Wait For It: An EEG Exploration Of Excitement In Dance Music

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Abstract

Previous brain-related studies on music-evoked emotions have relied on listening to long music segments, which may reduce the precision of correlating emotional cues to specific brain areas. Break routines in electronic dance music (EDM) are emotive but short music moments containing three passages: breakdown, build-up, and drop. Within build-ups music features increase to peak moments prior to highly expected drop passages and peak-pleasurable emotions when these expectations are fulfilled. The neural correlates of peak-pleasurable emotions (such as excitement) in the short seconds of build-up and drop passages in EDM break routines are therefore good candidates to study brain correlates of emotion. Thirty-six participants listened to break routines while undergoing continuous EEG. Source reconstruction of EEG epochs for one second of build-up and of drop passages showed that pre- and post-central gyri and precuneus were more active during build-ups, and the inferior frontal gyrus (IFG) and middle frontal gyrus (MFG) were more active within drop passages. Importantly, IFG and MFG activity showed a correlation with ratings of subjective excitement during drop passages. The results suggest expectation is important in inducing peak-pleasurable experiences and brain activity changes within seconds of reported feelings of excitement during EDM break routines.

Received November 27, 2019, accepted November 7, 2020.

Key words: break routines, peak-pleasurable emotions, expectancy, inferior frontal gyrus (IFG), middle frontal gyrus (MFG)

Peak-pleasurable experiences are defined as intense emotions to stimuli, such as music, which often co-occur with physiological responses, including increased heart rate and skin conductance (Blood & Zatorre, 2001; Gabrielsson, 2001; Habibi & Damasio, 2014; Lamont, 2011; Menon & Levitin, 2005; Särkämö & Soto, 2012; Solberg & Dibben, 2019). Previous research has shown that music can consistently evoke powerful emotions, such as excitement, which can make the music more attractive and be associated with motor sensory experiences, including the desire to dance (Holbrook & Gardner, 1993; Lamont, 2011; Panzarella, 1980; Solberg & Jensenius, 2017) Also, peak pleasure and excitement in music and their simultaneous physiological responses can be associated with the passive apprehension of music features, such as rhythm, pitch, and melodies, as well as brain activity related to reward, arousal, and emotion (Habibi & Damasio, 2014; Meltzer et al., 2015; Rolison & Edworthy, 2013; Särkämö & Soto, 2012). For instance, peak responses to music have been linked to greater levels of dopamine in the striatal system, as well as increased blood flow within the orbitofrontal cortex and ventral medial prefrontal cortex (Blood & Zatorre, 2001; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). Thus, music-evoked emotional experiences are correlated with patterns of brain activity associated with positive reward, noticeably within the prefrontal cortex (PFC).

One dominant theory exploring why music can be so emotive is that of expectancy (Meyer, 1956). Music is a temporal and dynamic construct that often includes certain syntactic structures, similar to language, allowing listeners to develop predictions and expectancies surrounding musical features (Huron, 2006; Jones, 1982; Koelsch, 2014; Kunert, Willems, Casasanto, Patel, & Hagoort, 2015; Solberg, 2014; Vuust & Witek, 2014). The schematic structure of music can be learned through repeated exposure to music genres, enabling statistical and rule-based learning, which facilitates expectations (Agres, Abdallah, & Pearce, 2017; Asano & Boeckx, 2015; Huron, 2006; Solberg & Dibben, 2019). Pleasurable emotions, including excitement, are proposed to occur when music expectations are fulfilled as expected, delayed, or violated in some unexpected development of the musical piece (Grewe, Nagel, Kopiez, & Altenmüller, 2007; Huron, 2006; Meyer, 1956; Solberg & Dibben, 2019). Different music genres create their structures in different ways, resulting in different expectancies and affects (Koelsch, 2014).

Huron’s (2006) theory of ITPRA (imagination, tension, prediction, reaction, and appraisal) suggests that expectancies are important to music’s peak-pleasurable emotions. As the structure of music is learned, listeners can predict the future direction of musical passages and can imagine this. Tension can be experienced as listeners predict and approach anticipated events in the music. (Huron, 2006; Solberg, 2014; Solberg & Dibben, 2019). When expectations are fulfilled, listeners react with peak-pleasurable emotions, such as excitement and satisfaction, which often co-occur with physiological sensations, including chills (Arjmand, Hohagen, Paton, & Rickard, 2017; Grewe et al., 2007; Koelsch, 2014; Koelsch, Fritz, & Schlaug, 2008; Omigie, 2016; Solberg & Dibben, 2019; Zentner, Grandjean, & Scherer, 2008). After, listeners may appraise the music's emotive experience, learning its structure and features and refining predictions in future listening (Huron, 2006; Solberg, 2014, Solberg & Dibben, 2019).

Peak-pleasurable experiences, particularly excitement, are well recognized in electronic dance music (EDM). Creators such as producers, DJs, and musicians use different methods, such as vocoders, harmonizers, and samplers to manipulate musical features and create effects to construct passages that increase emotive and physiological pleasure (Butler, 2006; Solberg & Dibben, 2019). EDM has a range of sub-genres including Dubstep, Trance, and House, which are usually played at social events such as clubs, parties, and raves with the purpose of dancing (Solberg & Jensenius, 2019; Thompson & Stevenson, 2015). It is often created electronically with prominent features including several musical layers, a repetitive beat and rhythmic focus, drum roll effects, complex grooves, and numerous gradual upward movements in musical parameters, including pitch: termed "uplifters" (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019). Noticeably, EDM songs usually contain at least one large and intense change in structure, texture, or dynamics, referred to as the *break routine* (Solberg & Dibben, 2019).

Break routines are particularly emotive sections of EDM, which utilize moments of expectancy to induce the peak-pleasurable experience of excitement in listeners (Huron, 2006; Meyer, 1956; Solberg, 2014). There are three passages to a break routine: the *breakdown*, *build-up*, and *drop*, which have specific functions, as their names imply (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019; Solberg & Jensenius, 2017). The breakdown refers to when a music track's groove and intensity is diminished with the removal of several instruments and layers, such as the bass and bass drum. Afterwards, the build-up passage occurs and instrumental layers are gradually reintroduced to build the track back up and bring listeners into a peak moment. Then the drop passage begins, where the bass and bass drum is "dropped" back into the track and the main groove returns (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019; for a visual example see **Error! Reference source not found.**).

Insert Figure 1 about here

In EDM, break routines occur at least once per track for around 20 seconds, meaning listeners expect these short, salient, and emotive passages to occur (Butler, 2006; Solberg & Dibben, 2019). As break routines frequently follow a similar structure of breakdown, build-up, and drop, listeners familiar with the genre expect the drop into the main groove to occur after being built up to a peak moment and held in suspense (Solberg, 2014). However, listeners are uncertain of exactly when and how drop passages will occur; meaning, when they finally happen, listeners experience peak-pleasurable emotions, such as excitement (Huron, 2006, Meyer, 1956; Solberg & Dibben, 2019). Therefore, the musical features and specific structure used in EDM break routines may result in the peak-pleasurable experience of excitement as they create powerful moments of highly expected drop passages.

Previous research has shown numerous brain areas to be consistently involved in processing musical features during passive music listening, such as structure, rhythm, pitch, and melodies including: the inferior frontal gyrus (IFG), dorsolateral prefrontal cortex (DLPFC), and the middle frontal gyrus (MFG) (Kunert et al., 2015; Lappe, Steinsträter, & Pantev, 2013; Nan & Friederici, 2013; Royal, Zendel, Desjardins, Robitaille, & Peretz, 2018; Thaut, Trimarchi, & Davide, 2014). These areas and more, like the medial prefrontal cortex (MPFC), dorsolateral frontal cortex (DLFC), striatum, and amygdala, have also been associated with peak-positive emotions in music, including excitement, as well as physiological responses indicative of positive feelings, such as "chills" (Belfi, 2016; Greene, Flannery, & Soto, 2014; Koelsch, Fritz, Cramon, Müller, & Friederici, 2006; Lehne, Rohrmeier, & Koelsch, 2014; Mitsuyoshi et al., 2011; Tabatabaie et al., 2014; Wallmark, Deblieck, & Iacoboni, 2018). One reason why numerous brain areas may relate to pleasurable emotions, like excitement, is that studies often record brain activity over time periods in the range of several minutes (Koelsch et al., 2006; Lehne et al., 2014; Tabatabaie et al., 2014).

Whereas the neural correlates of listening to emotional music have been studied to some extent, the neural correlates of peak-pleasurable music experiences, particularly excitement, are less well known. Our study uses EDM break routines as a tool to explore temporal brain activity changes during peak-pleasurable emotions, in this case excitement, within seconds of the drop passage (Solberg, 2014; Solberg & Dibben, 2019). Using only seconds of music enables a clearer picture of which brain areas relate to the peak-pleasurable experience of excitement at specific music moments.

We explored the relationship between peak-pleasurable emotions and brain activity (using electroencephalogram (EEG) and source reconstruction). Specifically, the present research focused on brain activity related to subjective excitement ratings within a 20 s section of music including build-up and drop passages in EDM break routines of varying rated strengths. We recorded EEG during the presentation of song clips and then developed 3D source reconstructions of brain activity differences across build-up and drop passages. Correlation of brain activity with subjective excitement ratings was also examined, allowing us to describe what brain activity changes may correlate with processing musical features and to peak-pleasurable experiences. We hypothesized that fewer areas of PFC activity, including the IFG, DLPFC, and MFG, would correlate with apprehension of short and highly expected drop passages in EDM break routines, as well as with greater subjective ratings of excitement.

Method

Participants

A total of 36 participants were recruited via the University of Kent's research participation scheme in exchange for course credits (24 females, age *M* = 20.36, *SD* = 4.37). Twenty-seven participants were white European, one black European, and the remaining eight were Asian. Participants had a mean of 2.32 (*SD* = 3.21) years of musical experience (*Mdn* = 1 year). They also indicated that on average they visit clubs 0.88 (*SD* = 0.83) times per week *(Mdn* = 0.5 times per week), and on average they hear similar songs for 2.30 (*SD* = 0.73) times a week *(Mdn* = 2 times per week). Participants were right-handed, required to have normal or corrected-to-normal vision and hearing, and no neurological illnesses. None of the participants were taking any centrally acting medication, which might modulate brain response to emotional stimuli. Participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol of the study was approved by the ethics committee at the University of Kent.

Stimuli

Originally, 180 songs that contained at least one break routine were identified by the first author and a student from a range of electronic dance music (EDM) genres, including:

Dance, Drum & Bass, Dub-Step, House, and Trance. These subgenres of EDM follow a similar overall structure including structured verses and choruses containing break routines, but differ in tempo, frequencies, and drop strengths. For instance, dance songs included Michael Calfan's "Nobody Does It Better" and Drum & Bass involved songs such as Mediks' "Original Selecta." For the complete list of songs see the associated data via DOI link 10.17605/OSF.IO/8WSTF. The times of build-up and drop within each song's break routine were noted by the first and third authors, and compared for reliability. The indicated times showed low variability, *M* (*SD*) = 70 (90) ms, *Mdn* = 10 ms. These values are within the time periods extracted from the EEG data: the last 1 s of build-up passage and the first 1 s of the drop passage. One break routine was then extracted from each song using MATLAB (MathWorks, California, US) to create a roughly 20-s clip containing the build-up and drop passages of a break routine with 1-s fade-in and -out. The duration of 20 s was selected based on the length of break routines, long enough to fit the build-up and part of the drop passages (**Error! Reference source not found.**).

Insert Figure 2 about here

All 180 break routine clips were then piloted online using Qualtrics and a university sample via a research participation scheme (*N* = 156). Stimuli were divided into three online questionnaires (60 clips and *n* = 52 per questionnaire) to avoid excessive fatigue. Participants rated the familiarity and strength of drops in the break routines using a 5-point (1 = *not familiar at all* and 5 = *extremely familiar*) and 10-point scale (1 = *not strong at all* and 10 = *extremely strong*), respectively. They also rated experienced excitement for each break routine with a 10-point scale (10 = *extremely exciting* and 1 = *not exciting at all*). Participants were instructed to indicate their levels of excitement on the scale via their computer mouse.

Highly familiar songs were then excluded and 90 break routine clips varying in strength and excitement ratings from the remaining clips were randomly selected to create the stimulus set for the main study.

	Pilot		
Mean (*SD*)	**Excitement (1-9)†**	**Strength (1-10)**	**Familiarity (1-5)**
Pilot			

Excitement	4.80 (1.13)		*r*(88) = .828, *p* < .001*	*r*(88) = .124, *p* = .245
Strength	4.72 (0.81)	*r*(88) = .828, *p* < .001*		*r*(88) = .425, *p* < .001*
Familiarity	1.97 (0.64)	*r*(88) = .124, *p* = .245	*r*(88) = .425, *p* < .001*	
Study				
Excitement	5.26 (0.48)	*r*(88) = .597, *p* < .001*	*r*(88) = .487, *p* < .001*	*r*(88) = .219, *p* = .038*

Table 1 shows the correlation between the three parameters of excitement, strength, and familiarity as elicited in the pilot phase. Selected clips for the main study were rated on average of being low familiarity (min = 1, max = 3.58, *M* = 1.97, *SD* = 0.64). Duration of stimuli in the main study varied between 18 to 22 s with the moment of drop varying between 12 to 16 s. Duration of drop music passages were kept to 6 s.

Insert Table 1 about here

To investigate the relationships between musical features and subjective ratings of excitement the break routine clips were imported and analyzed via the MIR toolbox (Lartillot, Toiviainen, & Eerola, 2008) for MATLAB. We extracted acoustic features related to dynamics, timbre, rhythm, and tonality (Solberg & Dibben, 2019).

Procedure

At arrival, participants provided written informed consent and then EEG was set up (see EEG Recording), taking approximately 40 min. High-performance headphones (Marley Positive Vibration headphones with 50 mm speakers) were carefully placed atop the EEG cap, ensuring no noise resulted from this placement. Participants listened to a piece of drum music to test volume, which was adjusted on an individual basis to ensure clear and comfortable listening.

The paradigm was then explained, informing participants they would be presented with 90 song clips, each 18–22 s long, and to listen to each clip carefully. Psychtoolbox v3 (Brainard, 1997) on MATLAB was used to present visual and auditory stimuli, and record subjective ratings. Each trial began with a fixation cross of 3 s jittered for ±1 s with uniform distribution. Subsequently, a break routine clip was presented alongside a fixation point on which participants were asked to keep their gaze on, minimizing eye movement. Following each break routine clip, a question mark was displayed. The participants' task was to indicate felt levels of excitement based on their own understanding of the peak-pleasurable experience. They had to rate their experienced excitement on a 9-point scale (9 = *very exciting* and 1 = *not exciting*) via the numerical pad on a computer keyboard. A 9-point scale was used instead of 10, as the numerical pads only went to 9 digits. Participants were asked to respond as quickly as possible within a 2-s period (See **Error! Reference source not found.**). Stimuli were randomly presented in four blocks with 5-min breaks in-between to prevent fatigue.

Insert Figure 3 about here

Once finished, MATLAB automatically closed, and the researcher stopped recording and removed the EEG. Participants then completed an online Qualtrics questionnaire with questions on demographics (gender and ethnicity), musical instrument ability, and social life (how often they visit clubs etc., and how often this occurs with music that contains break routines).

EEG Recording

EEG was recorded continuously from 32 Ag/AgCl electrodes with a BrainVision QuickAmp-72 amplifier system (Brain Products, Germany) placed according to the 10–20 electrode placement system (including electrodes; Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, TP9, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, PO9, Oz, PO10, and ground and reference electrodes). Two further electrodes were placed directly below and near the outer corner of the right eye to record vertical and horizontal eye movements. Raw EEG was sampled at 512 Hz with 12-bit resolution. Markers were placed at the beginning of each break routine clip, at the moment each drop passage began, at the end of each clip and when participants responded.

Analysis of Excitement Ratings

Ratings of experienced excitement were aggregated for each break routine clip, creating a mean excitement value per break routine across all participants. These ratings were compared with those in the pilot study using a two-sample independent *t*-test. Furthermore, correlations of these values with the three ratings recorded in the pilot study (excitement, drop strength, and familiarity) were calculated using nonparametric Spearman correlation analysis. Nonparametric Spearman correlation analysis was used as some of the measures were not normally distributed. False discovery rate (FDR) correction for multiple comparison was used (Benjamini & Hochberg, 1995; Finner & Roters, 2001).

Analysis of EEG Data

Our interest was to infer the neural substrates of excitement in response to break routines. Therefore, analysis was done at the source level. We used 3D source reconstruction to have an indication of activity locations, and to look at average differences in activity over build-up and drop passages in break routines.

EEG data were analyzed using SPM v12 (statistical parametric mapping, Wellcome Trust, London, UK). Data was filtered for 0.5–48 Hz using 7th order Butterworth filter, montaged based on average electrode activity, and downsampled to 128 Hz data. Then, artifacts contributed by eye-blinks were removed using activity of the FP2 electrode and the topography-based artifact correction method: spatial confounds were indicated based on Singular Value Decomposition (SVD) mode and sensor data was corrected using Signal-Space Projection (SSP) correction mode. A maximum of two components of spatial confounds was removed from the EEG data. At the next stage, 1 s of the end of build-up and 1 s of the beginning of drop passages were extracted. Finally, an automatic artifact detection algorithm was applied to the epochs, rejecting those with more than 100 μv peak to peak amplitude. A 3D source reconstruction algorithm was then used to extract brain maps of activity sources. EEG Boundary Element Methods (BEM) with normal mesh resolution was used on the SPM template and cortical smoothing for eight iterations. Therefore, overall 2 × 90 brain volumes were created: build-up and drop music passages for 90 break routines. Finally, brain volumes related to build-up and drop passages were subtracted to create 90 more “difference-activity volumes.” These difference-activity volumes were then subjected to two analyses (Table 2), as well as a validation analysis.

Insert Table 2 about here

Absolute activity: This analysis identified brain areas where activity was significantly different between the build-up and drop music passages. This was done with a one-sample *t*-test on the difference-activity volumes, where the value of each voxel was compared with 0 to show which voxels were significantly higher than 0 (indicating higher activity in the drop passage), or lower than 0 (indicating lower activity in the drop passage) across participants.

Correlational activity: The second analysis was to investigate brain areas where activity correlated with subjective excitement ratings. First, every voxel in difference-activity volumes were correlated with subject excitement ratings to calculate correlation coefficients per voxel. Coefficients were used to construct new brain volumes reflecting the relationship between brain activity differences and excitement ratings. These correlational brain volumes were then subjected to a one-sample *t*-test showing which voxels in difference activity volumes significantly correlated with subjective excitement ratings across participants.

Validation analysis: As a control for the passage of music and to ensure that the observed results were specific to the differences between build-up and drop music passages, we ran similar analyses examining changes in brain activity between earlier sections of break routine clips, as well as correlations of brain activity with subjective excitement ratings. We chose moments 4 s prior to the beginning of drop passages and extracted 1 s before and 1 s after as shifted build-up and shifted drop music passages, respectively (**Error! Reference source not found.**).

Insert Figure 4 about here

Family-wise error (FWE) correction for a 3 mm sphere around the peak voxel was used to investigate the significance of the *p* values (Flandin & Friston, 2019; Nichols & Hayasaka, 2003).

Results

Excitement Ratings

Mean subjective ratings of excitement were calculated for the 90 break routine clips. On average, clips were experienced as moderately exciting (M = 5.26, SD = 0.48, range 3.98–6.38). These values were also subjected to a correlation analysis with corresponding subjective ratings in the pilot study. This analysis showed a very strong correlation, $r(88)$ = .597, p < .001. Similar analyses were run to investigate correlations between subjective ratings of excitement during the main study and with subjective ratings of strength and familiarity in the pilot. These analyses showed significant correlations with both strength and familiarity measures (

Table 1). **Error! Reference source not found.** illustrates the distribution of the subjective excitement ratings for the pilot and main studies, as well as ratings of strength and

		Pilot		
	Mean (*SD*)	**Excitement (1-9)†**	**Strength (1-10)**	**Familiarity (1-5)**
Pilot				
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Study				
Excitement	5.26 (0.48)	$r(88) = .597, p < .001$*	$r(88) = .487, p < .001$*	$r(88) = .219, p = .038$*

familiarity in pilot study.

In order to check for possible associations between subjective ratings of excitement and musical features, we carried out correlational analyses between subjective ratings and acoustic features in the break routine clips (Table 3). Results of the analyses indicated significant positive correlations with spectral flux, brightness, roughness, and power spectrum for both studies, but not with loudness, beat clarity, or mode (Solberg & Dibben, 2019).

Insert Figure 5 about here

Insert Table 3 about here

EEG Analysis

Three participants were excluded, as their eye-blink activity was not within the first two components of spatial confounds. Therefore, data for 33 participants are reported here.

Analysis of the 3D source reconstructed data revealed areas with significant differences in activity between build-up and drop passages in a break routine. Specifically, inferior and middle frontal gyri (IFG and MFG) activity was significantly greater during drop passages, whereas pre and postcentral gyri (PreCG and PostCG) and precuneus (PCUN) activity was higher in build-up passages. For a table summarizing the analysis see Table 4, and also **Error! Reference source not found.** and **Error! Reference source not found.**.

Correlational analysis between differences in brain activity and excitement ratings demonstrated significantly greater activity in bilateral IFG and MFG areas during drop passages, meaning these areas correlated positively with subjective ratings of excitement in drop passages (see Table 4 and **Error! Reference source not found.**).

The results of validation analysis showed no significant difference between the brain activity in shifted build-up and shifted drop music passages (p's > .240 uncorrected).

Insert Table 4 about here

Insert Figures 6 + 7 + 8 about here

Discussion

Here we offer the first exploration into how music expectancy relates to brain activity and peak-pleasurable emotions across seconds, using EDM break routines. We showed that break routines (i.e., build-up passages and peak-pleasurable experiences within expected drop passages) correspond to significant increases in brain activity across several regions, including: the bilateral inferior frontal gyrus (IFG; BA47), right middle frontal gyrus (MFG; BA46), bilateral pre- and post-central gyri (PreCG and PostCG; BA4 and 3), and precuneus (PCUN; BA7). Despite not all changes in brain responses being predicted, prior research linking areas with music processing and highly pleasurable emotions, such as excitement, suggests why such changes occurred (Altenmüller, Siggel, Mohammadi, Samii, & Münte, 2014; Bianco et al., 2016; Schön et al., 2010; Tabei, 2015; Thaut et al., 2014). Importantly, increased IFG and MFG activity correlated with excitement ratings during drop passages, linking these regions with peak-pleasurable emotions at moments where music expectations are fulfilled.

Brain Differences During Build-up Passages

Differences in brain activity between build-up and drop passages suggest the regions' functionality in music and emotion processing. For instance, the PreCG, PostCG, and PCUN were more active during build-up compared to drop passages. Despite the PreCG and PostCG mostly being linked to motor functions, they have also been implicated in music processing and integrating motor, somatosensory, and auditory information (Potes, Gunduz, Brunner, & Schalk, 2012; Ramos-Murguialday & Birbaumer, 2015; Tanaka & Kirino, 2018). The PreCG, PostCG, and PCUN play a role in music attention, and processing of tempo alterations, absolute pitch, rhythm perception, and music intensity (Dohn et al., 2015; Ono, Nakamura, & Maess, 2015; Potes et al., 2012; Schön et al., 2010; Thaut et al., 2014). In support of our hypothesis, greater PreCG, PostCG, and PCUN activity during build-up passages could be traced to processing specific music features, including tempo, rhythm, and intensity as they increase into peak moments. For instance, using MIR toolbox with 1-s intervals within the break routine for the track “Tantrum” (**Error! Reference source not found.**a), the tempo decreases from 175 bpm to 120b pm during the breakdown, returns back to 175 bpm during build-up, to then suddenly reduce to 120 bpm within the drop passage. Similarly, amplitude reduces to 85% towards the end of the build-up passage before going back to 100% during the drop passage.

Additionally, differences in PreCG, PostCG, and PCUN activity during build-up passages could be related to experiencing tension and expectancy (Bjork & Hommer, 2007; James, Michel, Britz, Vuilleumier, & Hauert, 2012; Lehne & Koelsch, 2015; Lehne et al., 2014; Thaut et al., 2014; Vuilleumier & Trost, 2015). For example, the PCUN is linked to evaluating music’s continuous structure and making perception-based predictions (Alluri et al., 2017; Trost et al., 2014). Thus, activity in the PreCG, PostCG, and PCUN may be linked to processing the structure of break routines and creating expectancies for drop passages after build-up sections. Greater activity within build-up passages may have also correlated with increased experiences of tension, as musical features build ahead of the expected but uncertain (of exactly how and when) drop passages. Future research could clarify this with continuous ratings of tension during build-up passages.

Brain Differences During Drop Passages

Both the IFG and MFG increased in activity across break routine build-up and drop passages, with greater activity during drop passages. The IFG has been related to perceiving music features (such as rhythm) and syntax (Koelsch, 2014; Lappe et al., 2013; Schön et al., 2010; Thaut et al., 2014). For example, increased IFG cortical thickness relates to greater capability in absolute pitch, and complex music, rhythm, and harmony perception (Dohn et al., 2015). Greater IFG activity within drop passages may therefore link to processing the expected changes in musical features, such as the bass and bass drum being reintroduced to the track and the main groove returning (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019).

Similar to the IFG, MFG activity may also relate to processing changes in music features between build-up and drop passages. For example, the MFG has been linked to overall and implicit music processing, working memory (WM; alongside the IFG), and musical rule perception (Bogert et al., 2016). This suggests the MFG's role in assessing the structure of break routines via WM and statistical rule processing, enabling expectations for drop passages and peak-pleasurable experiences when these are fulfilled. Therefore, greater MFG activity during drop passages may also support our hypothesis that PFC brain activity increased due the fulfillment of expectancies in break routines.

Correlation of Brain Differences with Excitement

Many brain areas have been related to experiencing peak-pleasurable emotions in music, including the parahippocampal gyrus, right parietotemporal area, anterior cingulate, orbitofrontal cortex, and the ventral and dorsal striatum (Bogert et al., 2016; Heller, 1993; Mitterschiffthaler, Fu, Dalton, Andrew, & Williams, 2007; Rogenmoser, Zollinger, Elmer, & Jäncke, 2016). Of particular interest here were areas showing changing activity levels across EDM break routines and correlation with peak-pleasurable experiences, such as excitement. Only IFG and MFG activity correlated with excitement ratings, with greater activity related to peak-pleasurable emotions. Greater MFG and IFG activity has previously been linked to experienced pleasant music emotions including nostalgia, happiness, liking, and empathy (Altenmüller et al., 2014; Barrett & Janata, 2016; Brattico et al., 2011; Joucla et al., 2018; Kim, Shinkareva, & Wedell, 2017; Koelsch et al., 2006; Tabei, 2015; Wallmark et al., 2018). Thus, increased MFG and IFG activity during drop passages and their correlation with excitement ratings could suggest greater peak-pleasurable emotions in listeners when expectations are fulfilled during drop passages (Barrett & Janata, 2016; Bogert et al., 2016; Gebauer, Kringelbach, & Vuust, 2012; Kim et al., 2017; Kohn et al., 2014; Lehne et al., 2014; Pecenka, Engel, & Keller, 2013; Tillmann, Janata, & Bharucha, 2003; Wallmark et al., 2018).

Linking Break Routines, Brain Differences, and Emotions

Familiarity with EDM break routines facilitates expectations for build-up (escalating music features) and drop (where expectations are fulfilled) passages, relating to more peak-pleasurable emotions, as well as co-occurring IFG activity, respectively (Asano & Boeckx, 2015; Bianco et al., 2016; Huron, 2006; Koelsch, 2014; Kunert et al., 2015; Lehne & Koelsch, 2015; Lehne et al., 2014; Schön et al., 2010; Zatorre, Chen, & Penhune, 2007). We speculate that listener uncertainty about when and how drop passages will occur, alongside rising musical features, could relate to greater tension and PCUN activity during build-up passages (Vuilleumier & Trost, 2015). Therefore, preceding tension during build-up passages may amplify peak-pleasurable emotions within expected drop passages due to contrastive valence (which suggests positive emotions are increased when they are preceded by negative emotions) and relates to differences in IFG and MFG activity (Bianco et al., 2016; Huron, 2006; Lappe et al., 2013; Seger et al., 2013).

As break routines included in this study not only shared similar structures (breakdown, build-up, and drop passages) but also had common acoustic features, we ran correlations between music features and excitement ratings. Results showed significant correlations of spectral flux, brightness, roughness, and power spectrum with excitement ratings, but not loudness, beat clarity, or mode. Thus, several music features did appear to relate to experienced excitement, but not all prominent features in break routines, such as loudness, were linked to peak-pleasurable experiences.

The lack of significant differences in DLPFC activity across EDM break routines is inconsistent with our hypothesis that PFC activity would increase in relation to peak-pleasurable experiences during expected drop passages. The DLPFC is involved in music processing; specifically, it is more active during processing of highly familiar and rhythmic sounds, as well as during the detection of pitch alterations or deviances and experiencing pleasant emotions such as likability, empathy, arousal, and nostalgia (Altenmüller et al., 2014; Barrett & Janata, 2016; Bigliassi, León-Domínguez, & Altimari, 2015; Brattico et al., 2011; Doeller et al., 2003; Dohn et al., 2015; Flores-Gutiérrez et al., 2007; Joucla et al., 2018; Koelsch et al., 2006; Koelsch & Siebel, 2005; Plailly, Tillmann, & Royet, 2007; Platel et al., 1997; Seger et al., 2013; Wallmark et al., 2018). However, DLPFC activity may be genre-specific and is not always active during music listening. For example, increased DLPFC activity has been associated with classical music listening but not techno music (Bigliassi et al., 2015). Therefore, less DLPFC activity raises ambiguity as to its importance in processing EDM and break routines. Future research should evaluate the DLPFC’s role in peak-pleasurable emotions within other music genres.

Future Directions

Emotion was only recorded with one Likert scale on excitement, limiting responses to one emotion that is highly arousing with moderately positive valence (Russell, 1980). Different emotions with different levels of valence and arousal may elicit different neurological activity (the circumplex model; Russell, 1980; see Machizawa et al., 2020, for a three-axis model). For instance, differences in IFG and MFG activity might correspond to negative and arousing emotions (e.g., rage, anger, and fear; Chapin, Jantzen, Kelso, Steinberg, & Large, 2010; Flores-Gutiérrez et al., 2007). Also, physiological measures, such as skin conductance and heart rate alongside self-report would enable more reliable indications of emotions by capturing physical responses known to co-occur during peak-pleasurable experiences (e.g., the chills; Grewe et al., 2007; Solberg & Dibben, 2019).

We used 3D source reconstruction analysis of EEG data to assess changes in brain activity responding to peak-pleasurable emotions during EDM break routines. However, EEG has low spatial resolution and limited capacity to reach subcortical brain regions (Burle et al., 2015). Other neuroimaging methods, such as functional magnetic resonance imaging (fMRI), could clarify the brain regions related to break routines and peak-pleasurable emotions in further research. Also, other EEG analysis methods could be used to objectively measure peak-pleasurable emotions, such as independent component analysis (Lin, Duann, Feng, Chen, & Jung, 2014; Rogenmoser et al., 2016), functional connectivity (Alipour, Mohammadkhani, & Khosrowabadi, 2019; Wu et al., 2012), and frontal alpha-asymmetry (Briesemeister, Tamm, Heine, & Jacobs, 2013; Smith, Reznik, Stewart, & Allen, 2017). Future research could incorporate other EEG analysis methods and neuroimaging techniques, forming a better understanding of underlying brain responses, brain networks, and hemispheric differences.

Although we have demonstrated that EDM break routines relate to peak-pleasurable emotions and corresponding changes in PFC activity, we still do not know whether such effects are genre dependent. As break routines are highly expected and frequently occur within EDM, peak-pleasurable emotions may be experienced more strongly compared to other music genres (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019). Since peak-pleasurable experiences, such as excitement, relate to greater PFC activity, EDM may also correlate with increased PFC activity differences across break routine passages compared to other music genres. Further research should assess whether peak-pleasurable experiences related to music structures may vary in different genres.

Conclusions

This paper offers a novel insight into the neurological and emotive responses to short moments of expectancy in music, using EDM break routines. Activity in several brain areas including the IFG, MFG, PCUN, and PreCG and PostCG differed during either build-up (escalating music features) or drop (fulfilled expectations) passages, and may relate to the processing of specific music features (e.g., pitch and rhythm), syntax, tension, expectancy, and peak-pleasurable emotions (such as excitement). Future research should expand on the relationship between break routines, brain activity, and peak emotional responses within different music genres and using more neuroimaging and EEG methods, clarifying changes in brain activity and emotions linked to music structure and feature processing.

Author Note

Associated data can be accessed via DOI link 10.17605/OSF.IO/8WSTF. Data include raw EEG recordings per participant, all the 20s songs used in the study, their subjective ratings of excitement, strength and familiarity, as well as their musical features.

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Table 1. Summary of the Correlation Between Subjective Ratings in Pilot and Study for the 90 Songs Used in the Study

		Pilot		
	Mean (*SD*)	**Excitement (1-9)†**	**Strength (1-10)**	**Familiarity (1-5)**
Pilot				
Excitement	4.80 (1.13)		*r*(88) = .828, *p* < .001*	*r*(88) = .124, *p* = .245
Strength	4.72 (0.81)	*r*(88) = .828, *p* < .001*		*r*(88) = .425, *p* < .001*
Familiarity	1.97 (0.64)	*r*(88) = .124, *p* = .245	*r*(88) = .425, *p* < .001*	
Study				
Excitement	5.26 (0.48)	*r*(88) = .597, *p* < .001*	*r*(88) = .487, *p* < .001*	*r*(88) = .219, *p* = .038*

Notes: †Excitement value for the Pilot is mapped to 1-9 to match those in Study; * *p* ≤ .038, the family-wise discovery rate (FDR) corrected for multiple comparison (six correlations); *r*(degrees of freedom).

Table 2. Summary of the Brain Volumes Extracted for the Analyses and the Analyses Done on the Extracted Volumes

Volumes	
build-up passage volume	3D source reconstruction
drop passage volume	3D source reconstruction
difference-activity volume	drop passage volumes minus build-up passage volumes
correlation-coefficient volume	coefficients of correlations between difference-activity volumes and subjective excitement ratings
Analysis	
absolute activity	one-sample *t*-test on difference-activity volumes
correlational activity	one-sample *t*-test on correlation-coefficient volumes

Table 3. Spearman Correlation Between Subjective Ratings of Excitement in the Pilot and Main Study, and Various Acoustic Features

	Feature	**Pilot Study**	**Main Study**
Dynamics	Audio	$rs(88) = .223, p = .035^{\dagger}$	$rs(88) = .218, p = .039^{\dagger}$
	Global Energy (RMS)	$rs(88) = .227, p = .031$*	$rs(88) = .188, p = .076$
Timbre	Spectral Flux	$rs(88) = .512, p < .001$*	$rs(88) = .348, p = .001$*
	Brightness	$rs(69) = .563, p < .001$*	$rs(69) = .288, p = .015$*
	Roughness	$rs(88) = .413, p < .001$*	$rs(88) = .351, p = .001$*
Statistics	Spectrum	$rs(88) = .472, p < .001$*	$rs(88) = .391, p < .001$*
Rhythm	Beat Clarity	$rs(88) = -.136, p = .201$	$rs(88) = -.150, p = .157$
Tonality	Mode	$rs(88) = .228, p = .030$*	$rs(88) = .156, p = .142$

Notes: Brightness could not be calculated for some of the songs; $^{\dagger}p < .05$; $^{*}p \leq .031$, the false discovery rate (FDR) correction for multiple comparison (16 correlations); *rs*(degrees of freedom).

Table 4. Summary of the Analysis of the 3D Source Reconstruction of the EEG Data

								MNI		
	Brain Area	BA	K_E	P_{FWE}	T	Z	P_{uncorr}	x	y	z
Absolute Activity										
Drop > Build-up	r-Inf Frontal Gyrus	9	1021	.012	2.57	2.43	.007	56	22	16
	r-Mid Frontal Gyrus	46		.015	2.47	2.35	.009	46	38	10
Drop < Build-up	l-Precentral Gyrus	4	876	.016	2.44	2.32	.010	-58	0	14
	l-Precentral Gyrus	4		.017	2.41	2.29	.011	-58	-10	36
	l-Postcentral Gyrus	3		.019	2.37	2.26	.012	-64	-12	28
	r-Postcentral Gyrus	3	233	.031	2.11	2.03	.021	60	-14	24
	l-Postcentral Gyrus	40	244	.039	2.00	1.93	.027	-26	-38	60
	l-Precuneus	7		.041	1.98	1.91	.028	-24	-40	52
Correlational analysis										
Drop > Build-up	r-Inf Frontal Gyrus	47	457	.013	2.46	2.34	.010	46	32	-14
	r-Mid Frontal Gyrus	46		.016	2.38	2.27	.012	52	26	20
	l-Inf Frontal Gyrus	47	922	.014	2.44	2.32	.010	-40	34	-16

Note: K_E refers to the number of neighboring voxels with *p* value greater than the defined threshold of .05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; BA: Brodmann Area; Inf: Inferior; Mid: Middle; FWE is family-wise error correction for a 3 mm sphere around the peak voxel.

Figure Captions

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