology | Western SocialScience

LETTER OF INFORMATION FOR PARTICIPANTS

The Effects of Transcranial Direct Current Stimulation on Beat Perception and Motor Performance

Principal Investigator:
Jessica Grahn, Ph.D.
Brain and Mind Institute
Room 229, Natural Sciences Building
University of Western Ontario
London, Ontario, N6A 5B7
Email: jgrahn@uwo.ca
Phone: 519-661-2111 x84804

Introduction:
You are invited to voluntarily participate in a research study investigating the role of brain areas known to contribute to the perception of the beat in music and to motor performance, using transcranial direct current stimulation, or tDCS. The purpose of this study is to determine how specific brain regions may be responsible for different aspects of musical perception and experience. This letter of information will provide you with further information about behavioural tasks and techniques that will be used during the experiment allowing you to make an informed decision regarding participation in this research.

Research Procedures:
If you agree to participate in this study, your participation will involve behavioral tasks that include:

Rhythm/ Beat Perception Tasks:
During the study, you will hear stimuli that fall into three categories: metronomic/ isochronous beeps, metric or non-metric rhythms, and music clips (e.g. clips from recorded musicians). Tasks fall into four categories: discrimination, passive listening, beat-tapping, and reproduction tasks. You will hear stimuli and may be asked to simply listen passively, or to make perceptual judgments about the sounds, and/or make responses to the sounds. If the task is complex, you will be given a chance to practice before the session begins. You may be completing these tasks before and after tDCS is applied to the scalp (offline tDCS), or at the same time as tDCS is applied (online tDCS). Overall, these experiments will inform us about the role of different brain areas in music processing.

Transcranial direct current stimulation (tDCS)
First, we will estimate the scalp area overlying the cortical areas that will be stimulated using the international electroencephalographic 10-20 system. Subsequently, one electrode (the anode) will be placed onto that area while the other electrode (the cathode) will be placed on a reference location, such as your forehead. These sponge electrodes will be saline-soaked to increase

comfort, and the electrode positions on the scalp will be secured with rubber straps. A 2 milliampere direct current will be applied between the electrodes. In the proposed research, stimulation will be applied for 20-40 minutes. Depending on experimental protocol, you will either be performing the behavioral task during stimulation, or you will be at rest during stimulation. Stimulation will cease at a predetermined point after a maximum of 40 minutes. You may feel the stimulation as an itching or a tingling sensation

Electromyography (EMG):
Surface EMG is a non-invasive measure of electrical activity produced by skeletal muscles. Surface EMG will allow us to measure motor evoked potentials (MEP's), or muscle movement caused by direct stimulation of the motor cortex. Small electrodes will be placed on specific hand, arm, foot, or leg muscles. These electrodes require a small amount of sticky gel-like substance to conduct the electrical current.

Transcranial Magnetic Stimulation
Like tDCS, TMS is a safe, well studied, non-invasive brain stimulation method that affects the depolarization and hyperpolarization of brain cells. TMS uses electromagnetic induction to induce weak electric currents using a rapidly changing magnetic field; this can cause activity in specific areas of the brain. A TMS pulse is felt as a light tap on the head. TMS will be used to localize the scalp area overlying the motor cortex. By estimating the scalp area overlying the motor cortex, we will be able to estimate other candidate brain areas for tDCS stimulation, such as the premotor cortex and the supplementary motor area.

Risks:
Some participants may find the tingling or itching sensation of tDCS brain stimulation uncomfortable. In very rare cases, tDCS stimulation can cause minor skin abrasions or burns (expected to heal completely). Individuals with skin problems who are more susceptible to skin irritation will also be excluded from participating.
Susceptible individuals may experience a mild headache after brain stimulation. To reduce the likelihood of this, individuals who report susceptibility to migraines or frequent headaches will be excluded from participating.
All participants will be reminded that they may withdraw at any time without giving any reason and without any negative consequences.

Benefits:
There is no direct benefit to you from participating in this study. The results from this study may help us to better understand the brain regions underlying human motor performance and beat perception.

Voluntary Participation:
Participation in this study is voluntary. You may refuse to participate, refuse to answer questions, or withdraw from the study at any time.

Discontinuation of the Study by the Investigator:
At any time during the study, the investigators have the right to stop the study for any reason.

Participant Exclusion Criteria:

This study is intended for healthy individuals. You should not participate in this study if you fall into one of the following categories

- Participants with metallic implants, such as pacemakers, cerebral aneurysm clips or other electronic implants
- Female participants who are pregnant, trying to conceive, or who are sexually active and are not practicing an effective method of contraception
- Participants with a history of psychiatric or neurological problems such as epileptic seizures, Tourette's syndrome, ADHD, depression.
- Participants who require prescribed psychotropic medication or currently take other medication that makes them drowsy
- Participants who get migraines and/ or are susceptible to headaches
- Participants who are more susceptible to skin irritation, such as participants with eczema.

Estimate of Participant's Time and Compensation:

Depending on which experiment you have been assigned to, you may be asked to come in for one session or for multiple sessions (up to ten). Each session will last one to two hours. Each experiment within the research project will involve approximately 25 participants. The entire research project will involve multiple experiments, and may require up to 300 participants.

Upon completion of all parts of the study, you will receive $5/ half hour for your time and inconvenience. If the study has to be stopped for any reason, compensation will be adjusted according to the fraction of the study that was completed.

Confidentiality:

Any information obtained from this study will be kept confidential. Any data resulting from your participation will be identified by a number, without any reference to your name or personal information. Data will be stored on a secure computer in a locked room. After completion of the experiment, data will be archived on storage disks and stored in a locked room for a minimum of five years and a maximum of 15 years, after which they will be destroyed. Representatives of the University of Western Ontario Health Research Ethics Board may require access to your study-related records or may follow up with you to monitor the conduct of the study. If you choose to withdraw from this study, your data will be removed and destroyed from our database.

Consent Form

You do not waive any legal rights by signing the consent form. In the event of a study-related injury, your consent does not waive any medical or legal rights you may be entitled to. You will be provided with a copy of this letter of information and the consent form. You also reserve the right to withdraw any data collected from you, with no limitations on the feasibility of that withdrawal. You do not need to give any reason to withdraw, and there will be no implications on your medical or legal rights.

Contact Information

If you would like to receive a copy of the overall results of the study, or if you have any questions about the study please feel free to contact the Principal Investigator at the contact information provided above.

 Participant's Initials: _____

For questions about your rights as a research participant or the conduct of the study you may contact:
Office of Research Ethics

University of Western Ontario
519-661-3036 E-mail: ethics@uwo.ca

 Participant's Initials: _____

CONSENT FOR RESEARCH STUDY

The Effects of Transcranial Direct Current Stimulation on Beat Perception and Motor Performance

I have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

Name of Participant (Please print): _____

Signature of Participant: _____

Date: _____

Person Obtaining Informed Consent (Please print): _____

Signature: _____

Date: _____

Dated at Western University, London, Ontario.

Appendix B

Western Research Ethics Board approval covering this study.

Western Research

Date: 12 December 2022

To: Dr. Jessica Grahn

Project ID: 104725

Review Reference: 2022-104725-73648

Study Title: Effects of brain stimulation on beat perception and motor performance

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

REB Meeting Date: 10/Jan/2023

Date Approval Issued: 12/Dec/2022 08:36

REB Approval Expiry Date: 09/Jan/2024

Dear Dr. Jessica Grahn,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Electronically signed by:

Karen Gopaul, Ethics Officer on behalf of Dr. P. Jones, HSREB Chair 12/Dec/2022 08:36

Reason: I am approving this document

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix C

Song list for study, organised according to groove type.

Item no.	Song name	Artist	Groove	BPM	Year
1	Beggin	Maneskin	High	134	2022
2	Bite me	Avril Lavigne	High	170	2022
3	Take my breath	The Weekend	High	121	2022
4	Need to know	Doja Cat	High	130	2021
5	Serotonin	Girl in Red	High	149	2021
6	Butter	BTS	High	115	2021
7	I am not a woman	Halsey	High	180	2021
8	Just for me	PinkPantheress	High	133	2021
9	Montero	Lil Nas X	High	179	2021
10	Industry baby	Lil Nas X	High	150	2020
11	Good 4 you	Olivia Rodrigo	High	169	2020
12	Blinding lights	The Weekend	High	136	2020
13	Dance monkey	Tones and I	High	196	2020
14	Roses (Imanbek remix)	Saint Jhn	High	122	2020
15	Roxanne	Arizona Vervas	High	117	2020
16	High Hopes	Panic! At the Disco	High	164	2019
17	Sweet but psycho	Ava Max	High	133	2019
18	Youngblood	5 Seconds of Summer	High	120	2019
19	Better now	Post Malone	High	145	2019
20	Pure water	Mustard and Migos	High	202	2019
21	Kill bill	SZA	Low	89	2022
22	Anti-hero	Taylor Swift	Low	97	2022
23	Die for you	The Weekend	Low	67	2022
24	Golden hour	Jvke	Low	94	2022
25	Escapism	RAYE	Low	96	2022
26	Hell of a view	Erica Church	Low	99	2021
27	Alcohol-Free	TWICE	Low	97	2021
28	Wockesha	Moneybagg Yo	Low	82	2021
29	Damage	H.E.R.	Low	81	2021
30	Transparentsoul	Willow ft. Travis Barker	Low	90	2021
31	Adore you	Harry Styles	Low	99	2020
32	Memories	Maroon 5	Low	91	2020
33	The bones	Marren Morris	Low	77	2020
34	10,000 hours	Dan + Shay	Low	90	2020
35	Chasin you	Morgan Wallen	Low	97	2020
36	Sunflower	Post Malone & Swae Lee	Low	90	2019
37	7 Rings	Ariana Grande	Low	70	2019
38	Eastside	Halsey & Khalid	Low	89	2019
39	Shallow	Lady Gaga	Low	96	2019
40	Lucid dreams	Juice Wrld	Low	84	2019