The Pleasurable Urge to Move to Music is Unchanged in Musical Anhedonia

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Abstract

In cognitive science, the sensation of "groove" has been defined as the pleasurable urge to move to music. When listeners rate rhythmic stimuli on derived pleasure and urge to move, ratings on these dimensions are highly correlated. However, recent behavioural and brain imaging work has shown that these two components may be separable. To examine the separability of these two components, our study investigates the sensation of groove in people with specific musical anhedonia. Individuals with musical anhedonia have a blunted ability to derive pleasure from music but can still derive pleasure from other domains (e.g., sex and food). People with musical anhedonia were identified as those with scores in the lower 10% of scores on the Barcelona Musical Reward Questionnaire, but who had no deficits in music perception, no symptoms of depression, average levels of physical and social anhedonia, and normal sensitivity to punishment and reward. We predicted that if the two components of groove are separable from one another, then individuals with musical anhedonia would experience lower levels of derived pleasure but have comparable ratings of wanting to move compared to controls. Groove responses were measured in a large online study (N=148) for a set of rhythmic stimuli validated in several previous studies. In the full control sample our results replicated previous findings such that the highest levels of groove were elicited by rhythms of medium complexity compared to low and high complexity rhythms. Surprisingly, we found no significant differences in groove response between individuals with musical anhedonia (n = 17) and a matched control group (n = 17). Mediation analyses for the anhedonia sample found that wanting to move ratings fully mediated the effect of rhythmic and harmonic complexity on pleasure ratings. Taken together, these results indicate that the urge to move may compensate for the blunted pleasure response in

those with musical anhedonia. More generally, these results suggest that the urge to move is a primary source of pleasure in the groove response.

Introduction

For most of history, humans have listened to and created music[1]. We use music for various reasons, including mood regulation, social connection, and dancing.[2-4] One of the more intriguing features of music is that it often generates a pleasurable urge to move along. In music cognition literature, this pleasurable urge to move to music has been termed "groove".[5,6] The experience of groove is often described as having two different components, measured through ratings of pleasure and wanting to move, which are typically highly correlated ($r > 0.8$).[7-9] However, recent behavioural and neuroimaging work from our lab suggests that these components may be at least partially separable [8,12]. This raises the question of whether groove is a joint response – with pleasure and urge to move completely intertwined – or if they are separable components of the sensation. To test the separability of these components of the groove sensation, we assessed pleasure and wanting move ratings in people with specific musical anhedonia who have a blunted pleasure response to music.[10] We hypothesized that if the experience of pleasure and wanting to move were separable, people with musical anhedonia would show a blunted pleasure response but a preserved desire to move.

The experience of groove is related to various structural components of music influence, including meter, syncopation, harmonic complexity, and style[5,7,8,12]. Most of the work has focused on the rhythmic attributes of music, particularly syncopation. The term syncopation refers to a violation of the internal pulse or meter (i.e., the regularly recurring rhythmic pattern in the music) of a piece of music.[11] Syncopation has been found to have a quadratic, inverted-U-shaped relationship with ratings of pleasure and wanting to move, such that medium levels of syncopation result in the highest ratings, and both lower and higher levels of syncopation result in lower ratings.[7] One useful theory about why groove has an inverted-U shaped relationship with syncopation is predictive coding.[15-17] The theory proposes that when we listen to music, there are two parallel processes resulting in our sensation of groove: one bottom-up process where we perceive the sequence of notes and their temporal components, and a second top-down process based on an internal model or a set of expectations and predictions about music structure. When we listen, to music, we compare the incoming sensory information to our top-down model. When these processes do not concord, then it is theorized that your brain attempts to reduce the error in predictions through bodily movements, which is where the urge to move is thought to come from. The quadratic effect for rhythmic complexity has been replicated across a variety of music stimuli, including natural excerpts and stimuli composed to fit specific experimental parameters.[8, 9, 12-14] Previous work from our lab has replicated this effect by having participants listen to and rate their pleasure and wanting to move to music stimuli that varied in their syncopation.[8, 12]

Previous theory and research investigating the sensation of groove has found that the urge to move and pleasure are highly related.[7-9] A recent review has even begun to refer to the two as one sensation, rather than two separate components of a perception.[18] The strength of the relationship may depend on if wanting to move and pleasure are rated directly after one another or not.[12] However, there are two pieces of evidence from studies in our lab that suggest that pleasure and urge to move are at least partially separable from one another. Syncopation is not the only structural component of music that influences our groove response. In 2019, Matthews and colleagues explored the role of harmonic complexity in the pleasurable urge to move to music.[8] Harmonic complexity was manipulated by altering the tonality of the chords used to mark the rhythm. The authors found that low and medium harmonic complexity generated the highest levels of groove response compared to high harmonic complexity. Mediation analyses were also conducted to determine if either pleasure or wanting to move ratings were the driving factor in the relationship between harmonic complexity and groove. The analyses showed that pleasure ratings fully mediated the relationship between wanting to move ratings and harmonic complexity, indicating that harmonic complexity did not affect wanting to move directly, and only through its relationship with pleasure. These results support the possibility that the pleasure and wanting to move components of the groove percept may be at least partially separable.

A second piece of evidence that these components may be separable comes from a functional magnetic resonance imaging (fMRI) study from our laboratory using the same stimuli.[12] Behavioural results replicated our previous work, showing that people rated medium syncopation rhythms higher for both pleasure and wanting to move compared to high syncopation stimuli. Further, the results showed that pleasure ratings were more associated with activity in reward networks, such as the right nucleus accumbens (NAcc);[19] while wanting to move ratings were more associated with motor networks, such as the putamen and the caudate.[20] These results further support the idea that the pleasure and urge to move experienced in the groove response may be separable. To further to explore the separability of the urge to move and pleasure in the sensation of groove, the current project will utilize the same stimuli used in these previous two studies.

In order to further explore the separability of pleasure and wanting to move, we decided to assess the groove response in a large control sample and in people with specific musical anhedonia. While we often think of enjoying music as a universal experience, this is not true for everyone. Some individuals have a blunted ability to derive pleasure from music but are still able to derive pleasure from other aspects of life, such as sex or food.[10] This specific blunted pleasure response has been termed musical anhedonia. If pleasure and urge to move are separable, then those with musical anhedonia should show reduced ratings for pleasure and relatively preserved ratings for urge to move. If pleasure and the urge to move are not separable process, we should see a reduction in ratings for both in those with musical anhedonia.

Methods

The protocol was approved by the Concordia University Office of Research, Research Ethics Unit (#30004370). The present study was conducted in accordance with the local legislation and institutional requirements. Participants were recruited through Prolific and tested online through the Pavlovia platform. Prior to beginning the study protocol, participants provided written informed consent. Participants were provided monetary compensation in the form of 7.5 euros per hour. Data was collected from February 9th to July 29th, 2022. The battery of tests included the groove rating task used in previous studies.[8,9,12,21] To identify specific musical anhedonia participants completed the Barcelona Musical Reward Questionnaire (BMRQ),[22] as well as questionnaires to rule out depression, global anhedonia and reward sensitivity. These measures are described in detail below. We also used the Montreal Battery for the Evaluation of Amusia (MBEA)[23] and an online version of four subtests from the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA)[24,25] to rule out global deficits in music perception. Finally, participants also completed a short demographics and musical history questionnaire.

Participants

A total of 204 participants were tested. Twenty-five were excluded for failing to follow instructions and/or for invalid responding (e.g., three or more questionnaires in which their responses did not show appropriate variation). An additional 12 participants were excluded for having Amusia as determined by the scale, contour, and interval tests of the MBEA described below (score of less than 21)[26]. Seventeen individuals were identified as having musical anhedonia based on their scores on the BMRQ and other questionnaires as described below. After excluding those with specific musical anhedonia and low scores on the MBEA, the full control sample included 148 individuals (Age Range: 18 – 67, Age *M* = 26.05, Age *SD* = 7.76, Females = 75, Males = 71, Years of Musical Training *M* = 4.42, Years of Musical Training *SD* = 6.3). Seventeen participants were identified as meeting the criteria for specific musical anhedonia (Age Range = 21 – 67, Age *M* = 33.12, Age *SD* = 13.87, Females = 4, Males = 13, Years of Musical Training *M* = 4.29, Years of Musical Training *SD* = 11.03) based on the criteria described below (see Table 1). In order to examine groove ratings in the people with musical anhedonia, a control sample was selected from the full control group that was matched to the anhedonia sample on age, gender, and years of musical experience (Age Range = 22 – 63, Age *M* = 33.06, Age *SD* = 10.58, Females = 4, Males = 13, Years of Musical Training *M* = 4.42, Years of Musical Training *SD* = 6.3).

Table 1. Results from WAS, SPSRQ, BIS/BAS, & BAASTA for Control and Musical Anhedonia Sample

	Full Control		*Musical Anhedonia*		*Matched Control*	
	M	*SD*	*M*	*SD*	*M*	*SD*
WAS: Physical Anhedonia	10.30	1.54	9.65	2.12	10.5	1.55
WAS: Social Anhedonia	7.73	1.86	7.59	2.15	7.94	2.21
BIS	21.46	3.87	20.35	4.15	21.69	3.63
BAS: Drive	10.43	2.58	8.29	1.83	10.81	2.66
BAS: Fun Seeking	11.66	2.46	10.06	1.95	10.88	2.45
BAS: Reward Responsiveness	16.71	2.92	15.47	2.03	16.75	1.98
SPSRQ: Sensitivity to Reward	11.23	4.02	8.88	3.74	11.19	5.65
SPSRQ: Sensitivity to Punishment	15.7	4.7	15.12	4.7	12.75	6.69
BAT: D-Prime	2.55	0.9	2.81	0.73	2.5	0.78
Un-paced Tapping: ITI CV	0.068	0.034	0.058	0.015	0.070	0.046
Paced Tapping Isochronous: VL	2.67	1.07	2.6	0.55	3.22	0.79
Paced Tapping to Music: VL	1.7	1.94	1.43	1.8	1.93	1.97

WAS = Wisconsin Anhedonia Scales, BAS =Behavioural Activation Scales, BIS = Behavioural Inhibition Scales, SPSRQ = Sensitivity to Punishment and Reward Questionnaire, BAT = Beat Alignment Task, ITI = Inter-Tapping Interval, CV = Coefficient of Variation, VL = Logit-transformed Vector Length, M = mean, SD = standard deviation.

Groove Rating Task

Participants were instructed to listen to the 54 musical stimuli (see Figure 1) made to elicit groove taken from Matthews et al. (2019)[7]. Due to technical errors, three groove stimuli were not played for all participants, which resulted in only 51 included in the final analysis. All groove stimuli were computer-generated, used piano timbre and were composed using Cubase Pro (v8.0.30). Each stimulus lasted for a total of 10 seconds. These groove stimuli varied in rhythmic and harmonic complexity across three levels: low (17 stimuli for rhythmic complexity; 15 for harmonic complexity), medium (18; 18), and high (16; 18). Rhythmic complexity was manipulated through the degree of syncopation present in the sequence. Each rhythmic pattern consisted of five onsets. Additionally, each stimulus consisted of four repetitions of each rhythmic pattern. Medium rhythmic complexity stimuli included the son clave, rumba clave and an experimenter-created rhythm. Low rhythmic complexity stimuli were rhythms with the syncopation removed, and high rhythmic complexity had only the first onset fall on the strong beat. Harmonic complexity was influenced by manipulating the chords present in each musical stimulus. All chords were in the key of D. For low harmonic complexity, chords were created using the D major triad and two inversions. Medium-complexity chords were composed of four-note chords and an extension. Lastly, high-complexity chords had a flat ninth interval between the chord note and extension.

Fig 1. Example of the musical notation of a stimulus with a medium rhythmic complexity (son clave) and a medium harmonic complexity (four-note chord with extensions). The upper bar denotes the hi-hat. Figure originated from Matthews et al., 2019

The order of presentation for the musical stimuli was randomized per participant. Following the presentation of each stimulus, participants were asked to rate on a 5-point Likert scale “How much pleasure do you experience listening to this musical pattern?” and “How much does this musical pattern make you want to move?”, with one indicating low levels of derived pleasure/wanting to move and five indicating high levels. The order in which these two questions were presented was randomized. To ensure participants responded to each question appropriately, images were included to symbolize either pleasure or wanting to move.

<u>Identification of Specific Musical Anhedonia & Assessment of Musical Perception</u>

Musical anhedonia refers to a specific blunting of the pleasure response to music that is not better explained by an impairment in perception, embedded in a more global anhedonia or depressive symptomology.[10] In order to identify individuals with musical anhedonia, we used the BMRQ, as done in previous work.[10,27] The BMRQ is a 20-item questionnaire that assesses individuals' reward response to music in various situations.[22] The BMRQ is composed of a total score and five subscales. These subscales include music seeking, emotion evocation, mood regulation, sensory-motor, and social reward. Individuals with musical anhedonia have previously been identified as individuals who score in the bottom 10% of total scores (65 or lower).[10,26] In addition to the BMRQ, participants completed additional measures assessing various domains to determine that their anhedonia was specific to music.

To determine if participants' abilities to perceive and produce rhythm fall within the average range, participants completed four subtests from the BAASTA,[24] adapted in an online version on BRAMS Online Testing Platform. To evaluate participants' ability to perceive rhythm, participants completed the Beat Alignment Test (BAT). During this test, participants were presented with four musical excerpts that lasted for 20 quarter notes. Two excerpts were taken from Bach's "Bandinerie," and the other two from Rossini's "William Tell Overture", both with inter-beat intervals (IBI) of 600 milliseconds (ms). A metronome with the timbre of a triangle is overlayed on top of each music excerpt. This metronome is either synchronous with the beat of the music or not aligned. Participants are required to judge whether the metronome is aligned with the beat or not. Participants were presented with three different versions of the musical excerpts, which varied in tempo. Stimuli varied between inter-beat intervals (IBIs) of 600 milliseconds (ms). Participants were presented with a total of 24 trials. In 8 trials (33%), the metronome was synchronous with the beat of the music, and in 16 trials (66%), the metronome was asynchronous with the music's beat. The outcome variable used for the BAT was a d-prime value[22,23]. The task lasted approximately 8 minutes. Scores below two standard deviations from the control population were considered not pure musical anhedonia.

To assess beat production abilities, participants completed three different tasks from the BAASTA; the un-paced tapping, paced tapping to an isochronous sequence and paced tapping to music tasks. Participants were asked to tap on their spacebar to the beat for all production tasks. The un-paced tapping task requires participants to tap at a comfortable rate with no accompanying stimulus for 60s. Participants are asked to try and keep the tapping rate constant throughout the 60s. The paced tapping to an isochronous sequence task asks participants to tap to a metronome (inter-onset interval – IOI – of 600 ms) with the timbre of a piano for 36s. This was repeated twice. In the paced tapping to music task we asked participants to tap for 36s to the same excerpts presented in the BAT with an IOI of 600 ms. Each excerpt was presented to each participant twice. The measures for the production tasks are inter-tap-interval (ITI), coefficient of variation (CV = mean ITI / SD ITI) and synchronization consistency (vector length). Participants' ITI represents the time between two taps, while the ITI CV is representative of the variability of the inter-tap interval. The vector length is calculated via circular statistics methodology and represents the consistency of alignment between the tapping times and the beat times. A vector length of 1 indicates perfect alignment, while a value of 0 indicates lack of synchronization degree of tap consistency. In order to reduce data skewness typical of synchronization data, all vector lengths were submitted to logit transformation prior to analysis.[27] For more details see Dalla Bella et al. (2017, 2023)[24,25]. The tasks lasted approximately 8 minutes. Scores below two standard deviations from the control population were considered not pure musical anhedonia. Out of the 148 participants from the full control sample, eight did not complete the task due to technical errors, and 12 failed to follow instructions and were subsequently excluded from the analysis. Thus, the full control sample for the BAASTA tasks included 128 participants.

To assess for possible impairments in pitch perception, we used the MBEA. Congenital amusia refers to the limited ability to accurately perceive pitch that is not better explained by hearing loss, neurological damage, or intellectual deficits.[26] The MBEA[23] is a perceptual task composed of six tests used to assess deficits in the perception of music. Online versions of the scale, contour, and interval tests of the MBEA were employed in the present study to screen participants for congenital amusia, as has been done in previous studies.[26] All three tests follow a similar structure. Participants are presented with 31 pairs of five-second melodies and then instructed to indicate if the melodies are the same or different. Half of the trials in all three tests contain identical melodies, while the other half differ based on a single note. The difference between the tests is how the other trials differ. In the scale test, the unmatched melodies contain one note that is altered to be out of scale but does not alter the overall contour of the melody. The contour test has one note that is altered to change the contour while not deviating from the scale. Lastly, the interval test has an altered note that does not impact the scale or the contour of the melody. In all three tests, the 31^{st} trial is a catch trial in which the melodies differ in two domains compared to one. Participants with amusia were identified as individuals with an average composite score of below 21.36 across all three tests, as outlined in previous work.[25]

To rule out the presence of anhedonia secondary to depression, we had participants complete the Beck Depression Inventory-II (BDI-II)[29]. A symptom of depressive disorders are feelings of global anhedonia.[30] The BDI-II is a 21-item questionnaire, where for each item, participants are required to select one of four statements that best describes themselves over the past two weeks. The BDI-II is considered a gold-standard self-report measure of depressive symptomology.[31,32] Participants who met criteria for moderate to severe levels of depressive symptoms were not considered to have specific musical anhedonia.

While certain conditions are characterized by anhedonia, it is also possible that individuals may also have varying levels of anhedonia from various other sources. To rule out global anhedonia, we employed the Anhedonia Scales from the Wisconsin Schizotypal Scales, henceforth referred to as the Wisconsin Anhedonia Scales (WAS).[33,34] The WAS are two 15-item questionnaires that assess physical and social anhedonia. Scores below two standard deviations from the control population were considered not pure musical anhedonia, following an adapted procedure from Martinez-Molina et al., 2016.[27]

To rule out blunted global sensitivity to punishment and reward, participants were asked to complete the sensitivity to punishment and reward questionnaire (SPSRQ).[35] The SPSRQ is a 48-yes/no-item questionnaire assessing participants' sensitivity to punishment and reward. The questionnaire comprises two subscales, one for punishment and one for reward, each composed of 24 items. Participants who scored two standard deviations from the control population were considered not to have pure musical anhedonia, as done previously by Martinez-Molina et al., 2016.[26] Another way to conceptualize individuals' sensitivity to reward and punishment is to think of it in terms of motivational systems. We wanted to assess participants' motivation to approach rewarding and avoid punishing stimuli, commonly referred to as the Behavioural Approach System (BAS) and the Behavioural Inhibition System (BIS)[36]. To quantify this, participants completed the BIS/BAS Scale.[37] The BIS/BAS is a 24-item questionnaire scored on a 4-point Likert scale. The BAS is composed of three subscales, Drive, Fun Seeking and Reward Responsiveness. Participants who scored outside of two standard deviations from the normative sample for the BIS/BAS were considered not to meet the criteria for specific musical anhedonia following an adapted procedure based on Martinez-Molina et al. (2016).[27]

Demographics and Musical Background Questionnaire

Participants were asked to complete a short questionnaire assessing their demographics and musical experience. Participants' age and gender were collected through the questionnaire, while their country of origin was collected through Prolific. Data was collected surrounding participants' history playing music, including if they have ever taken lessons for an instrument or singing, if they are currently playing an instrument, the age they started, the age they finished, and the hours a week they play. The same questions were asked of participants regarding their experience with dance.

Procedure

All measures, excluding the BAASTA subtests, were coded on PsychoPy (v2021.2.3) and hosted on Pavlovia. The BAASTA tasks were hosted on the International Laboratory for Brain, Music, and Sound Research (BRAMS) Online Testing Platform (OTP). To limit burnout, the experiment was split into three separate modules. Module 1 comprised the consent form, the demographics and musical background questionnaire, the BMRQ, and the MBEA. Module 2 contained the WAS, the BDI-II, and the musical rating task. The third and final module consisted of the BAT and the paced tapping to music task. Modules 1 and 2 took approximately 40 minutes to complete, while module 3 took approximately 20 minutes.

Data analysis

All analyses and graphs were conducted using R (v4.1.2) and RStudio. Linear mixed-effects models were conducted using the *lme4* and *lmerTest* packages. Variance was estimated using restricted maximum likelihood. Degrees of freedom were estimated using the Satterwaite method.[37] All linear mixed effects included by-participant random intercept. Ratings were averaged across the three versions within each level of complexity. Models were built in a hierarchal fashion, starting with an intercept-only model with no fixed effects and adding variables to the model and comparing if there is an increase in model fit indices through likelihood ratio tests. The base model contained only the by-participant random intercept. Following this, variables were entered in the following order, rhythmic complexity, harmonic complexity, and lastly, any additional variables that were required for that analysis. Contrast analysis was employed to investigate the effect between the levels of rhythmic and harmonic complexity using the R package *emmeans*. Mediation analyses were conducted using the *mediation* package. Mediation analyses were conducted using 1000 simulations. All models were assessed to ensure they met appropriate statistical assumptions. Significance was determined at the cut-off of p-values less than 0.05.

Results

<u>Full Control Sample</u>

For visualization of the data, please see Figure 2. The full control sample consisted of the remaining 148 participants after excluding those with musical anhedonia. For pleasure ratings, the addition of rhythmic complexity ($\chi^2(2) = 260.34$, $p < 0.001$), harmonic complexity ($\chi^2(2) = 166.41$, $p < 0.001$), and the interaction between rhythmic and harmonic complexity ($\chi^2(2) = 45.58$, $p < 0.001$) as predictors to the model significantly increased the model fit indices (see Supplementary Table 2). Results indicated a significant interaction between rhythmic and harmonic complexity on pleasure ratings ($b(1048) = 0.092$, $p < 0.001$, 95% CI [0.043, 0.141]). Contrast analyses indicated that both rhythmic ($b(894) = -1.53$, $p < 0.001$, 95% CI [-1.63, -1.43]) and harmonic complexity ($b(894) = -0.14$, $p = 0.005$, 95% CI [-0.237, -0.043]) contained significant quadratic relationships. Contrast analyses indicated that medium rhythmic complexity resulted in significantly higher ratings of pleasure compared to low rhythmic complexity ($b(575) = -0.382$, $p < 0.001$, 95% CI [-0.448, -0.316]), while low complexity resulted in higher ratings of pleasure compared to high complexity ($b(149) = 0.56$, $p < 0.001$, 95% CI [0.479, 0.64]). The quadratic relationship for rhythmic complexity was stronger than for harmonic complexity. While the quadratic relationship for harmonic complexity is significant, the results from the contrast analyses support more of a linear relationship between the levels of harmonic complexity. Low harmonic complexity resulted in significantly higher ratings of pleasure compared to medium complexity ($b(666) = 0.21$, $p < 0.001$, 95% CI [0.147, 0.273]), and medium harmonic complexity resulted in higher ratings compared to high complexity ($b(666) = 0.35$, $p < 0.001$, 95% CI [0.287, 0.413]).

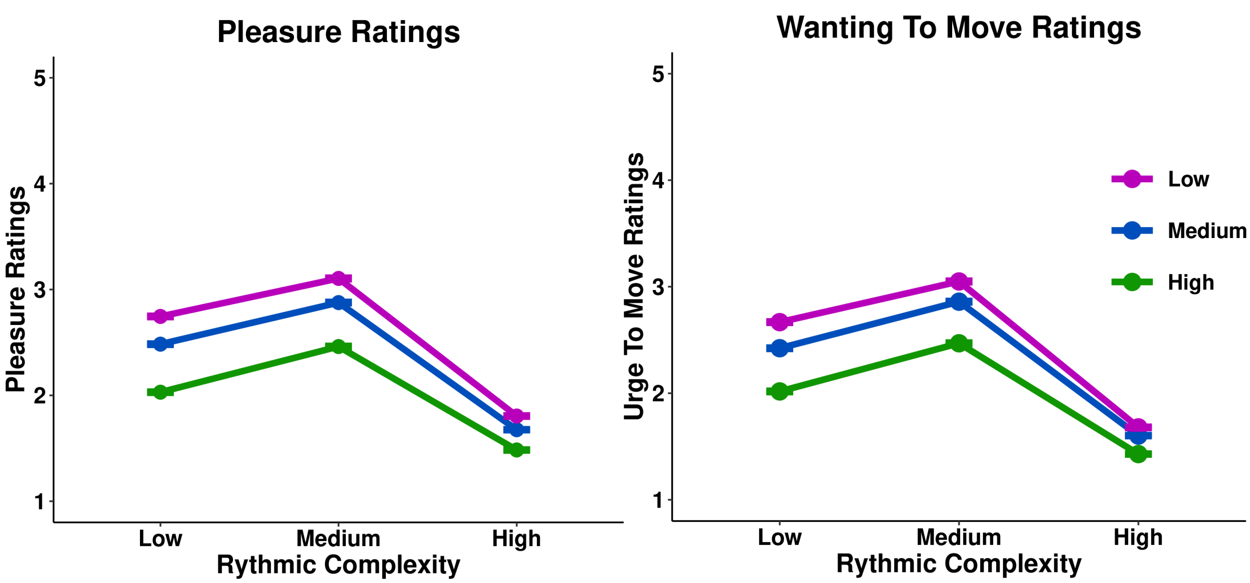

Fig 2. The Effect of Rhythmic and Harmonic Complexity on Groove Response for the Full Control Sample. The y-axis represents pleasure or wanting to move ratings on a 5-point Likert scale. The x-axis represents the metric complexity of the musical samples. Colours indicates the level of harmonic complexity of the musical sample. Dots represent means derived from raw values.

For wanting to move ratings, adding rhythmic complexity ($\chi^2(2) = 272.72$, $p < 0.001$), harmonic complexity ($\chi^2(2) = 120.82$, $p < 0.001$) and the interaction between rhythmic and harmonic complexity ($\chi^2(2) = 11.74$, $p < 0.001$) as predictors to the model significantly increased the model fit indices (Supplementary Table 2). Results indicated a significant interaction between rhythmic and harmonic complexity on wanting to move ratings ($b(1197) = 0.092$, $p < 0.001$, 95% CI [0.039, 0.145]). Similar to pleasure ratings, the contrast analyses indicated a significant quadratic trend for both rhythmic ($b(1195) = -0.896$, $p = 0.01$, 95% CI [-0.989, -0.803]) and harmonic complexity ($b(1328) = -0.144$, $p = 0.01$, 95% CI [-0.253, -0.035]). Wanting to move ratings follow a similar trend to pleasure ratings regarding rhythmic complexity, as medium complexity resulted in significantly higher ratings compared to low complexity ($b(1195) = -0.122$, $p < 0.001$ 95% CI [-0.176, -0.068]), and low resulted in significantly higher ratings compared to high complexity ($b(1195) = 0.652$, $p < 0.001$, 95% CI [0.598, 0.706]). As in pleasure ratings, the quadratic effect was stronger for rhythmic complexity than harmonic complexity. While the quadratic trend was also significant, like with pleasure ratings, the contrasts demonstrate more of a linear relationship. Low harmonic complexity resulted in a significantly higher wanting to move ratings compared to medium complexity ($b(1195) = 0.177$, $p < 0.001$, 95% CI [0.114, 0.24]), while medium complexity resulted in significantly higher ratings compared to high complexity ($b(1195) = 0.774$, $p < 0.001$, 95% CI [0.72, 0.828]).

It is counterintuitive to think that harmonic complexity affects wanting to move ratings on its own. Therefore, it would make sense that harmonic complexity affects wanting to move ratings via its effect on pleasure ratings. This concept is further supported by previous research using the same stimuli, which demonstrated that pleasure ratings mediate the effect of harmonic complexity on the wanting to move ratings.[8] We conducted the same analyses in the current sample and replicated the previous findings. For rhythmic complexity, when pleasure ratings are added into the model, the effect on wanting to move ratings significantly decreased. An indirect effect (*IE*) emerged (*IE* = -0.33, $p < 0.001$, 95% CI [-0.368, -0.29]), but the average direct effect (*DE*) remained significant (*DE* = -0.03, $p < 0.001$, 95% CI [-0.049, -0.01]).

When pleasure was introduced into the model as a predictor, the effect of harmonic complexity on wanting to move ratings, an indirect effect emerged (*IE* = -0.218, $p < 0.001$, 95% CI [-0.218, -0.18], and the direct effect became non-significant (*DE* = 0.017, $p = 0.064$, 95% CI [-0.002, 0.03]. These results replicate the findings of Matthews et al., 2019,[8] supporting the idea that harmonic complexity influences wanting to move ratings primarily through its effect on pleasure ratings.

Musical Anhedonia and Match Sample Comparisons

For visualization of the data, please see Figure 3. Consistent with the results for the control sample, adding rhythmic ($\chi^2(2) = 19.13$, $p < 0.001$) and harmonic complexity ($\chi^2(2) = 19.65$, $p < 0.001$) as predictors to the models predicting pleasure ratings within the musical anhedonia sample significantly increases the model fit indices. Unlike the full sample, the addition of the interaction effect between rhythmic and harmonic complexity did not result in a significant improvement to the model fit ($\chi^2(2) = 2.16$, $p = 0.142$; See Supplementary Table 2). The same is seen for the model predicting wanting to move ratings (Rhythmic complexity: $\chi^2(2) = 20.82$, $p < 0.001$, Harmonic complexity: $\chi^2(2) = 17.22$, $p < 0.001$, Rhythmic/Harmonic Complexity Interaction: $\chi^2(2) = 2.9$, $p = 0.085$). Both the musical anhedonia and the matched control group followed the same pattern of results seen for the full control sample, with rhythmic and harmonic complexity being significant predictors of both pleasure and wanting to move ratings (see Table 2). To compare the musical anhedonia and matched control group sample, an effect of group and its interaction was added to both the pleasure and wanting to move models. Results from the models indicated that there was no statistically significant difference between the musical anhedonia and matched control group or between the interactive effects of rhythmic or harmonic complexity (see Table 2). Additionally, the correlation between pleasure and wanting to move ratings were similar between the musical anhedonia (*r* = 0.939) and matched control group (*r* = 0.914).

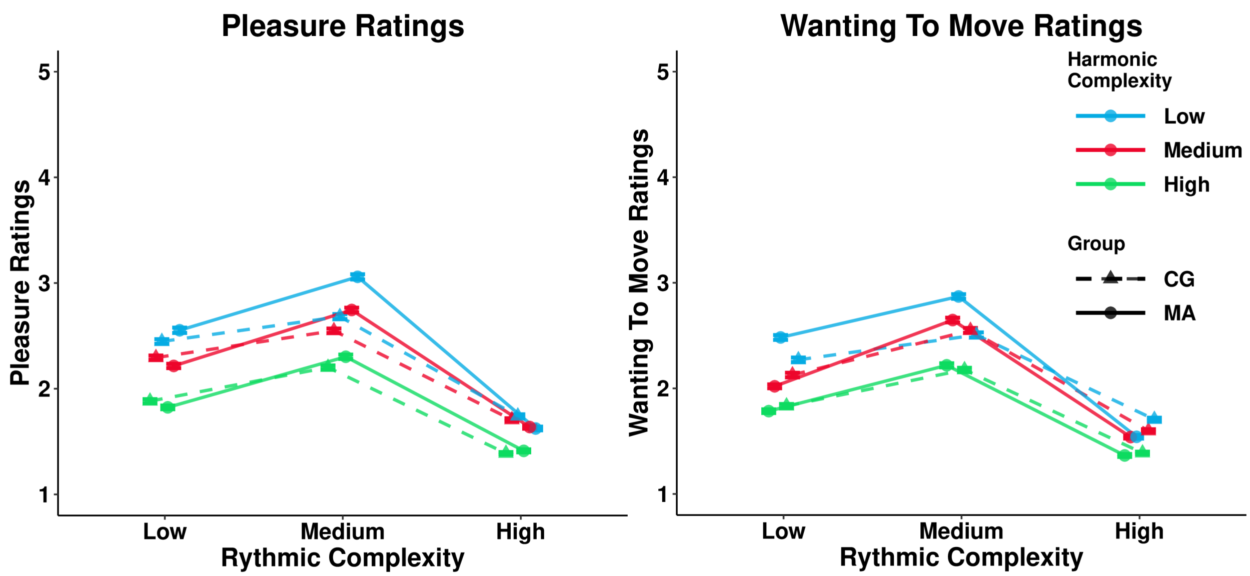

Fig 3. The Effect of Rhythmic and Harmonic Complexity on Groove Response for the Musical Anhedonia. The musical anhedonia sample values were adjusted by 0.2 on the x and y-axes for graphical representation. The y-axis represents pleasure or wanting to move ratings on a 5-point Likert scale. The x-axis represents the metric complexity of the musical samples. Colours indicates the level of harmonic complexity of the musical sample. Shapes and line type indicates if it is either the musical anhedonia sample, or the matched control sample. Dots represent means derived from raw values.

Table 2. Linear Mixed Effect Model Results for the Musical Anhedonia and Matched Control Sample

	Pleasure Ratings					*Wanting To Move Ratings*				
	df	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*	*df*	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*
RC	266	-0.645	0.062	-1.32	0.029	266	-0.749	0.027*	-1.41	-0.088
HC	266	-0.687	0.047*	-1.36	-0.013	266	-0.753	0.026*	-1.41	-0.092
GRP	261	-0.411	0.437	-1.45	0.62	263	-0.608	0.24	-1.62	0.404
RC ~ HC	266	0.163	0.307	-0.149	0.475	266	0.204	0.194	-0.102	0.509
RC ~ GRP	266	0.106	0.625	-0.32	0.532	266	0.194	0.365	-0.224	0.612
HC ~ GRP	266	0.166	0.45	-0.26	0.592	266	0.244	0.254	-0.174	0.662
RC ~ HC ~ GRP	266	-0.049	0.63	-0.246	0.149	266	-0.077	0.434	-0.271	0.116

RC = Rhythmic Complexity, HC = Harmonic Complexity, GRP = Group, ~ signifies an interaction, *df* = Degrees of freedom, CI = Confidence Intervals, * indicates *p*-value < 0.05

The same contrast analyses conducted for the full control sample were conducted for the musical anhedonia. Rhythmic complexity showed a significant quadratic relationship with both pleasure ($b(132) = -1.630$, $p < 0.001$, 95% CI [-1.97, -1.29]) and wanting to move ($b(132) = -1.57$, $p < 0.001$, 95% CI [-1.88, -1.26]) ratings. Unlike in the full sample, in the musical anhedonia sample, harmony did not show a significant quadratic relationship with either wanting to move ($b(132) = -0.043$, $p =$ 0. 79, 95% CI [-0.358, 0.272]) or pleasure ratings ($b(132) = -0.122$, $p = 0.482$, 95% CI [-0.461, 0.217]). Besides this, the pattern of results was identical to those seen in the analysis of the full sample (see Table 3). The contrast analyses for matched control sample showed a similar pattern of results to the musical anhedonia sample (see Table 3).

Table 3. Contrast Analyses for the Musical Anhedonia and Matched Control Sample

	Pleasure Ratings					*Wanting To Move Ratings*				
	df	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*	*df*	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*
MA: LR - MR	132	-0.505	< 0.001*	-0.701	-0.309	132	-0.483	< 0.001*	-0.665	-0.301
MA: MR - HR	132	1.126	< 0.001*	0.93	1.322	132	1.09	< 0.001*	0.908	1.272
MA: LH - MH	132	0.232	0.0564	0.036	0.428	132	0.236	0.032*	0.054	0.418
MA: MH - HH	132	0.354	0.002*	0.158	0.55	132	0.279	0.009*	0.097	0.461
CG: LR - MR	132	-0.271	< 0.001*	-0.387	-0.155	140	-0.333	0.001*	-0.508	-0.158
CG: MR - HR	132	0.871	< 0.001*	0.757	0.985	140	0.862	< 0.001*	0.687	1.037
CG: LH - MH	132	0.088	0.303	-0.029	0.204	140	0.049	0.848	-0.126	0.224
CG: MH - HH	132	0.353	< 0.001*	0.24	0.466	140	0.288	0.005*	0.113	0.463

MA = Musical Anhedonia Sample, CG = Matched Control Sample, LR = Low Rhythmic Complexity, MR = Medium Rhythmic Complexity, HR = High Rhythmic Complexity, LH = Low Harmonic Complexity, MH = Medium Harmonic Complexity, HH = High Harmonic Complexity, *df* = Degrees of freedom, CI = Confidence Intervals, * indicates *p*-value < 0.05

Mediation Analysis – Musical Anhedonia and Matched Control Sample

We expected that individuals with musical anhedonia would experience lower perceived pleasure from music. Therefore, we hypothesized that the relationship between rhythmic and harmonic complexity and pleasure responses was maintained through the relationship via wanting to move ratings. A mediation analysis was conducted to determine if wanting to move ratings mediated the effect of rhythmic and harmonic complexity on pleasure ratings. When wanting to move was added to the model, the significant direct effects of both harmonic ($DE = -0.044$, $p = 0.12$, 95% CI [-0.097, 0.01]) and rhythmic ($DE = -0.014$, $p = 0.62$, 95% CI [-0.069, 0.04]) complexity on pleasure ratings became non-significant, indicating that wanting to move ratings completely mediated these effects (Harmonic complexity: $IE = -0.287$, $p < 0.001$,95% CI[-0.421, -0.17]; Rhythmic complexity: $IE = -0.303$, $p < 0.001$, 95% CI [-0.432, -0.17]). Contrast analyses indicated that when wanting to move was added to the model, all of the contrast analyses became non-significant (see Table 4). To determine if these findings were due to lack of statistical power or not, the same mediation analysis was run on the matched control sample. Unlike with the musical anhedonia sample, when wanting to move ratings were added to the model, the significant direct effects of both rhythmic ($DE = -0.073$, $p = 0.008$, CI [-0.124, -0.02]) and harmonic complexity ($DE = -0.079$, $p = 0.002$, CI [-0.126, -0.03]) were significantly reduced, and an indirect effect emerged for both (Rhythm: $IE = -0.257$, $p < 0.001$, CI [-0.349, -0.17]; Harmony: $IE = -0.192$, $p < 0.001$, CI [-0.282, -0.11]). Contrast analyses indicated that when wanting to move ratings were added to the model, some of the contrast analyses, but not all became non-significant, supporting partial mediation (see Table 4).

Table 4. Contrast Analyses for the Mediation Analysis for the Musical Anhedonia and Matched Control Samples

	Musical Anhedonia Group					*Matched Control Group*				
	df	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*	*df*	*b*	*p*	*Lower Bound 95% CI*	*Upper Bound 95% CI*
LR - MR	135	-0.049	0.668	-0.161	0.631	130	0.006	0.993	-0.092	0.104
LR-HR	138	0.049	0.69	-0.068	0.166	134	0.165	0.006*	0.611	0.269
MR - HR	143	0.098	0.367	-0.044	0.24	140	0.16	0.026*	0.041	0.279
LH - MH	129	0.01	0.983	-0.096	0.125	127	0.055	0.484	-0.039	0.099
LH-HH	136	0.101	0.192	-0.012	0.214	131	0.171	0.002*	0.073	0.269
MH - HH	130	0.091	0.218	-0.015	0.198	130	0.116	0.053	0.019	0.213

LR = Low Rhythmic Complexity, MR = Medium Rhythmic Complexity, HR = High Rhythmic Complexity, LH = Low Harmonic Complexity, MH = Medium Harmonic Complexity, HH = High Harmonic Complexity, *df* = Degrees of freedom, CI = Confidence Intervals, * indicates *p*-value < 0.05

Discussion

The present study set out to investigate if pleasure and the urge to move can be separated from one another in the sensation of groove. We did this by comparing ratings of wanting to move and pleasure in a large sample of controls and in people with specific musical anhedonia. We hypothesized that if wanting to move and pleasure are separable, individuals with specific musical anhedonia would show reduced ratings of pleasure but preserved ratings of wanting to move. Instead, those with musical anhedonia showed the same inverted U-shaped response to groove stimuli for both pleasure and wanting to move as controls. We then used mediation analysis to show that the pleasure response in those with musical anhedonia was fully mediated by wanting to move ratings, whereas the pleasure response in controls showed only partial mediation. This pattern of results indicates that for those with musical anhedonia the urge to move preserves their pleasure response. More broadly, these findings suggest that the desire to move may itself generate pleasure, contributing directly to the experience of groove.

For both ratings of wanting to move and pleasure we found an inverted U-shaped pattern of responses for rhythmic complexity across all our samples such that medium levels of complexity produced the highest ratings. This is consistent with previous studies using the same stimuli [8] and with other studies using either real musical clips or drum breaks.[7,14] Inconsistent with results from Matthews et al., 2019,[8] our contrast analyses indicated that low harmonic complexity induced significantly higher ratings of pleasure and urge to move compared to medium harmonic complexity. These findings are, however, consistent with those found by Stupacher et al., 2022.[9] The mediation analyses conducted for the full sample also replicated the findings of our previous study using the same materials.[8] Pleasure ratings acted as a partial mediator for the effect of rhythmic complexity on urge to move ratings. The effect of harmonic complexity on the urge to move ratings was also fully mediated by pleasure ratings. Both results support the concept that pleasure and urge to move ratings are partially separable from one another

Surprisingly, we found no difference in pleasure or urge to move ratings between the musical anhedonia sample and the matched control sample, either in terms of overall ratings or in the inverted-U shaped pattern across levels of metrical complexity. This indicates the overall blunted pleasure response to music in those with musical anhedonia does not affect their ability to derive pleasure from groove stimuli. We hypothesized that this preserved response might be based on pleasure derived from the urge to move in these participants. To test this idea, we conducted a mediation analysis on the musical anhedonia sample and demonstrated that the wanting to move ratings completely mediated the effect of both harmonic and rhythmic complexity on pleasure ratings. These results support the idea the groove may be maintained in those with musical anhedonia through the urge to move ratings. More broadly, these results imply that the urge to move is a central component of groove that differentiates it from other modalities of enjoying music.

Further work needs to be done to identify why the pleasure component of groove is different than other forms of pleasure derived from music. One potential mechanism could be that the pleasure derived from groove originates from the urge to move through its refinement of our predictions. Predictive coding conceptualizes the urge to move as the brain's attempt to minimize the prediction error between our top-down model and the bottom-up sensory information. Previous work has demonstrated that individuals' perceived accuracy on tapping tasks was associated with higher pleasure ratings [40]. If the urge to move arises from minimizing our prediction error in an attempt to produce a more accurate prediction, then it would make sense if the pleasure elicited from groove is derived from this perception of a more accurate perception.

This idea of the urge to move being the producer of the pleasure response in groove makes sense to explain why we may see the observed pattern of responses in those with musical anhedonia. A previous brain imaging study found that individuals with musical anhedonia had decreased functional connectivity between the right auditory cortex and the ventral striatum.[22] Areas of the ventral striatum, such as the NAcc, are related to the processing of reward stimuli.1[8,40-42]. Given this disruption in functional connectivity between the auditory cortex and ventral striatum, one would expect to see lower ratings for pleasure from music. The sensation of groove could rely more on temporal predictive process supported by motor and premotor areas. Work has been done to demonstrate that the anticipation of beat and beat perception relies on the motor system including the dorsal striatum.[43-46] This is consistent with the findings of Matthews et al. (2020),[12] who showed that both dorsal and ventral striatum were active in response to high groove stimuli and that activity in the dorsal striatum was primarily related to ratings of urge to move.

Conclusion

The present study found that individuals with musical anhedonia demonstrate a preserved pleasure response for groove stimuli that is potentially mediated through the urge to move. The urge to move has been linked to dorsal striatal reward circuits, while pleasure is more associated with ventral striatal circuits (Matthews, 2020). Thus, we hypothesize that the groove response in anhedonia is preserved through dorsal striatal connections with motor and auditory regions. More generally, our results suggest that the sensation of groove may be different from other types of musical pleasure in that the urge to move may be a primary source of the pleasurable experience. This thinking aligns with definitions of the groove sensation that emphasize the role of movement (Janata et al. (2012)[6] and Madison (2006))[5]. Future work examining possible intrinsic reward value of movement could shed light on these findings.

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