The Emotional & Neurological Effects of Expectancy and Tension Within Electronic Dance Music

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Declaration

Research presented within this thesis was conducted at the School of Psychology, University of Kent, while a full-time postgraduate student. Theoretical and empirical work was supported by the supervision of Dr. Amir-Homayoun Javadi. Some data collect was assisted by others. Findings from Chapters 2, 3, 4 and 5 are in different stages of publication (please see below). Data from this thesis were also presented at the conferences listed below.

Journal Articles:

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Abstract

Music undeniably evokes emotions, including peak-pleasurable emotions defined as strong and positive feelings, such as excitement. Researchers have taken a great interest in music-evoked emotions and their correlating brain activity, attempting to understand how, when, and why music is emotive. Previous researchers have suggested music structures which create and fulfil expectations are key to peak-pleasurable emotions and relating brain activity patterns. Research has also proposed that expectancy’s effects on peak-pleasurable emotions and brain activity can be magnified by preceding feelings of tension (ITPRA; Huron, 2006). In this thesis, I further examined music structures, expectations, and tensions’ influence on peak-pleasurable emotions and correlating brain activity, using understudied electronic dance music (EDM) motifs called break routines. EDM break routine structures consist of three segments: break down, build-up and drop passages. Particularly important are build-up passages, where acoustic features are gradually reintroduced and intensify to peak levels, which increases tension. Followed by drop passages, where songs return to their main grooves and fulfil listener expectations. This makes EDM break routine structures useful in assessing tension and expectancies influence on music-evoked emotions. In four experiments, I used EDM break routines, electroencephalography (EEG), and the circumplex model of emotions to investigate music structures effect on peak-pleasurable emotions and correlating brain activity. First, I established EDM break routines can induce peak-pleasurable emotions, such as excitement, and specific brain activity patterns across build-up and drop passages. Results suggested build-up passages intensified tension, as well as increased premotor cortex (PMC) and precuneus (PCUN) activity. Meanwhile, drop passages fulfilled expectations, inducing peak-pleasurable emotions, and correlating with greater middle frontal gyrus (MFG) and inferior frontal gyrus (IFG) activity. Second, I demonstrated the extent break routine structures evoked peak-pleasurable emotions and correlating brain activity, by comparing EDM and analogue classical break routines, which shared similar structures but varied in acoustic features. Similar peak-pleasurable emotions and correlating PMC and MFG activity, suggests EDM and analogue classical break routine structures (of tension and expectancy) influence peak-pleasurable emotions and relating brain activity to a greater extent than other musical elements, such as acoustic features. My third study then examined tension levels during EDM break routines and its influence on music-evoked emotions. This showed that while tension increased within build-up passages before decreasing during expected drop passages, greater tension levels did not magnify peak-pleasurable emotions from fulfilled expectations. Lastly, I used transcranial direct current stimulation (tDCS) to assess the PMC and MFG's causational influence on peak-pleasurable emotions. Findings suggested that PMC and MFG activity have an indirect cause on music-evoked emotions, mediated by the perception of EDM break routine structures, and consequently levels of expectancy and tension. Overall, these results clarified the extent music structures (which intensify tension prior to fulfilling expectations) alongside mediating PMC and MFG activity, can evoke peak-pleasurable emotions using EDM break routines.

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Chapter 1 – General Introduction

Studies in this thesis explored the emotional and neurological effects of break routines in electronic dance music (EDM). We attempted to better understand the observed and shared emotional impacts of environments, such as parties and clubs, as well as how these relate to EDM structure, current theories of expectation, and brain activity. For example, listeners show moments of suspense and stillness prior to simultaneous instances of release, excitement, and movement during EDM break routines, relating to EDM structures of build-up prior to expected drop passages, as well as different brain activities (Butler, 2006; Solberg, 2014; Solberg, Solberg & Jensenius, 2019; Turrell et al., 2021). The main objective of this thesis was to better understand the theoretical reasons of how music structure can evoke strong positive emotions and related brain activity, using the under researched music genre of EDM.

Music and music-emotion research includes a wide variety of disciplines, including areas such as sociology, musicology, and psychology. The scope of this thesis is limited to psychological, specifically cognitive psychological, functions behind EDM processing and its influences on emotions, behaviour, and brain activity. Specifically, we investigated the following research questions: what emotional responses and correlating brain activity occurred during EDM break routines: how structure, expectancy, and tension influenced such emotive effects applying ITPRA (imagination, tension, prediction, reaction, and appraisal; Huron, 2006): the extent structure influenced emotions through similarities and differences between EDM and classical break routines: as well as the causational link between brain activity and emotions during break routines, using transcranial direct current stimulation (tDCS).

Chapter 1 first provides a review of current literature. Chapter 2 will then establish whether short and highly expected EDM break routines evokes strong positive emotions and related brain activity. After, Chapter 3 will attempt to disentangle the extent expectancy in EDM break routine structures influences emotions by comparing EDM with classical music. As expectancy in EDM break routines appears to influence music-evoked emotions and relating brain activity, chapter 4 examines the mediating effect of prior feelings of tension. Chapter 5 will then establish the causational role of previously related brain areas during EDM break routines, using brain stimulation. Lastly, chapter 6 will provide an overall discussion of how EDM break routines evoke strong positive emotions via their structure of tension and expectancy and how this relates to specific brain activity.

Music and Emotion

Music has a significant role in human everyday life, often being used to elicit powerful and reliable emotions (Habibi & Damasio, 2014; Koelsch, 2014; Nagel & Bradshaw, 2013; Koelsch, 2014; Sloboda et al., 2001). The passive apprehension of music induces an array of emotions, such as happiness, fear, anticipation, and excitement (Grynberg et al., 2012; Habibi & Damasio, 2014; Koelsch et al., 2013; Särkämö & Soto, 2012; Tabatabaie et al., 2014). Such emotive effects have led people to use music across the world and cultures to evoke, regulate, alter, and release emotions (Bogert et al., 2016; Luck, 2014; Omigie, 2016). It has also led to an extensive amount of research from numerous disciplines, including psychology, philosophy, neurology, and musicology, all attempting to understand music's emotional ability and leading to an array of theories and potential explanations behind this prominent yet somewhat elusive affect (Butler, 2006; Cochrane et al., 2013).

For example, acoustic features and how they are structured in music are considered to evoke emotions. Music is a dynamic and temporal construct, consisting of numerous smaller blocks of acoustic features; including rhythm, tempo, frequency, pitch, and key, that are layered together in intricate semantic structures, similarly to language, and evoke a range of emotions (Gingras et al., 2014; Gordon, 2016; Hsu et al., 2015; Jones, 1982; Juslin & Sloboda, 2011; Kerer et al., 2014; Koelsch, 2014; Komosinski & Mensfelt, 2016; Kunert et al., 2015; Meltzer et al., 2015; Tervaniemi et al., 2014; Vuust & Witek, 2014; Weidema et al., 2016). For instance, minor music keys, slower tempos, chromatic harmonies, and lower pitch induce negative emotions, like sadness and anger, while quicker tempos, major keys, high pitch, and varied rhythms evoke positive emotions, such as happiness, joy, and excitement (Vaidya, 2004; Juslin & Sloboda, 2011). Some suggest that the combination of these acoustic features allows listeners to imagine, predict, and expect features, timing, and content (such as melodies and harmonies; Huron, 2006; Meyer, 1956; Rohrmeier & Koelsch, 2012; Vuust & Witek, 2014). This may increase music's cognitive and emotive affects, to the extent that passive listening relates to powerful emotions (Rolison & Edworthy, 2013; Särkämö & Soto, 2012; Thaut et al., 2005).

However, the consideration of music (its structure and features) alone is a reductionistic view of complex music-evoked emotions, not accounting for music's individual and subjective interactions with people (Daly et al., 2015). Music can evoke differing emotions across individuals, affected by numerous mechanisms including individual's memories, experiences, mood, personality, the environment, culture, and more

(Juslin & Sloboda, 2013; Swaminathan & Schellenberg, 2015; Vaidya, 2004). Factors, such as familiarity, can also impact emotional responses with greater liking for familiar music, suggesting it can be a strong predictor for music liking, preference, and emotional intensity (Madison & Schiölde, 2017; North & Hargreaves, 1995; Ward et al., 2014; Van den Tol & Ritchie, 2014). Additionally, repeated music exposure is important in forming associated memories, particularly autobiographical memories, and enhances memory formation due its strong emotional effect (Jäncke, 2008; Raglio et al., 2016; Schulkind et al., 1999). Thus, music-evoked emotions may not only arise because of acoustic features and structure but also with the extent and context of previous exposure to similar music.

Music-evoked emotions may also be elicited indirectly via mediators, including metaphors and external meanings. Such mediators can occur alongside and between key stages of music processing and emotional responses (Pannese et al., 2016). For instance, metaphors are a well-known tool for linking and making conscious connections between stimuli, such as between music and emotions (Pannese et al., 2016). This indirectness may explain how music-evoked emotion inconsistencies can occur, like the negative emotion paradox (the positive experience of negative music-evoked emotions; Konečni, 2008; Pannese et al., 2016; Schubert, 2016). Prior emotional state can also impact emotional responses to music and the type of emotional music people choose to listen to. For example, prior feelings of sadness and happiness can elevate emotions of pleasure and ‘chills’ in music, while earlier feelings of disgust can also increase listeners preference for happy music (Nusbaum et al., 2014; Taylor & Friedman, 2014, respectively). Thus, music-evoked emotions can be influenced by indirect external factors and existing emotional experiences.

Environmental factors can also affect music-evoked emotions. The social context and functions of music in forming social identity, relationships, social cohesion, and emotions are fundamental to music use (Hargreaves & North, 1999; Park et al., 2019; Schäfer & Eerola, 2020). For instance, whether one listens to a music piece alone or within a group impacts its emotional effects. Listeners may experience greater positive emotions, arousal, and physiological ‘chills’ when listening to music alone, perhaps from less social distractions and more concentration on the music (Egermann et al., 2011). However, other researchers suggest that shared music experience, such as when listening with close friends, a partner, or at a live concert, can amplify emotion, create feelings of togetherness, and increasing group cohesion (Liljeström et al., 2013; Schäfer & Eerola, 2020). Thus, the emotional impact of music is a complex interaction between the music itself, the listener, and the context in which it is heard.

This can also be seen in embodied music theories, suggesting traditional cognitive explanations are too reductionist and that music-evoked emotions are a multimodal experience, resulting from cognitive, movement, and environmental interactions (Leman, 2007; van der Schyff, 2013). Specifically, music perception and emotions occur from the dynamic integrations of auditory processing, motor movements, physiological responses, emotional systems, and environments (Leman, 2007; Leman & Maes, 2014; Maes et al., 2014). Music meaning, structure, and emotions are considered to relate to body movements, so much so that individuals can reliably interpret emotions from others bodily reactions in music (Burger et al., 2012; Leman & Maes, 2014; Naveda & Leman, 2010; Niedenthal et al., 2014; Sedlmeier et al., 2011). In fact, movement in muscles with positive emotional associations can lead to greater music liking and strengthen preferences (Sedlmeier et al., 2011). The perception of acoustic music features including, rhythm, pulse, and beat, as well as their emotional effects have also been related to embodied reactions, such as head and leg movements (Scherer, 2004; Sievers et al., 2013). Therefore, music-evoked emotions seemingly result from complex integrations of acoustic features, music structures, and bodily movements, suggesting embodied music responses are also important to consider.

The complexity of music-evoked emotions can make interpreting music’s emotional impact difficult. Even the categorisation and labels given to emotions (such as happiness, sadness, and fear) may be oversimplified and not representative of complex music-evoked emotions (Trost et al., 2012). The very uniqueness of music’s ability to induce strong and complex emotions is debated, some suggesting music is unique in evoking and regulating powerful and intricate emotions, such as nostalgia and wonder (Omigie, 2016; Randall et al., 2014). While others argue that other art forms, such as paintings, can evoke comparable emotional responses via similar mechanisms, such as certain brain activity and cognitive processes like memory (Juslin & Västfjäll, 2008; Miu et al., 2016). Such ambiguity can make music-evoked emotion research, as well as its conclusions and theories tenuous.

However, the exploration of physiological responses can clarify music-evoked emotions. Physiological responses, such as heart rate, can be induced by, be more objective measures of, and predict music-evoked emotions with between 76 and 84% accuracy (Goshvarpour et al., 2017; Habibi & Damasio, 2014; Huron, 2006; Koelsch & Jäncke, 2015; Nardelli et al., 2015; Scherer & Zentner, 2001). Such physiological differences can confirm the genuineness of music-evoked emotions or whether they are emotive music expressions (Lundqvist et al., 2009). Research has also suggested classifiable physiological differences between negative and positive music-evoked emotions (Hu et al., 2018). For example, happy music induces lower finger temperatures, as well as greater skin conductance, blood pressure, electrodermal activity, and different respiration rates compared to sad music that has larger alterations in heart rate, skin conductance, blood pressure, and temperature (Khalfa et al., 2008a; Krumhansl, 1997; Lundqvist et al., 2009). Although, physiological response differences between music-evoked emotions can be small, inconsistent, or similar between emotions, such as reduced heart rate and skin conductance across happiness and sadness (Koelsch & Jäncke, 2015; White & Rickard, 2016). Thus, links between physiological measures and music-evoked emotions can be ambiguous and should be considered with caution.

Still physiological measures including skin conductance, heart rate, and respiration changes are also influenced by music structures and features. Gomez and Danuser (2007) demonstrated the relationship between acoustic features, emotions, and physiological responses, suggesting the internal structure of music is important. Specifically, music that was fast, accentuated, and contained sharply detached notes induced greater breathing rates, heart rates, and skin conductance (Gomez & Danuser, 2007). However, other studies suggest links between music-evoked emotions, certain physiological responses, and specific acoustic features are less clear. For example, studies also fail to show evidence for heart rate being influenced by acoustic features, such as beat (Koelsch & Jäncke, 2015). Therefore, including physiological measures to assess music-evoked emotions and their correlating neurological activity can be helpful, but ambiguous as to how they are specifically affected by music's structure and features.

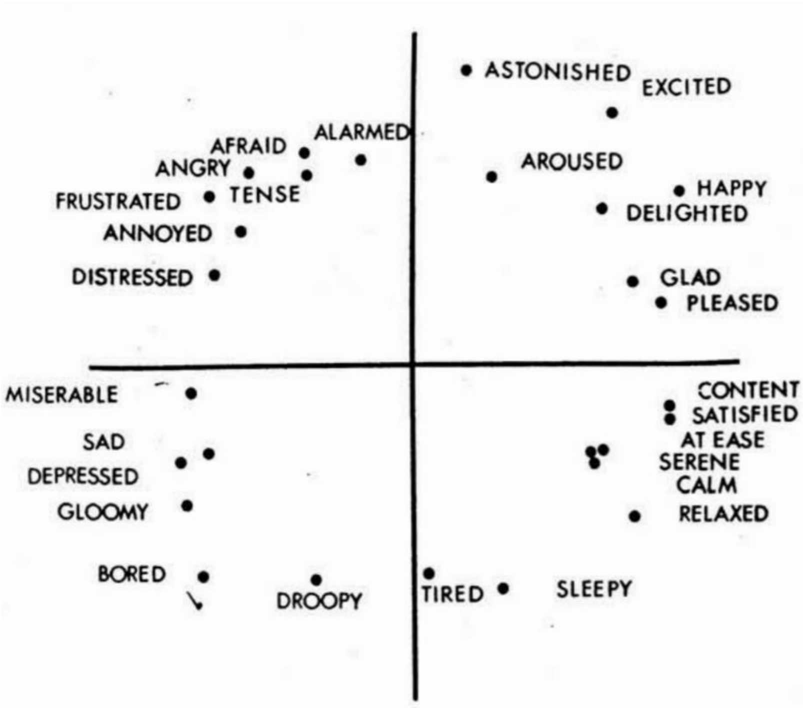
Circumplex Model of Emotion

The ambiguity around music-evoked emotions suggests a need to standardise and classify them to fully understand them. Research most commonly categorises music-evoked emotions with dimensional approaches; including the circumplex model that plots emotions on two axes of valence and arousal (Eerola & Vuoskoski, 2012; Egermann et al., 2015; Kim et al., 2011; Russell, 1980; Sandstrom & Russo, 2010; Wheeler et al., 2011). Valence ratings refers to the negativity (unpleasantness) or positivity (pleasantness) of emotion, whilst arousal represents the physiological stimulation or alertness of an emotion (Eerola & Vuoskoski, 2012; Russell, 1980). Most often valence is placed on the vertical axes and arousal on the horizontal axes, which cross to make four quadrants of emotional space.

Different emotions are then placed within this two-dimensional space according to their combined levels of valence and arousal. The right side of the space refers to positively valenced emotion and the left to negative emotions. The upper part of the space represents highly stimulating and arousing emotions, whilst the lower part refers to unstimulating and none arousing emotions (Eerola & Vuoskoski, 2012; Russell, 1980; Yang et al., 2006; see Figure 1-1).

Figure 1-1

The 2-Dimensional Space of Valence (Horizontal Axes) and Arousal (Vertical Axes) with 28 Examples of Emotional Labels; Taken from Russell, 1980

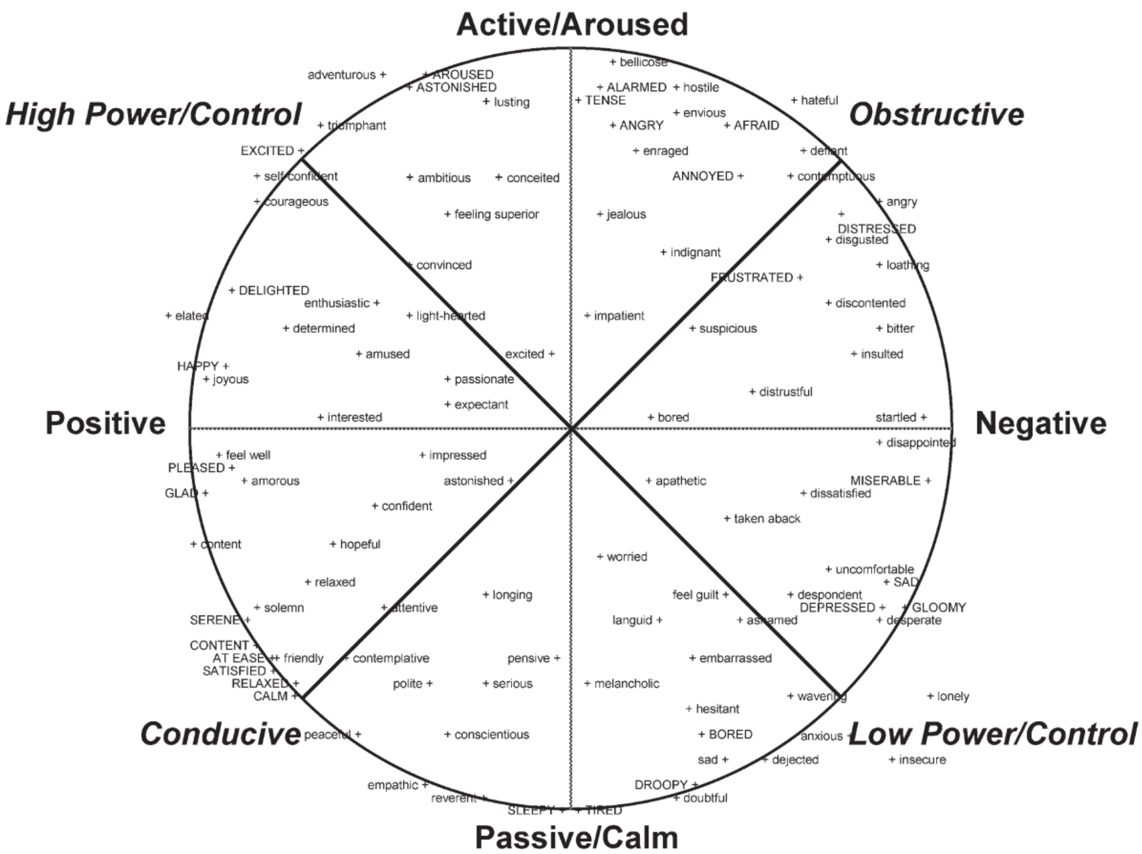


The circumplex model has been used extensively in music-evoked emotion research with around 70% using some variation, perhaps because it can be easily understood and recognised by listeners (Ilie & Thompson, 2006; Eerola & Vuoskoski, 2012). Music-evoked emotions also fit well into the four quadrants of valence and arousal, which have been regularly associated with physiological responses and specific brain areas (Altenmüller et al., 2002; Vieillard et al., 2008; Witvliet & Vrana, 2007). However, music-evoked emotions are more easily classified for arousal than valence, which may derive from a skewed commonality for positive emotions in music and from negative music-evoked emotions also being experienced positively (Huq et al., 2010; Juslin & Laukka, 2004; Schubert, 2016).

The placement of emotional labels within valence and arousal dimensions may also not be truly representative all emotional experiences. Emotions that are distinctively different can be placed close together, offering limited differentiation (Scherer, 2004; Song et al., 2016). For example, melancholy and boredom are both low in arousal and negatively valenced, placing them close together in the dimensional space, yet their emotional experience can be very different (Eerola & Vuoskoski, 2012). Thus, valence and arousal may not account for all variation in music-evoked emotions, explaining why music-evoked emotions can be impaired with no effect on arousal and valence, and leading some researchers to apply further dimensions, such as tension, dominance, and intensity (Collier, 2007; Ilie & Thompson, 2006; Luck et al., 2008; Scherer, 2005; Schubert, 2007; Song et al., 2016; see Figure 1-2).

Figure 1-2

Example of Alternative Dimensional Space for Emotions, Taken from Scherer, 2005



Despite these uncertainties, the simpler circumplex model with valence and arousal is commonly used (around one third of studies) to measure music-evoked emotions and was used throughout this thesis to ensure participant understanding and more valid peak-pleasurable emotion responses (Eerola & Vuoskoski, 2012). This suggests the circumplex model is a more reliable and informative measure than other categorical models and enables good comparison with other research (Song et al., 2016). Valence and arousal were recorded together within the two-dimensional space as it enabled responses more indicative of true emotions (which are experienced as the combination of valence and arousal and not as separate sub-divisional elements; Eerola & Vuoskoski, 2012; Russell, 1980; Scherer, 2005).

Additionally, recorded ratings of valence and arousal from the 2-dimensional space within this thesis' studies were used to calculate two further measures of emotions: emotional strength (amplitude) and emotional response (angle; for details on how these were calculated, please see the 'Behavioural Analysis' in Chapter 3). These additional dimensions, such as intensity or strength, were added as they can better differentiate different emotions that share the same space within the 2-dimensional model (Russell, 1980; Scherer, 2005). Calculations of these measures enabled polar analysis and allowed for more valid and identifiable emotions according to the combined levels of valence and arousal (Burger et al., 2012; Mencattini et al., 2014; Taverner et al., 2020).

Music & Brain Activity

The neurology of music has become popular to study in modern neuroscience. The development of imaging techniques, such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and magnetoencephalography (MEG) has allowed the exploration of brain activity in real time as we listen to music (Warren, 2008; Popescu et al., 2004). Such exploration has led to a shift in thinking from music only involving individual brain areas to music processing being a 'whole-brain' activity, engaging a wide network of areas that process the emotional, cognitive, and movement or embodied aspects of music in different ways and to different degrees (Daly et al., 2015; Koelsch, 2005; Koelsch, 2014; Leman, 2007; van der Schyff, 2013; Warren, 2008).

This wide range of brain activity that music evokes, more than other auditory information (such as language), includes the insula, nucleus accumbens, amygdala, hypothalamus, upper brainstem, cingulate cortex, thalamic limbic cortex, frontal cortex, inferior frontal gryus, frontoparietal cortex, orbitofrontal cortex, left temporal pole, and hippocampus (Bogert et al., 2016; Flores-Gutiérrez et al., 2007; Habibi & Damasio, 2014; Koelsch, 2014; Liégeois-Chauvel et al., 2014; Moore, 2013; Omigie, 2016; Rogenmoser et al., 2016; Trost et al., 2015). Research has also shown several brain areas involved in processing acoustic features, such as rhythm, pitch, acoustic event density, beats, structure, consonance, dissonance, meter, and melodies; including the dorsolateral prefrontal cortex, inferior frontal gyrus (IFG), orbitofrontal cortex, middle frontal gyrus (MFG), amygdala, insula, caudate nucleus, lateral premotor cortices (PMC), somatomotor areas, and supplementary motor areas (Kunert et al., 2015; Lappe et al., 2013; Nan & Friederici, 2013; Popescu et al., 2004; Royal et al., 2018; Thaut et al., 2014; Trost et al., 2014; Trost et al., 2015). Thus, music listening relates to activity changes in an extensive network of brain areas, making it more difficult to study and differentiate which associate with specific music-evoked emotions.

Music, Emotion, & Brain Activity

In the last two decades there has also been an accompanying uptake in the neurological exploration of music-evoked emotions, with more research on the topic annually (Koelsch, 2020). Music-evoked emotions influence brain activity in numerous areas including, the auditory cortex, amygdala, prefrontal cortex, MFG, IFG, hippocampus, hypothalamus, precuneus (PCUN), limbic system, insula, and brain stem (Altenmüller et al., 2014; Baumgartner et al., 2006; Klineburger & Harrison, 2015; Liégeois-Chauvel et al., 2014; Trost et al., 2015; Turrell et al., 2021). Several brain areas, such as those in the limbic system and motor cortex, have also been linked to embodied music reactions, including dancing and physiological responses, which can then induce pleasurable emotions in music (Niedenthal et al., 2014; van der Schyff, 2013). Such a variety of active brain areas is similar to other emotional stimuli, such as food, sex, and drugs, and makes the neurological correlates of music-evoked emotions complex and difficult to interpret (Trainor & Schmidt, 2003; Vaidya, 2004).

Previous neurological research has attempted to decipher which brain areas correlate with music and music-evoked emotions using EEG. For example, peak frontal asymmetry occurs in frontal brain regions during key music changes (Arjmand et al., 2017). Research has also shown differences in brain activity (larger alpha-power density) within frontal, parietal, and temporal regions between music-evoked emotions and other art forms, such as pictures (Baumgartner et al., 2006). This suggests music changes and their emotional affects relate to noticeable and fast brain activity alterations. In fact, Daly et al. (2015) suggests that more than 20% of music-evoked emotion variance can be predicted via the combination of acoustic features and brain activity. So, music elicits emotions that may also induce specific and differentiating patterns of brain activity.

Past research has also applied MRI or fMRI when assessing brain activity during music-evoked emotions. Listening to music in naturalistic conditions over some course of time (seconds to minutes) allows the study of temporal brain activity as music changes. Trost et al. (2015) showed synchronous temporal changes in the left amygdala and insular, as well as right caudate nucleus activity increased arousal. Synchrony also happened in the left nucleus accumbens, which influenced feelings of reward. Yet decreased amygdala and caudate activity also evoked positive valence. In another paper, Trost et al. (2014) also linked acoustic feature processing with brain activity and emotions, as the basal ganglia processed rhythm and emotions in music. Thus, there are distinct patterns of brain activity across real time music listening which relate to music-evoked emotions.

Individual music-evoked emotions associate with numerous and distinct brain areas. For example, alterations in amygdala, anterior cingulate, orbitofrontal cortex, hippocampus, MFG, right paralimbic areas, right frontopolar areas, and parahippocampal gyrus activity evoke unpleasant, sad, and scary emotions in music (Bogert et al., 2016; Flores-Gutiérrez et al., 2007; Gosselin et al., 2005; Gosselin et al., 2006; Mitterschiffthaler et al., 2007). While pleasant music-evoked emotions, such as happiness, transcendence, liking, nostalgia, and empathy, link to orbitofrontal cortex, IFG, MFG, anterior cingulate, parahippocampal gyrus, midbrain, posterior temporal, inferior parietal, ventral medial prefrontal cortex, dorsolateral prefrontal cortex, and the ventral and dorsal striatum activity (Altenmüller et al., 2014; Barrett & Janata, 2016; Beaty, 2015; Blood & Zatorre, 2001; Bogert et al., 2016; Brattico et al., 2011; Flores-Gutiérrez et al., 2007; Joucla et al., 2018; Kim et al., 2017; Koelsch et al., 2006; Mitterschiffthaler et al., 2007; Omigie, 2016; Tabei, 2015; Wallmark et al., 2018a). Thus, different music-evoked emotions can be influenced by distinct brain activity, but active areas are extensive and overlap, making it more difficult to interpret and predict.

Specific brain activity has also been linked to the circumplex model of emotions (Russell, 1980). Valence can be influenced by activity in the ventromedial prefrontal cortex, ventral posterior parietal cortex, and frontal lobes, as well as frontal inter-hemisphere and parietal bilateral connectivity (Dolcos et al., 2004; Greene et al., 2014; Heller, 1993; Rogenmoser et al., 2016; Shahabi & Moghimi, 2016). Meanwhile, arousal can be affected by activity in the posterior cingulate, right parieto-temporal region, dorsal posterior parietal cortex, and dorsomedial prefrontal cortex, as well as decreased alpha frequency (Dolcos et al., 2004; Greene et al., 2014; Rogenmoser et al., 2016; Shahabi & Moghimi, 2016). This suggests that music-evoked emotions, measured via the circumplex model, can be influenced by co-occurring patterns of brain activity and that valence and arousal are evoked differently in music with unique areas of brain activity.

Interactions between and various combinations of valence and arousal to create different emotions within the circumplex model can also be seen within activity for specific brain areas, such as the left ventral posterior parietal cortex (Greene et al., 2014). Low arousing and positive emotions induce activity in the orbitofrontal cortex, ventromedial prefrontal cortex, right striatum, and hippocampus; while high arousing and positive emotions evoke insula, left ventral striatum, and motor and sensory area activity (Trost et al., 2012). Research has also shown connectivity patterns between brain areas in response to pleasurable music, such as between the ventral striatum, ventral tegmental area of the brain stem, and hypothalamus (Menon & Levitin, 2005; Habibi & Damasio, 2014). Thus, different combinations of arousal and valence not only induce various emotions, but also activity in specific brain areas.

Music, Emotion, & Causational Brain Activity

Double dissociations between brain activity and emotions can be helpful to clarify which brain areas influence music-evoked emotions and causational links. For example, frontotemporal lobar degeneration (FTLD) reduces grey matter within the amygdala, insula, medial prefrontal cortex, orbitofrontal cortex, and subcortical mesolimbic system. This reduction can impair recognition for music happiness, sadness, and fear, suggesting the causational role of these frontal regions in music-evoked emotions (Omar et al., 2011). Also, music anhedonia (dysfunction in processing positive emotions in music) can occur with damage to the right inferior parietal lobe and result in the localised impairment of emotions in music (Belfi et al., 2017; Satoh et al., 2011). Evidence from frontotemporal dementia also suggests different emotional levels and modality to music (including musicophilia) when there is damage to the posterior and anterior superior temporal cortices, inferior frontal cortices, and dorsal brainstem (Agustus et al., 2015). Thus, there is some specialisation of brain activity for music-evoked emotions, with several influential brain areas being in the frontal and parietal lobes.

Recent developments in technology have enabled causational links between brain areas and music to be explored using stimulation, such as transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), which overcome the shortfalls of studying clinical populations (Peretz & Hébert, 2000). Stimulation research has established causational connections between the supramarginal gyrus and superior temporal gyrus, with processing acoustic features like pitch, memory, and melody (Garcea et al., 2017; Schaal et al., 2013; Vines et al., 2006). Deep brain stimulation has also expanded on lesion studies and validated the causational role of damaged areas, such as the nucleus accumbens, in functions like music preference formation and music reward processing (Mantione et al., 2014). Therefore, stimulation techniques can be used effectively in music research to assess the causational roles of brain areas in processing music.

Researchers have also applied stimulation techniques in assessing music-evoked emotions. TMS has shown perceived music pleasure is affected by the left dorsolateral prefrontal cortex (DLPFC). Anodal DLPFC stimulation modulated activity within the fronto-striatal pathways, as well as increasing music pleasure, motivations, and physiological responses (such as skin conductance), while cathodal stimulation reduced these (Goupil & Aucouturier, 2019; Koelsch, 2018; Mas-Herrero et al., 2018). This suggests that the DLPFC and its connectivity with fronto-striatal pathways can cause music-evoked emotions, such as pleasure. However, there is little research currently establishing causational links between brain activity and music-evoked emotions, with more research investigating music processing, preforming, and memory (Andoh et al., 2018; Heimrath et al., 2016; Ross et al., 2016; Schaal et al., 2015a; 2015b; Zwi, 2020). Further research is needed to fully understand the complex causational role of multiple brain areas in music-evoked emotions.

Music, Peak-Pleasurable Emotions, & Brain Activity

One category of emotions that are often studied with the circumplex model, having high positive valence and high arousal, are peak-pleasurable emotions, such as excitement (Mori & Iwanaga, 2017; Russell, 1980). Peak-pleasurable emotions are defined as intense emotions to stimuli, such as music, which often co-occur with physiological responses, including increased heart rate, skin conductance, and ‘chills’ (Blood & Zatorre, 2001; Gabrielsson, 2011; Habibi & Damasio, 2014; Lamont, 2011; Menon & Levitin, 2005; Sachs et al., 2018; Särkämö & Soto, 2012; Solberg & Dibben, 2019). Music can consistently evoke powerful emotions, such as excitement, which can make it more attractive and induce motor sensory and embodied experiences, including the desire to dance (Holbrook & Gardner, 1993; Lamont, 2011; Panzarella, 1980; Solberg & Jensenius, 2017). Also, peak-pleasurable emotions in music can be influenced by the passive apprehension of acoustic features, such as rhythm, pitch, and melodies, as well as brain activity involved in reward, arousal, and emotion, such as the orbitofrontal cortex and ventral medial prefrontal cortex (Blood & Zatorre, 2001; Habibi & Damasio, 2014; Salimpoor et al., 2011; Särkämö & Soto, 2012; Meltzer et al., 2015; Rolison & Edworthy, 2013). Thus, peak-pleasurable emotions are a good emotion to assess in music, using the circumplex model (valence and arousal) and brain activity.

Music-Evoked Emotions, Expectancy & Predictions

A dominant theory explaining music-evoked emotions is expectancy (Meyer, 1956). The dynamic and temporal structure of music enables listeners to make predictions and expectations around acoustic features and song progression (Jones, 1982; Huron, 2006; Koelsch, 2014; Kunert et al., 2015; Solberg, 2014; Tillmann et al., 2014; Vuust & Witek, 2014). Music's structure can be learnt through repeated listening with statistical and rule-based learning, which can enable cognitive processes, such as expectations and predictions. Deviation, delay, or fulfilment of music predictions/expectations can lead to strong emotions, increased arousal, and tension (the prediction effect; Agres et al., 2017; Arjmand et al., 2017; Asano & Boeckx, 2015; Grewe et al., 2007b; Huron, 2006; Koelsch, 2014; Lehne et al., 2014; Meyer, 1956; Mikutta et al., 2012; Zentner et al., 2008). Music predictions and expectancy also correlate with greater brain activity in the basal ganglia, amygdala, nucleus accumbens, and orbitofrontal cortex (Koelsch et al., 2008; Lehne et al., 2014; Salimpoor et al., 2011; Salimpoor et al., 2013). Thus, the ability for listeners to create music expectations or predictions could be fundamental to music-evoked emotions and their relating brain activity.

Huron's (2006) theory of ITPRA expands on the importance of expectancy and prediction in music-evoked emotions. ITPRA has five factors; Imagination, Tension, Prediction, Reaction and Appraisal, all of which Huron suggests influences music-evoked emotions. As the structure of music is learned, listeners can *predict* the future direction of music passages and *imagine* this. *Tension* is then experienced as listeners predict developments in acoustic features but are uncertain of exactly how and when expected moments may occur, which relates to greater left orbitofrontal cortex, PCUN, and right amygdala activity (Huron, 2006; Lehne et al., 2014; Turrell et al., 2021; Vuilleumier & Trost, 2015). When expectations are fulfilled, listeners *react* with peak-pleasurable emotions, such as excitement and satisfaction, which often co-occur with greater physiological sensations and embodied reactions (including chills, the urge to move and dance, skin conductance, heart rate, and blood volume), as well as increased amygdala, IFG, MFG, motor cortex, and orbitofrontal cortex activity (Arjmand et al., 2017; Egermann & McAdams, 2013; Grewe et al., 2007a; 2007b; Koelsch, 2014; Koelsch et al., 2008; Lehne et al., 2014; Mikutta et al., 2015; Omigie, 2016; Solberg & Dibben, 2019; Steinbeis et al., 2006; Turrell et al., 2021; Vuilleumier & Trost, 2015; Zentner et al., 2008). After, listeners *appraise* the music's emotive experience, learning its structure and features, and refining future predictions (Huron, 2006; Solberg, 2014, Solberg & Dibben, 2019).

Additionally, Huron (2006) suggests that tension can have a magnifying effect on music-evoked emotions due to contrastive valence. This suggests that positive emotions can be amplified if they are immediately preceded by negative emotions, as the preceding negative emotion offers a lower baseline and thus greater contrast between emotions. This greater contrast means that individuals experience positive emotions more strongly as it is more drastically different from preceding negative emotions, compared to neutral (Huron, 2006). In ITPRA, tension is influenced by not knowing exactly how predicted or expected music moments may occur and is a negative emotion. Negative feelings of tension occur before positive emotional reactions from correctly fulfilled predictions (the prediction effect; Huron, 2006), meaning that a negative emotion (tension) precedes positive emotions. Contrastive valence suggests that positive emotions from the prediction effect are amplified by preceding tension. Therefore, this combination of ITPRA factors can clarify how music induces peak-pleasurable emotions.

EDM Break Routines & Emotion

Peak-pleasurable emotions have been well researched in music (Habibi & Damasio, 2014). However, previous exploration of music-evoked emotions has over-relied on a limited selection of music, mostly classical music and small, specifically manipulated music pieces with one feature altered, such as tempo (Eerola & Vuoskoski, 2012; Omigie, 2016; Schutz, 2017; Seger, 2009; Seger et al., 2013). This may limit insights into music-evoked emotions, as different music genres may be created differently with unique structures, expectations, and emotional effects (Koelsch, 2014).

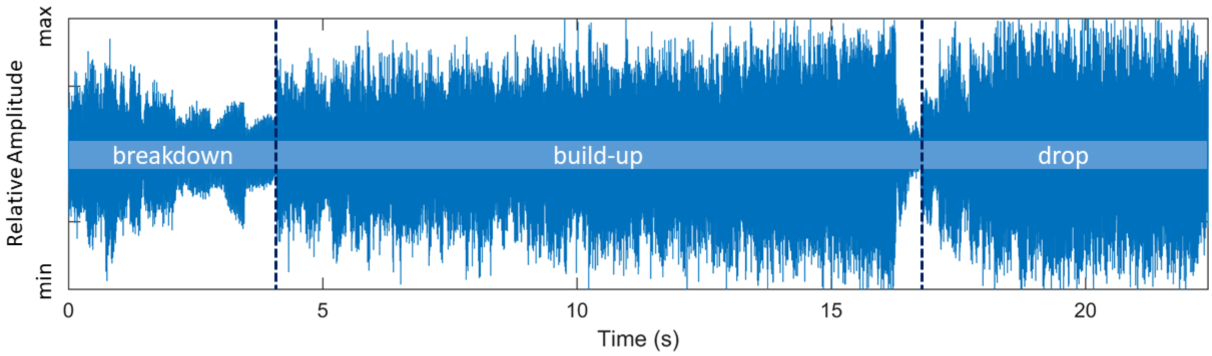
There has been a recent interest in EDM and peak-pleasurable experiences, particularly excitement. EDM is a unique and techno-centric genre of popular music which emerged in the early 1990's with the development of digital music software and instruments, such as the synthesizer and mixing board (Butler, 2006). With modern digital recordings and multiple audio and editing software containing automatic features, such as quantization and correcting features, sounds can easily be copied and modified into music compositions and crescendos, without as much training (Butler, 2006). The basic features of EDM are quite consistent with a constant 4/4 beat and tempo usually within the range of 120-180 beats per minute, repetitive motifs, emphasis on low bass frequencies, and playing at high volumes (Butler, 2006). However, digital software then allows for different combinations of a variety of sound sources, such as brief and fragmented vocal components (Butler, 2006). This technology also allows for practices such as beat matching, where DJ's mix and overlap two songs by synchronising the beats to create a continuous flow of music (Brewster & Broughton, 2014; Butler 2006).

EDM consequently 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 specific purpose of dancing (Butler, 2006; Solberg & Jensenius, 2019; Thompson & Stevenson, 2015). It is often created electronically with prominent features including several music layers, a repetitive beat and rhythmic focus, drum roll effects, complex grooves, timbral manipulation, and numerous gradual upward movements in music parameters, including pitch: termed "uplifters" (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019). Creators such as producers, DJs, and musicians use different methods including vocoders, talk boxes, harmonizers, sequencers, and samplers, to manipulate acoustic features and construct expected passages that increase emotive and physiological pleasure (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 tension and expectancy to induce peak-pleasurable experiences, such as excitement, and embodied reactions, like dancing, in listeners (Huron, 2006; Meyer, 1956; Solberg, 2014; Solberg & Jensenius, 2017). 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 (the way in which short configurations of musical bassline and percussion flows or unfolds in repeated cycles) and intensity is reduced with the removal of several instruments and layers, such as the bass and bass drum (Butler, 2006). Then the *build-up* passage comprises the gradual reintroduction of these instrumental layers to build the music track back up to a peak moment, increasing listeners feelings of tension. Afterwards, the *drop* passage occurs, where the bass and bass drum are 'dropped' back into the music track and the main groove returns (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019; for a visual example see Figure 1-3).

Figure 1-3

A Sample Break-Routine Consisting of Breakdown, Build-up, and Drop Passages (Solberg & Dibben, 2019; Turrell et al., 2021). The vertical axis represents relative digital signal amplitude with max and min representing 1 and -1, respectively.



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 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, adding to feelings of tension during build-up passages. When expected drop passages finally happen, listeners experience greater bodily movement and peak-pleasurable emotions, such as excitement, which are also amplified by preceding negative feelings of tension (contrastive valence; Huron, 2006, Meyer, 1956; Solberg & Dibben, 2019; Solberg & Jensenius, 2017). Therefore, EDM break routine structures of expectancy and tension can result in peak-pleasurable emotions, as they intensify tension during build-up passages before highly expected drop passages.

Current Research

This thesis aims to assess the emotive and neurological effects of EDM break routines in more detail, applying a range of neuroimaging and behavioural measures which includes EEG, tDCS, continuous rating scales, and the 2-dimensional space of valence and arousal. EEG was used due to its high temporal ability, as we compared seconds of brain activity during EDM listening (Nunez et al., 2016; Read & Innis, 2017). The following chapters will each detail a research question and the study we applied to assess it, beginning with the basic exploration of correlating brain activity and emotions during EDM break routines and working up to the more complicated investigation of how music structure, brain activity and emotions interact.

Specifically, chapter 2 will explore brain activity changes across EDM break routine build-up and drop passages and in relation to excitement, assessing if and how break routines evoke peak-pleasurable emotions. Chapter 3 will establish the extent break routine structure evokes peak-pleasurable emotions and relating brain activity, through the comparison of EDM break routines and analogue classical break routines. Chapter 4 will explore tension levels during EDM break routines and whether increased tension during build-up passages magnifies peak-pleasurable emotions from expected drop passages. Chapter 5 will investigate the causational role of MFG and PMC activity (areas previous chapters saw to be active during break routines and peak-pleasurable emotions), using anodal tDCS. Lastly, chapter 6 will provide a comprehensive discussion of our findings in the emotional effect of break routines, underlying mechanisms of structure, expectancy, tension, and relating brain activity, as well as how research can utilise and expand on our findings.

Figure 1-4

A Visual Schematic Providing the Overall Structure of the Following Chapters

Chapter 2 - Excitement in Electronic Dance Music

- Emotions in EDM break routines, specifically Excitement
- Defining Break routines and it's three passages
    - Breakdown, Build-up, Drop
- Applying ITPRA (Imagination, Tension, Prediction, Reaction, Appraisal)
- Exploring emotion inducing variables
    - Expectancy, Prediction, Tension, and Contrastive Valence
- Correlating brain activity (EEG) with EDM break routine passages and evoked emotions

Chapter 3 - The Extent Structure Effects Music-Evoked Emotions

- Further exploring mechanisms for emotions during EDM break routines
- Emotions measured via Circumplex Model of Valence and Arousal
- Acoustic features Vs structure of tension and expectation
- Compared EDM and analogous classical break routines - similar structures but differing features
- Similarities in evoked emotions and correlating brain activity (EEG) suggests greater influence of structure

Chapter 4 - How Tension Mediates Music-Evoked Emotions

- Further assessing ITPRA and Contrastive Valence
- The mediating role of tension in EDM break routine evoked emotions
- Suggests greater tension does not always induce greater peak-pleasurable emotions
- Discusses optimal tension curve theory

Chapter 5 - Electrical Brain Stimulation and Music-Evoked Emotions

- Reviewing current literature on neuroimaging and music-evoked emotions
- Differentiating the role of singular brain areas for music-evoked emotions
- Establishing causational roles of correlating brain areas from previous chapters
- Specifically, anodal stimulation to the MFG and PMC (tDCS)
- Discusses indirect brain effects – brain activity alters music structure processing which mediates evoked emotions

Chapter 6 – General Discussion

- Reviewing and discussing all evidence from previous chapters
- Concluding EDM break routines are particularly emotive due to their structure of tension and expectation (ITPRA), as well as relating to specific brain activity, including the MFG and PMC, which mediate evoked emotions

Chapter 2 – Excitement in Electronic Dance Music

Introduction

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 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 acoustic 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 et al., 2011). Thus, music-evoked emotional experiences are correlated with patterns of brain activity associated with positive reward, noticeably within the prefrontal cortex (PFC).

Dominant theories exploring why music can be so emotive is that of expectancy and ITPRA (Huron, 2006; Meyer, 1956). Music is a temporal and dynamic construct that often includes certain syntactic structures, allowing listeners to develop predictions and expectancies surrounding musical features (Huron, 2006; Jones, 1982; Koelsch, 2014; Kunert et al., 2015; Solberg, 2014; Vuust & Witek, 2014). The delay, violation, or fulfilment of music expectations can then influence levels of tension (Huron, 2006; Margulis, 2005; Miller, 1967). Music structures which intensify tension prior to fulfilling expectations can induce greater peak-pleasurable emotions due to contrastive valence (Huron, 2006; Lehne & Koelsch, 2015). Electronic dance music (EDM) break routines are particularly emotive music passages, which manipulate moments of expectancy to increase prior levels of tension during build-up passages and thus magnify peak-pleasurable emotions, such as excitement, from fulfilled expected drop passages (Butler, 2006; Huron, 2006; Meyer, 1956; Solberg, 2014; Solberg & Dibben, 2019; for a visual example see Figure 1-3).

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 et al., 2013; Nan & Friederici, 2013; Royal et al., 2018; Thaut et al., 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 et al., 2014; Koelsch et al., 2006; Lehne et al., 2014; Mitsuyoshi et al., 2011; Tabatabaie et al., 2014; Wallmark et al., 2018a; 2018b). 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. The present study attempted to answer the research question whether short EDM break routines could evoke peak-pleasurable emotions and how this would relate to specific brain activity. 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 experience with a musical instrument (*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; see Appendix A for an example of demographic questions used). 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.

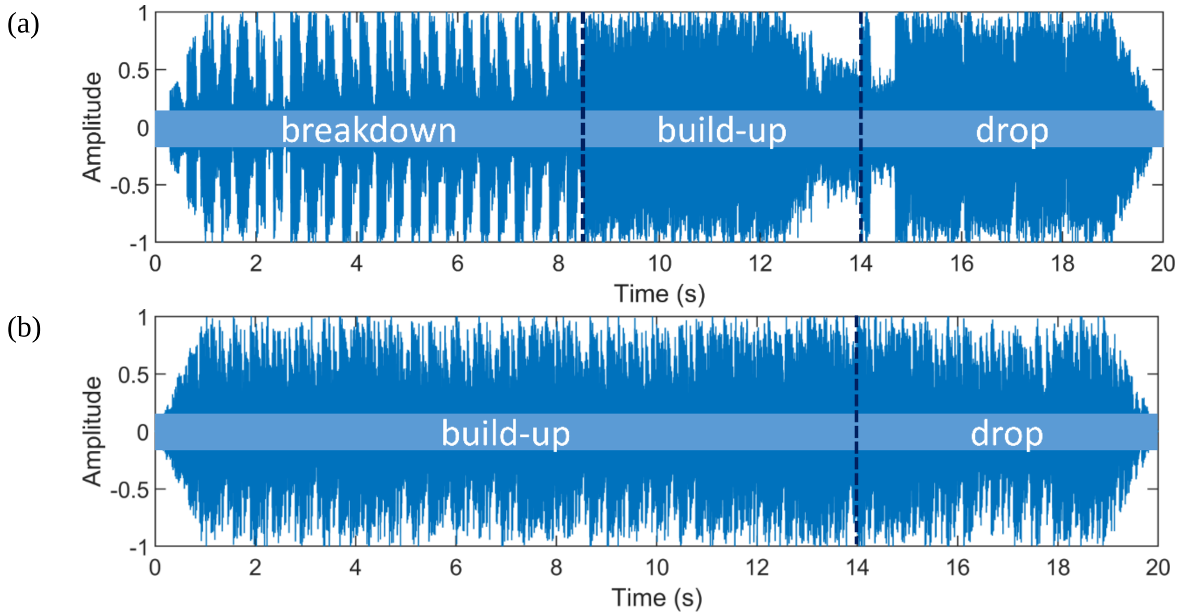
Stimuli

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. Key acoustic features altering across all these break routines included tempo, rhythm, pitch, and loudness which are withdrawn and then gradually reintroduced, building listeners up to peak moments before pausing and returning to the main motif (Butler, 2006; Solberg, 2014). The subgenres of EDM follow a similar overall structure including structured verses and choruses containing break routines, but differ in acoustic features, like 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 use of 20 s break routine clips may undermine some expectancy effects within full EDM songs, as break routines 'break away' from established overall structures. However, the duration of 20 s was selected based on the length of break routines, long enough to fit build-up and part of drop passages (Figure 2-1), enabling smaller music segments that affected tension and expectancy but with greater control over other influential music variables.

Figure 2-1

Sample Waveforms for a Song with (a) a Strong Drop ('Tantrum' with Subjective Excitement Rating of 6.61 in Pilot and 5.65 in Study), and (b) a Weak Drop ('Exposure' with Subjective Excitement Rating of 2.50 in Pilot and 3.98 in Study). The vertical axes represent normalised digital signal amplitude, which has no scale (similarly to figures in Solberg, 2014; Solberg & Dibben, 2019).



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*). Pilot questions included "How familiar did you find the music in the clip you just heard?", "How strong would you rate the musical change in the clip you just heard?", and "How excited did you feel during the clip you just heard?". Participants were instructed to indicate their levels of excitement on the scale via their computer mouse (see Appendix B for distributions of strength, familiarity, and excitement ratings).

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. Table 2-1 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.

Table 2-1

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)	$r(88) = .597$, $p < .001$*	$r(88) = .487$, $p < .001$*	$r(88) = .219$, $p = .038$*

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

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

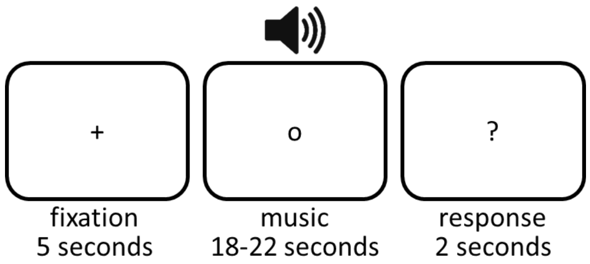
Procedure

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 Figure 2-2). Stimuli were randomly presented in four blocks with 5-min breaks in-between to prevent fatigue.

Figure 2-2

Procedure of Each Trial where Participants First Saw a Fixation Cross, then were Presented Each Break Routine Clip, Followed by a '?' were they Rated their Felt Excitement using the Computer Keyboard



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 analysed 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 (see Table 2-2).

Table 2-2

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

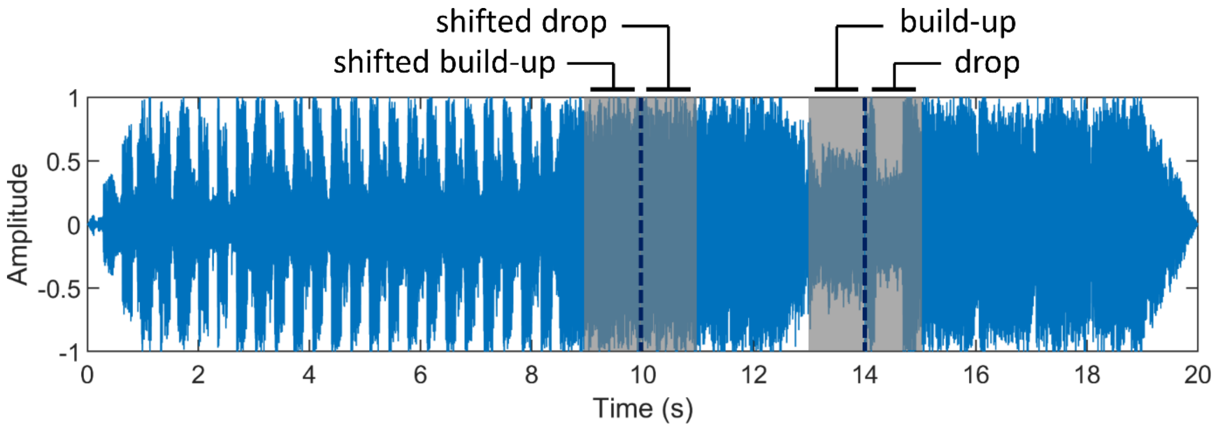
Absolute activity: This analysis identified brain areas where activity was significantly different between the build-up and drop music passages. This was done with a one-sample *t*-test on the difference-activity volumes, where the value of each voxel was compared with 0 to show which voxels were significantly 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 (Figure 2-3).

Figure 2-3

Sections of Build-up and Drop Extracted for the Main and Validation Analyses. The vertical axis represents digital signal amplitude.



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

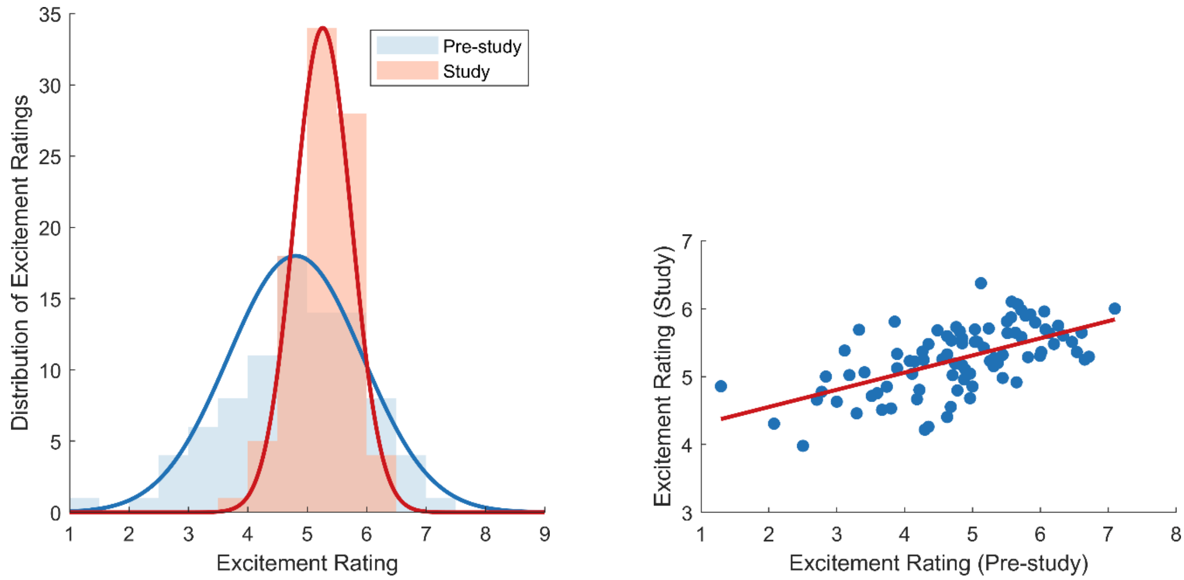
Excitement Ratings

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 2-1). Figure 2-4 illustrates the distribution of the subjective excitement ratings for the pilot and main studies, as well as ratings of strength and 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 2-3). Results of the analyses indicated significant positive correlations with timbre (spectral flux, brightness, and roughness), but not with loudness (global energy (RMS)), rhythm (beat clarity), or mode (Solberg & Dibben, 2019).

Figure 2-4

(a) Histogram of Distribution (count) of the Subjective Ratings of Excitement in the Pilot and Study. (b) Excitement Ratings in Pilot and Study Showed a Very High Correlation (r = 0.597, p < 0.001) (see also Table 2-1).



(a) (b)

Table 2-3

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

	Feature	Pilot Study	Main Study
Dynamics	Global Energy (RMS)	$r_s(88) = .227$, $p = .031$*	$r_s(88) = .188$, $p = .076$
Timbre	Spectral Flux	$r_s(88) = .512$, $p < .001$*	$r_s(88) = .348$, $p = .001$*
	Brightness	$r_s(69) = .563$, $p < .001$*	$r_s(69) = .288$, $p = .015$*
	Roughness	$r_s(88) = .413$, $p < .001$*	$r_s(88) = .351$, $p = .001$*
Rhythm	Beat Clarity	$r_s(88) = -.136$, $p = .201$	$r_s(88) = -.150$, $p = .157$
Tonality	Mode	$r_s(88) = .228$, $p = .030$*	$r_s(88) = .156$, $p = .142$

Note. Brightness could not be calculated for some of the songs; †$p < .05$; *$p \leq .031$, the false discovery rate (FDR) correction for multiple comparison (16 correlations); r_s(degrees of freedom).

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 premotor cortex (PMC) and precuneus (PCUN) activity was higher in build-up passages. For a table summarizing the analysis see Table 2-4, and also Figure 2-5 and Figure 2-6.

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 2-4 and Figure 2-7).

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).

Table 2-4

Summary of the Analysis of the 3D Source Reconstruction of the EEG Data

							MNI		
	Brain Area	K_E	P_{FWE}	T	Z	P_{uncorr}	**x**	**y**	**z**
Absolute Activity									
Drop > Build-up	r-Inf Frontal Gyrus	1021	.012	2.57	2.43	.007	56	22	16
	r-Mid Frontal Gyrus		.015	2.47	2.35	.009	46	38	10
Drop < Build-up	l-Premotor Cortex	876	.019	2.37	2.26	.012	-64	-12	28
	r-Premotor Cortex	233	.031	2.11	2.03	.021	60	-14	24
	l-Precuneus		.041	1.98	1.91	.028	-24	-40	52
Correlational analysis									

Drop > Build-up	r-Inf Frontal Gyrus	457	.013	2.46	2.34	.010	46	32	-14
	r-Mid Frontal Gyrus		.016	2.38	2.27	.012	52	26	20
	l-Inf Frontal Gyrus	922	.014	2.44	2.32	.010	-40	34	-16

Note. K_E refers to the number of neighbouring 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; Inf: Inferior; Mid: Middle; FWE is family-wise error correction for a 3 mm sphere around the peak voxel.

Figure 2-5

Brain Areas Showing Higher Activity in Drop as Compared to Build-up Music Passages; The Right Inferior and Middle Frontal Cortices (y = 30, z = 8) (Cluster Size k > 5 Voxels, P_{FWE} < 0.05). The Colourbar Indicates the T Statistical Values

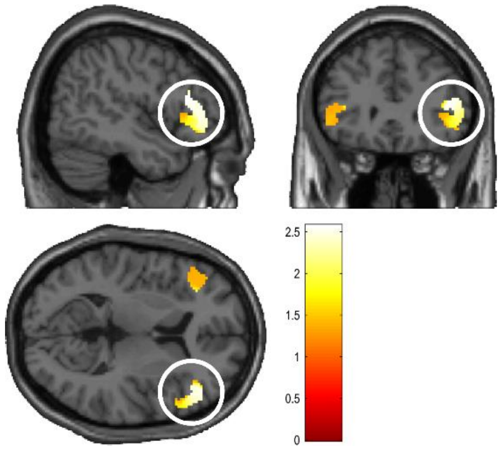


Figure 2-6

Brain Areas Showing Lower Activity in the Drop as Compared to Build-up Music Passages (Cluster Size k > 5 Voxels, P_{FWE} < 0.05) (a) Bilateral Premotor Cortex (y =11, z = 23), (b) Left Precuneus (y = -40, z = 52). The Colourbar Indicates the T Statistical Values

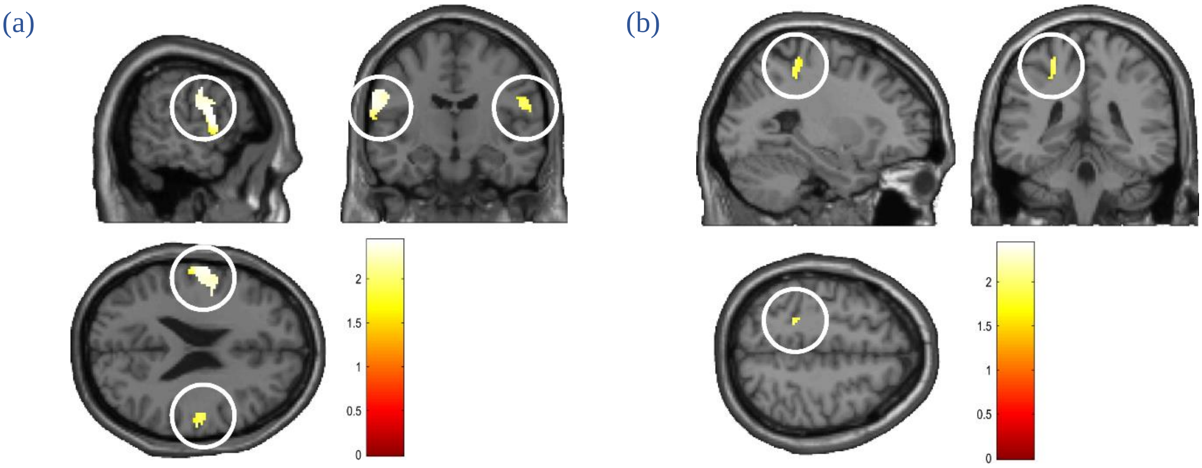
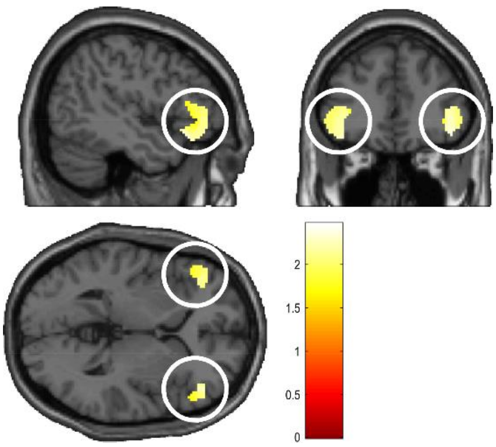


Figure 2-7

Correlation of the Difference Activity (Drop Minus Build-up Music Passages) with Subjective Rating of Excitement Showing Bilateral Inferior and Middle Frontal Cortices (y = 38, z = 2) (k > 5 Voxels, P_{FWE} < 0.05). The Colourbar Indicates the T Statistical Values



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), right middle frontal gyrus (MFG), bilateral premotor cortex (PMC), and precuneus (PCUN). 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 et al., 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 PMC and PCUN were more active during build-up compared to drop passages. Despite the PMC mostly being linked to motor functions, they have also been implicated in music processing and integrating motor, somatosensory, and auditory information (Potes et al., 2012; Ramos-Murguialday & Birbaumer, 2015; Tanaka & Kirino, 2018). The PMC 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 et al., 2015; Potes et al., 2012; Schön et al., 2010; Thaut et al., 2014). In support of our hypothesis, greater PMC and PCUN activity during build-up passages could be traced to processing specific acoustic 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" (Figure 2-1a), 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 PMC and PCUN activity during build-up passages could be related to experiencing tension and expectancy (Bjork & Hommer, 2007; James et al., 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 PMC 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 acoustic 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 acoustic 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 et al., 2007; Rogenmoser et al., 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 et al., 2017; Koelsch et al., 2006; Tabei, 2015; Wallmark et al., 2018a). 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 et al., 2012; Kim et al., 2017; Kohn et al., 2014; Lehne et al., 2014; Pecenka et al., 2013; Tillmann et al., 2003).

Linking Break Routines, Brain Differences, and Emotions

Familiarity with EDM break routines facilitates expectations for build-up (escalating acoustic 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 et al., 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 acoustic 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 acoustic 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 et al., 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 et al., 2007; Platel et al., 1997; Seger et al., 2013; Wallmark et al., 2018a). 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 et al., 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., 2007b; 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 et al., 2014a; 2014b; Rogenmoser et al., 2016), functional connectivity (Alipour et al., 2019; Wu et al., 2012), and frontal alpha-asymmetry (Briesemeister et al., 2013; Smith et al., 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 PMC differed during either build-up (escalating acoustic features) or drop (fulfilled expectations) passages and may relate to the processing of specific acoustic 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.

Chapter 3 – The Extent Structure Effects Music-Evoked Emotions

Introduction

Research has shown music can evoke peak-pleasurable emotions, defined as intense emotions with high positive valence and arousal that commonly co-occur with physiological responses, such as elevated heart rate and ‘chills’ (Blood & Zatorre, 2001; Habibi & Damasio, 2014; Menon & Levitin, 2005; Mori & Iwanaga, 2017). In many music genres, peak-pleasurable emotions, such as excitement, are induced by acoustic features combined and ordered to create structures, which enable the fulfillment of expectations and predictions of subsequent musical motifs (Juslin et al., 2008; Huron, 2006; Meyer, 1956; Omigie, 2016). These emotions also are correlated with brain activity in areas for arousal, reward, and positive emotions, including the orbitofrontal cortex (OFC) and medial prefrontal cortex (PFC; Habibi & Damasio, 2014; Salimpoor et al., 2011; Särkämö & Soto, 2012; Rolison & Edworthy, 2013).

As discussed in earlier chapters, a well-supported theory describing music emotions is ITPRA: imagination, tension, prediction, reaction, and appraisal (Huron, 2006; see ‘Music-Evoked Emotions, Expectancy & Predictions’ from Chapter 1). This theory suggests that music’s structure enables listeners to predict, expect, and consciously imagine musical features, which differ across music genres (Huron, 2006; Koelsch, 2014; Meyer, 1956; Rohrmeier & Koelsch, 2012; Vuust & Witek, 2014). Music listeners may also experience various levels of tension due to the uncertainty of exactly how and when expected music moments may occur in different music genres (Huron, 2006; Lehne & Koelsch, 2015; Solberg, 2014; Turrell et al., 2021). When expectations are fulfilled in any music genre, listeners can experience arousing and positively valenced peak-pleasurable emotions, such as excitement, as well as co-occurring physiological sensations like chills (Arjmand et al., 2017; Daly et al., 2015; Omigie, 2016). Then, listeners consciously appraise the music’s structure, assessing the quality of the emotive experience and strengthening future music expectations for that music genre (Huron, 2006; Solberg, 2014, Solberg & Dibben, 2019).

Music genres construct their structures in different ways, with various levels of expectancy, tension, and acoustic features. For instance, electronic dance music (EDM) and rap have a greater emphasis than other genres on rhythm during large build-ups to moments of highly expected changes. Classical or opera music build-ups and expectations are characterized more by melody and harmonic progression, folk music build-ups and expectations are frequently distinguished by features such as pitch and onset predictability, and classic Indian music (Raga) uses pitch, note density, and sensory dissonance during expected moments and build-ups (Mathur et al., 2015; Sauvé et al., 2018; Solberg, 2014; Turrell et al., 2021). Such different acoustic events are nevertheless intended to instantiate expectations and evoke peak-pleasurable emotions (Juslin & Västfjäll, 2008) but may achieve this result to different degrees and with different corresponding brain activity (Bigliassi et al., 2015; Grewe et al., 2007a; Koelsch, 2014; Seger et al., 2013; Turrell et al., 2021).

Acoustic features that differ across music genres, such as rhythm, melody, groove, tempo, and pitch also induce changes in activity in middle frontal gyrus (MFG), premotor cortex (PMC), superior marginal gyrus (SMG), dorsolateral prefrontal cortex (DLPFC), and inferior frontal gyrus (IFG) activity (Dohn et al., 2015; Garcea et al., 2017; Padala et al., 2019; Schaal et al., 2013; Thaut et al., 2014; Turrell et al., in submission, c). For example, DLPFC, STG, auditory cortex, and PMC activity patterns are genre-specific and differ across classical, techno, reggaeton, electronic, and folk music corresponding to processing differences in acoustic features (Bigliassi et al., 2015; Martín-Fernández et al., 2021; Nakai et al., 2018; Nakai et al., 2021). Acoustic features and related brain activity, like MFG and PMC activity, correlate with induced peak-pleasurable emotions, including liking, happiness, and excitement (Altenmüller et al., 2014; Kornysheva et al., 2010; Kim et al., 2017; Turrell et al., 2021). This suggests that music genres with differing acoustic features may evoke different, and to varying extents, peak-pleasurable emotions and concomitant brain activity patterns.

However, music genres can also share similarities in their structures and subsequent emotional effects (Pachet & Cazaly, 2000; van Venrooij, 2015; West & Lamere, 2006). Processing similar structures across music genres predicts shared patterns of PFC, MFG, DLPFC, IFG, precuneus (PCUN) and PMC activity irrespective of the genre, as well as to evoked peak-pleasurable emotions (Gordon et al., 2018; Koelsch, 2009; 2014; Kunert et al., 2015; Osnes et al., 2012; Turrell et al., 2021; Turrell et al., in submission, c). Our previous chapter suggested music structures that increase tension levels prior to expected changes in groove or motifs can potentially evoke peak-pleasurable emotions (like excitement) and relating IFG, MFG, and PMC activity when expectations are fulfilled (Butler, 2006; Huron, 2006; Koelsch 2014; Lehne et al., 2014; Solberg, 2014; Turrell et al., 2021). This suggests that evoked peak-pleasurable emotions and accompanying brain activity can be similar across genres if they also share similar structures, particularly those involving tension and expectations.

The majority of studies on emotion in music use Western classical music or simplified stimuli specifically created or manipulated to alter one basic component, such as tempo (Omigie, 2016; Schutz, 2017; Seger, 2009; Seger et al., 2013), perhaps limiting the extent that similarities and differences in music emotions and brain activity across multiple genres can be understood. Therefore, exploring and directly comparing diverse music styles, with different acoustic features, can clarify the extent acoustic features and music structures influence our previous findings of peak-pleasurable emotions and their associated brain activity (Koelsch, 2014; Sauvé et al., 2018).

This study explored how musical moments with similar structures but different acoustic features and implementation influence peak-pleasurable emotions and brain activity across two music genres, using a particular music moment referred to in EDM as a *break routine* (Solberg, 2014; Solberg & Dibben, 2019; see the 'EDM Break Routines & Emotion' section in Chapter 1). As break routines often follow a predetermined structure, the drop passage is highly expected after the build-up passage and similar moments can be found in different genres. Listeners are unsure of exactly how and when highly expected drop passages will happen but when they finally occur, listeners experience highly arousing and positively valenced peak-pleasurable emotions, like excitement (Huron, 2006; Meyer, 1956; Solberg, 2014; Solberg & Dibben, 2019).

Break routines have also been associated with patterns of brain activity related to processing music structures, as well as to experiences of tension and peak-pleasurable emotions. The previous chapter showed build-up passages increased PMC and PCUN activity, whereas drop passages resulted in increased activity within the IFG and MFG (Turrell et al., 2021). Therefore, the structure of break routines creating growing tension during build-up passages prior to a highly expected change in drop passages, induces peak-pleasurable emotions and characteristic brain activity. This makes them a good tool to explore whether the emotive and neurological effects of music differ across genres with similar structures of creating tension before expectations, but with different low-level acoustic features and implementation.

Break routines predominantly occur in EDM, for example the song 'SASH!' by Ecuador which has rapid and drastic increases and decreases in acoustic features such as global energy (RMS), brightness, and beat clarity across the end of build-up and drop passages (14-16s; see Figure 3-1). Within this EDM break routine, the texture starts with a simple repeating two-note undulating motif. This gradually increases in tempo with an underlying increase in frequency on a synthesized sound to build tension. Then about halfway, the two-note motif increases rapidly in tempo with an added beat, which soon after rapidly increases again, building the listener up in tension to a peak moment. The motif suddenly stops, forming the break, as we hear only a simple drum sequence. Then, the main pulsating feel of the song is reintroduced for the remaining 5s of the break routine clip.

Similar, yet slightly acoustically different, moments can also be found in different music genres, such as classical music. For instance, one excerpt we used was measures 57-68 from the first movement of ‘Brahms Symphony No 1 in C Minor, Op.68, Un poco sostenuto, Meno Allegro’. During this analogue break routine, the texture begins simply with a two-note descending motif for all strings in unison. But tension is built as that motif restarts but on a higher pitch that includes woodwinds, then a pulse (dividing the beat into triplets) starts in the strings and the harmony becomes very unsettled, until there is a (brief) resting point of harmonic resolution for full orchestra. The break then occurs as the theme resumes quietly, and in a lower register with just a few instruments. In more acoustic terms, features such as spectral flux, mode, and spectrum increase to then decrease across the passages, similarly to the EDM break routine example but to a lesser extent (see Figure 3-1 and Figure 3-2 and Figure 3-3). Break routines in EDM and classical music thus have similar structures, as they both manipulate listener expectations to create moments of building tension before expected structural changes and evoke peak-pleasurable experiences (Butler, 2006; Solberg & Dibben, 2019; Turrell et al., 2021).

However, the acoustic features, as well as the frequency and way implemented may differ between EDM and analogue classical break routines. EDM break routines often contain greater global energy (RMS), spectral flux, brightness, spectrum, and beat clarity but lower tonality mode than classical analogue break routines (see Table 3-2). Also, EDM break routines are heavily identified with EDM production (Butler, 2006). EDM Producers and DJ’s specifically implement break routines for their highly emotive and reinvigorating dance effects, that are desired in contexts where it is commonly used, such as clubs and parties (Solberg & Jensenius, 2017; Solberg & Dibben, 2019). In contrast, classical music is less clearly associated with break routines, implementing them less frequently and consistently while also applying a broad range of other, abstract musical techniques to create peak-pleasurable emotions (Simonton, 2010). Thus, while the structures of break routines are similar in classical and EDM, they may be more salient in EDM due to differences in acoustic features and implementation, as well as being more expected and predictable, amplifying experienced peak-pleasurable emotions.

To assess the research question on the extent music structure of tension and expectancy influences music-evoked emotions, in this chapter we presented EDM break routines and analogue classical break routines to enable a direct comparison of the emotional and neurological effects across genres with similar music structures but implemented with different acoustic features. Peak-pleasurable emotions and concomitant patterns of brain activity were measured using the 2-dimensional emotional space of valence and arousal rating and continuous electroencephalography (EEG). We hypothesized that musical structure (EDM break routines and analogue classical break routines) would increase valence and arousal ratings, indicating peak-pleasurable emotions and brain activity in the MFG, IFG, and PMC. Similarities between EDM and analogue classical break routines would suggest the importance at the neural and behavioural level of the break routine structure.

However, peak-pleasurable emotions and MFG, IFG, and PMC activity may be different and greater for EDM given acoustic features, such as global energy (RMS), are higher and break routines are implemented more regularly, making them more expected. If patterns of behavioural and brain activity are similar but stronger in EDM break routines, this would suggest an interaction with acoustic features perhaps magnifying the effects of structure. Assessing these similarities and differences between EDM and analogue classical break routines allows the separation of how much brain activity and peak-pleasurable responses result from acoustic features and how much is due to the music structure.

Method

Participants

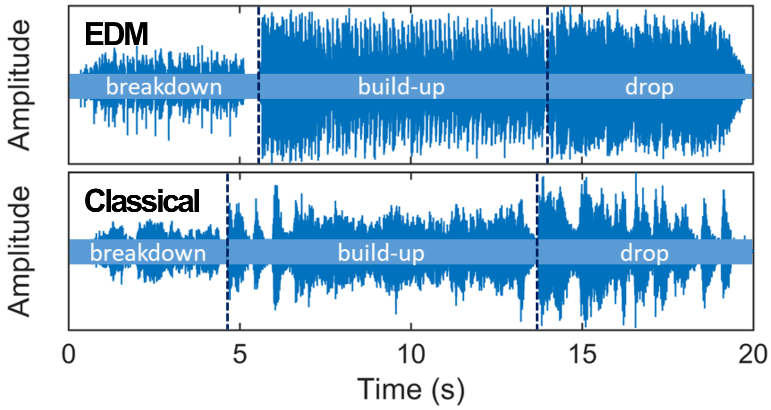
Power calculation on a previous similar study indicated a minimum sample size of 54 was required (effect size 0.5, target power 0.95; G*Power 3.1.9.4). A total of 64 participants were recruited (n=53 (82.8%) females, age *M(SD)* = 19.10(1.34)). Participants had *M*(*SD)* = 1.75(1.82) years of experience with a musical instrument (*Mdn* = 1 for 0-1 year) and on average heard similar classical music (*M(SD)* = 2.50(.78), *Mdn* = 3), EDM (*M(SD)* = 3.33(.76), *Mdn* = 3), and break routines (*M(SD)* = 3.27(.80), *Mdn* = 3) on Likert scales of 1 (never) to 4 (often). Participants were right-handed, had normal/corrected to normal vision and hearing, no neurological illnesses, and took no centrally acting medication. All participants gave written informed consent in line with the Declaration of Helsinki. The study protocol was approved by the local ethics committee in the School of Psychology at the University of Kent.

Stimuli

Stimuli consisted of 18-22 seconds EDM break routines and analogue classical music break routines. Ninety-seven analogue classical break routines were initially identified by the PhD and an undergraduate student from classical songs such as, Eric Whitacre Etude in c-sharp minor, Op.42, No.5. Classical clips selected were similar to EDM break routines with comparable structures of intensifying tension before fulfilling expected drop passages, hence the name ‘analogue classical break routines. Times of analogue build-up and drop passages for each song’s break routine were noted when identified as possible stimuli. These times were further noted independently by the last author, which were then compared to investigate reliability (difference *M(SD)* = 82(96)ms, *Mdn* = 16ms). One analogue classical break routine was extracted for each song using MATLAB r2018b (MathWorks, California, US) to create 20s clips containing analogue break routine build-up and drop passages with 1s fade-in and -out. The duration of breakdown and build-up passages was 14-16s while drop passages were 4-6s (see Figure 3-1).

Figure 3-1

Relative Amplitude Plotted for an Example EDM Break Routine and Analogue Classical Music Break Routine: Divided into Breakdown, Build-up, and Drop Passages. The vertical axes represent digital signal amplitude.



However, analogue classical and EDM break routines differ in how they are created, the instruments used, and acoustic features, such as timbre, rhythm, and mode, which can have varying effects on music-evoked emotions (Gomez & Danuser, 2007; Kim et al., 2010; Wu et al., 2014). For example, analogue classical break routines included in this study occasionally involved fewer instruments, such as solely piano, or an orchestra with various instruments. Meanwhile, EDM break routines often contained many layers of structured, instrumental, and electronically produced sounds (Butler, 2006; Solberg & Dibben, 2019). Such differences between analogue classical and EDM break routines may have influenced how they are processed and resulting music-evoked emotions, including excitement (Baume, 2013; Juslin & Sloboda, 2011).

To control for these acoustic feature differences, selected classical and EDM break routine clips had similar varying pilot questionnaire ratings on psychological aspects, including emotional dimensions of valence and arousal, perceived drop strengths, and observed similarities between the genres. All 97 analogue classical break routines were piloted using Qualtrics and a University of Kent research participation scheme sample (N = 320; see Appendix C). Analogue break routines were divided into four online questionnaires (24 analogue break routine clips and n = 80 per questionnaire) to prevent fatigue. Participants rated familiarity (*M(SD)* = 2.36(1.25)), strength of the drop passage (*M(SD)* = 2.61(1.07)), similarity to an EDM break routine (*M(SD)* = 2.19(1.18)), felt arousal (*M(SD)* = 2.03(1.07)), and felt valence (*M(SD)* = 3.08(0.87)) on 5-point Likert scales.

From these ratings, 30 analogue classical break routines that were low in familiarity (min = 1.65, max = 2.14, *M(SD)* = 1.94(0.12)) and ranging in break routine strength (*M(SD)* = 2.65(0.48)) were randomly selected to create the stimulus for the main study. Table 3-1 shows the correlations between these parameters of familiarity, strength, and similarity to EDM break routines.

Table 3-1

Summary of Correlations Between Pilot Study Subjective Ratings on Familiarity, Drop Passage Strength, and Similarity to EDM for the 30 Analogue Classical Break Routines Used in this Study

	Familiarity	**Strength**	**Similarity**
Familiarity		$r(28) = 0.057$, $p = .767$	$r(28) = 0.030$, $p = .876$
Strength	$r(28) = 0.057$, $p = .767$		$r(28) = 0.958$, $p < .001$*
Similarity	$r(28) = 0.030$, $p = .876$	$r(28) = 0.958$, $p < .001$*	

Note. * FDR corrected $p < .05$.

EDM break routines were selected from a wider collection of 90 clips used Chapter 2 (Turrell et al., 2021). See the 'Stimuli' section in Chapter 2 for details on EDM break routines selection and piloting. A structured randomized draw of 30 EDM break routines from this earlier study enabled a comparable selection with low familiarity (min = 1.16, max = 2.86, *M(SD)* = 1.84(0.50)) and ranging break routine strength (*M(SD)* = 2.52(0.43)). Durations of EDM and analogue classical break routines in the main study varied between 18-22s with the moment of drop passages varying between 12-16s. Duration of drop music passages were kept to 6s. For the complete list of songs see the associated data via DOI link https://doi.org/10.17605/OSF.IO/JY7GK.

To further investigate musical features between the two genres, EDM break routine and analogue classical break routine clips were compared on acoustic features (Solberg & Dibben, 2019) using the MIR toolbox (Lartillot et al., 2008; see Table 3-2). Specifically, we compared global energy (RMS, referring to average loudness), timbre (the sound quality of musical notes), rhythm (beat clarity), and mode (the type of musical scale) (Butler, 2006; Bispham, 2006; Juslin & Sloboda, 2011; Solberg, 2014; Theimer et al., 2008).

Table 3-2

Differences in Acoustic Features Between EDM and Analogue Classical Break Routines

	Measurement	**Classical M*(SD)***	**Dance M*(SD)***	***p***
Sub. Rating	Familiarity	1.943 *(0.122)*	1.839 *(0.509)*	0.040
	Strength	2.651 *(0.492)*	2.525 *(0.438)*	0.325
Dynamics	Global Energy (RMS)	0.807 *(0.171)*	0.890 *(0.090)*	0.044
Timbre	Spectral Flux	441.8 *(104.5)*	621.3 *(116.2)*	< 0.001*
Rhythm	Beat Clarity	0.194 *(0.125)*	0.581 *(0.181)*	< 0.001*
Tonality	Mode	-0.059 *(0.024)*	-0.044 *(0.025)*	0.019*

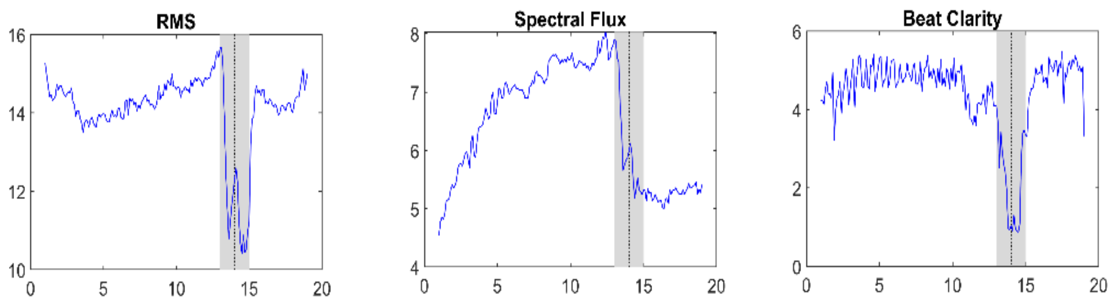
Note. Two-independent sample Mann-Whitney U Test; * FDR corrected $p < 0.05$.

Plots of acoustic features for both EDM and analogue classical break routines were also created on 2 seconds of data around every time point on the horizontal axis: one second before and one second after (see Figure 3-2 and Figure 3-3). This was done as more than one time point is needed to listen to music stimuli and is why the plots do not reach 0 or 20s. The

2 seconds around the moment of the drop are represented by the shaded area within the plots and the dotted lines represent 14s. Within the EDM break routine example, acoustic features rapidly and drastically increase and decrease in acoustic features such as global energy (RMS), timbre (spectral flux), rhythm (beat clarity), and mode across the end of build-up and drop passages (13-15s; Figure 3-2).

Figure 3-2

Plots for Acoustic Features Across an EDM Break Routine in 'SASH!' by Ecuador.

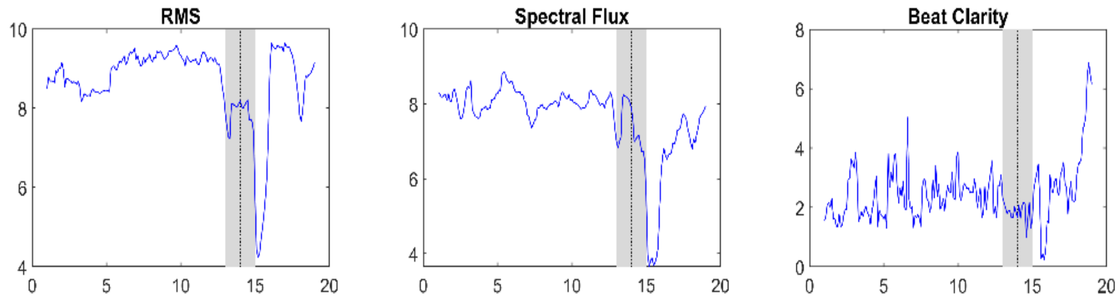


Note. The horizontal axes represent time in seconds and the vertical axes represent the average of digital signal amplitude for RMS, watts for spectral flux, and an index of beat similarity for beat clarity. The shaded area between 13-15 represents the transition between build-up and drop passages.

During the classical analogue break routine example, acoustic features such as timbre (spectral flux), mode, and global energy (RMS) also increase to then decrease across the passages, but to a lesser extent than in the EDM break routine example (see Figure 3-3). This suggests that EDM break routines increase to louder volumes, faster rhythms, as well as greater timbres and modes. Thus, acoustic features within EDM and analogue classical break routines shared similar patterns of increasing then decreasing at around 13-15 seconds but to differing degrees, which could create varying amounts of tension and expectation and consequently different music-evoked emotions.

Figure 3-3

Plots for Acoustic Features Across an Analogue Classical Break Routine in 'Brahms, Symphony No.1 in C Minor, Op.68, Un poco sostenuto, Meno Allegro'



Note. The horizontal axes represent time in seconds and the vertical axes represent the average of digital signal amplitude for RMS, watts for spectral flux, and an index of beat similarity for beat clarity. The shaded area between 13-15 represents the transition between build-up and drop passages.

Procedure

Participants received training on the definitions of valence (the essential goodness/positivity or badness/negativity of the break routine) and arousal (feelings of being awake/alert or being highly stimulated or not) to better understand the two axes and how they combine to give one emotional rating, alongside training on how to respond in the 2-dimensional response screen. The 2-dimentional response screen consisted of horizontal and vertical axes for valence and arousal ratings, respectively, both ranging from -100 to 100 (see Figure 3-4a). To ensure accurate 2-dimensional space responses, participants first received pen and paper training by marking the location of six pairs of valence-arousal (e.g., -50 valence and 100 arousal) with a researcher's guidance (see Appendix D). Also, to confirm participants' understanding of 2-dimensional space responding, 11 more increasingly difficult practice trials with live feedback were run on the computer monitor and mouse prior to the main paradigm (see Figure 3-4a). Training was repeated if participants failed to correctly indicate the location of more than four valence-arousal pairs. After training, the definitions of valence and arousal were repeated to consolidate understanding and it was reiterated that 2-dimensional space responses should represent how participants felt during the break routines.

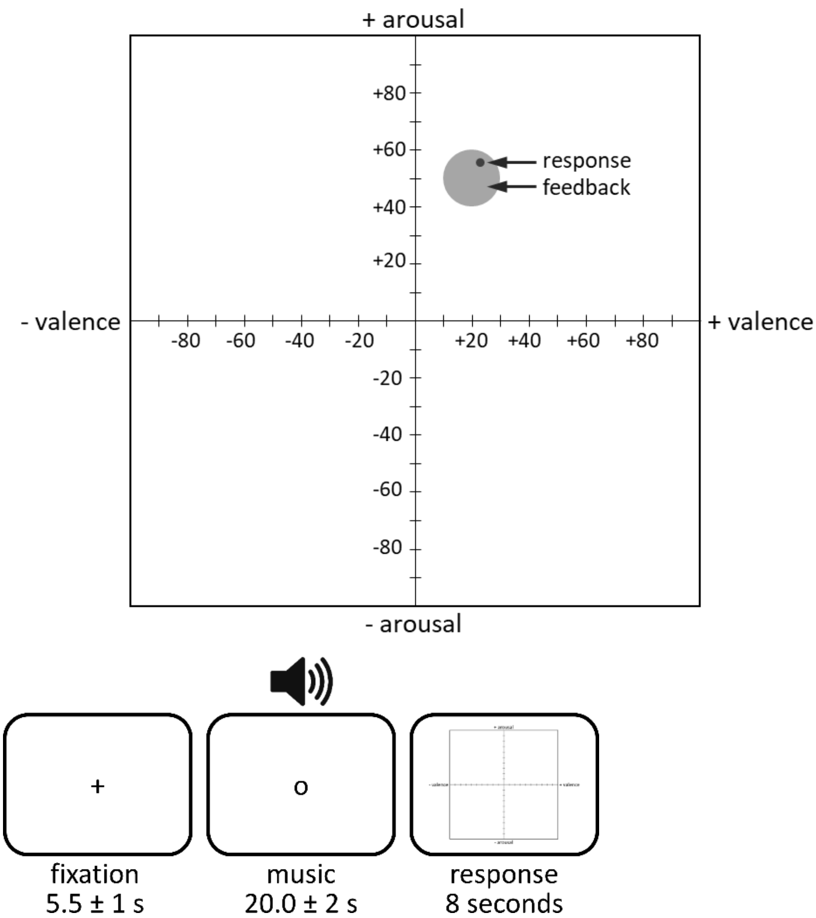
Participants were presented with 60 song clips, each about 18-22s long, and were instructed to listen to each clip carefully. Psychtoolbox v3 (Brainard, 1997) on MATLAB was used to present the paradigm and auditory stimuli, as well as record subjective 2-dimensional response ratings. The sixty break routine clips (30 of each genre) were presented in four blocks with 2min breaks in between to prevent fatigue and had an alternate order of either EDM break routines or classical analogue break routines. The starting genre was randomized across participants. Each trial began with a fixation cross of 5.5s jittered for ±1s with uniform distribution. A break routine or analogue break routine was then presented with a fixation point (a ‘o’) which participants fixed their gaze on to reduce eye movement. After listening to each clip, participants indicated their levels of felt valence and arousal using the presented 2-dimensional space (see Figure 3-4b) by selecting the location with a mouse click. Participants had 8s to respond.

Figure 3-4

(a) Computer Response Screen Showing Participant’s Response to Valence (20) and Arousal (50) During Training and the Provided Feedback. (b) Procedure of a Trial

(a)

(b)



EEG Recording

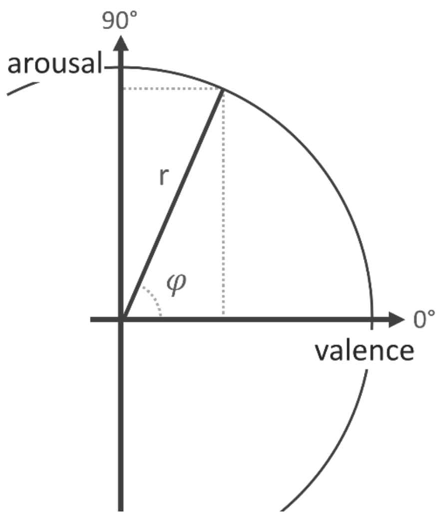
Continuous EEG was required to examine when brain activity occurred across EDM and analogue classical break routines to determine similarities and differences from structure and acoustic features. Continuous EEG was recorded using 32 passive silver and silver/silver-chloride (Ag/AgCl) electrodes with a BrainVision QuickAmp-72 amplifier system (Brain Products, Germany) placed per the 10-20 International Electrode system (including 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.

Behavioural Analysis

Participants' individual ratings of valence and arousal within the 2-dimensional space were separately recorded for each EDM break routine and analogue classical break routine clip. Subsequently we calculated the emotional strength (amplitude values) and emotional response (angle values) of 2-dimensional space responses (Figure 3-5). Emotional strength was a number between $100 \times \sqrt{2}$ and zero, $100 \times \sqrt{2}$ being the strongest feeling on the outer four corners of the response screen. The emotional responses were angles between 0 and 360°, with the right middle being zero, the top middle being +90°, the left middle being +180°, and finally the bottom middle being +270° (Figure 3-5). For example, excitement would have emotional strength values between 0 and $100 \times \sqrt{2}$ and an emotional response angle of around 45°.

Figure 3-5

Calculation of Emotional Strength (Amplitude) and Emotional Response (Angle) Based on Polar Analysis of Valence and Arousal. Emotional Strength is a Value Between $[0{,}100 \times \sqrt{2}]$ *and Emotional Response is a Value Between 0 and 360°*



x:valence

y:arousal

$$r = \sqrt{x^2 + y^2}$$

$$\varphi = \begin{cases} 2\arctan\left(\dfrac{y}{\sqrt{x^2 + y^2} + x}\right) & \text{if } x > 0 \text{ or } y \neq 0 \\ \pi & \text{if } x < 0 \text{ and } y = 0 \\ 0 & \text{if } x = 0 \text{ and } y = 0 \end{cases}$$

amplitude (line length): r

emotion (line angle): φ (expressed in degrees)

Valence, arousal, emotional strength, and emotional response were used as dependent variables in multiple linear multi-level mixed-model analyses to control for random variation across participants whilst assessing any differences between EDM and classical break routines in valence, arousal, emotional strength, and emotional responses.

Additionally, polar analysis was conducted to assess differences between EDM and classical break routines on combined measures of valence and arousal. Emotional rating values were split across 60 bins ranging from zero to 360°. Polar analysis was done using paired-sample t-tests on different bins to compare emotional responses across the different music genres.

Post-hoc tests were then run-on significant interactions, where the liner multi-level model was repeated with the data split by genre. This provided more information on the direction of relationships between valence and arousal ratings, emotional strength, and emotional response. Correlations and t-tests were also conducted to assess the effects of frequency of past exposure to classical music, EDM, and break routines on valence, arousal, emotional strength, and angle, which were then included as covariates in another round of multi-level mixed-model analyses. False discovery rate (FDR) correction for multiple comparison was used (Benjamini & Hochberg, 1995; Finner & Roters, 2001).

EEG Analysis

Our interest was to infer the neural substrates and any differences in responses to EDM break routines and analogue break routines in classical music. Thus, analysis was done at the source level and we used 3D source reconstruction to have an indication of activity locations, looking at average differences in activity across the two music genres and over build-up and drop passages in break routines.

Preprocessing of the EEG data followed similar steps to Chapter 2 (Turrell et al, 2021). EEG data was analysed using SPM v12 (Statistical Parametric Mapping, Wellcome Trust, London, UK). Data was filtered for 0.5-48Hz using 7th order Butterworth filter, montaged based on average electrode activity, and downsampled to 128Hz data. Eye-blinks were then 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, 1s of the end of build-up and 1s of the beginning of drop passages were extracted for both EDM break routines and classical analogue break routines. Finally, an automatic artifact detection algorithm was applied to the epochs, rejecting those with more than 100μv 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. Overall 2×2×30 brain volumes were created: build-up and drop passages for 30 EDM break routines and for 30 classical analogue break routines. Subsequently, brain volumes related to drop passages minus build-up passages were used to create 60 ‘difference-activity volumes. Finally, using these difference-activity volumes, we created further volumes based on the correlation coefficients between difference-activity volumes and measures of subjective responses of valence, arousal, emotional strength, and emotional response.

Two sets of analyses were conducted (Table 3-3). *Drop activity and inter-genre drop activity* assessed significant changes between build-up and drop passages, and between the two break routine genres, respectively. *Correlation and inter-genre correlational activity* assessed the correlations between difference-activity volumes and subjective responses between build-up and drop passages, as well as between classical and EDM break routines, respectively.

Table 3-3

Summary of the Brain Volumes Extracted for the Analyses and the Analyses Done

Volumes	
passage volumes	3D source reconstruction • build-up 2×30 volumes • drop 2×30 volumes
difference-activity volumes	drop passage volumes minus build-up passage volumes • 2×30 volumes
correlation-coefficient volumes	coefficients of correlations between difference-activity volumes and subjective response • arousal 2×30 volumes • valence 2×30 volumes • drop 2×30 volumes • angle 2×30 volumes
Analyses	
drop activity per genre	1-sample t-test on difference-activity volumes • × 2 analyses 1-sample t-test on correlation-coefficient volumes • arousal × 2 analyses • valence × 2 analyses • drop × 2 analyses • angle × 2 analyses
Inter-genre drop activity	paired-sample t-test on difference-activity • × 1 analysis paired-sample t-test on correlation-coefficient volumes • arousal × 1 analysis • valence × 1 analysis • drop × 1 analysis • angle × 1 analysis

Like in Chapter 2, 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 on an earlier section of the EDM break routine and analogue classical break routine clips (Turrell et al., 2021). We chose moments 4s prior to the beginning of drop passages and extracted 1s before and 1s after as shifted build-up and shifted drop music passages, respectively (see Figure 2-3 in Chapter 2).

Results

Behavioural Data

Separate linear multi-level analyses were run for each emotional rating response (valence, arousal, emotional strength, and emotional response) to assess differences in peak-pleasurable emotion ratings between EDM and analogue classical break routines. For all four emotional rating responses there was a significant main effect of genre: EDM break routines were rated significantly higher than analogue classical break routines for valence, arousal, emotional strength, and emotional response ratings (Table 3-4, Figure 3-6, and Figure 3-7).

Table 3-4

Results from the Linear Multi-level Analysis Assessing the Effects of Break Routine Genre on Valence, Arousal, Emotional Strength, and Emotional Response

Effects	*F*	*p*	Estimate	Classical M*(sem)*	EDM M*(sem)*	CI
Valence	*F*(3714.79)=36.15	<.001*	-8.62	11.27*(24.70)*	20.00*(25.48)*	[-11.44, -5.81]
Arousal	*F*(3714.67)=438.20	<.001*	-26.57	11.55*(20.19)*	38.13*(22.88)*	[-29.06, -24.08]
Emotional Strength	*F*(3709.44)=114.36	<.001*	-8.77	60.94*(16.61)*	69.75*(16.48)*	[-10.38, -7.17]
Emotional Response	*F*(3710.44)=130.53	<.001*	-29.40	16.50*(38.28)*	45.80*(27.60)*	[-34.45, -24.36]

Note. M*(sem)*: mean score and standard error for the mean; CI: 95% confidence interval; * FDR adjusted $p < .05$.

Figure 3-6

Polar Distribution of Valence, Arousal, Emotional Strength, and Emotional Responses for Classical and EDM Break Routines, Showing Significant Differences for the 45° Angle, Corresponding to the Top Right Quadrant of the 2-Dimensional Space

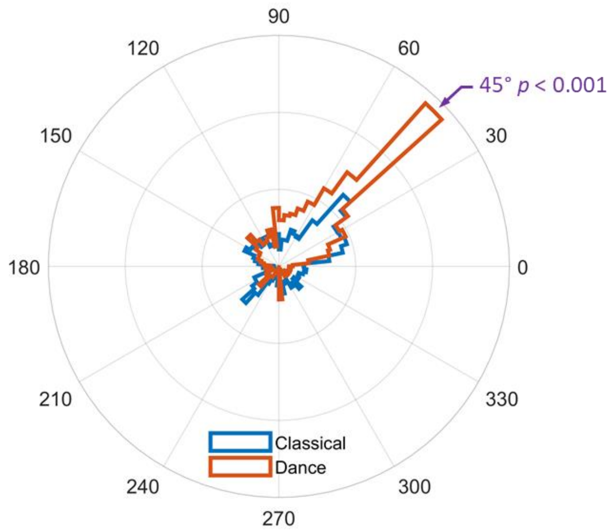
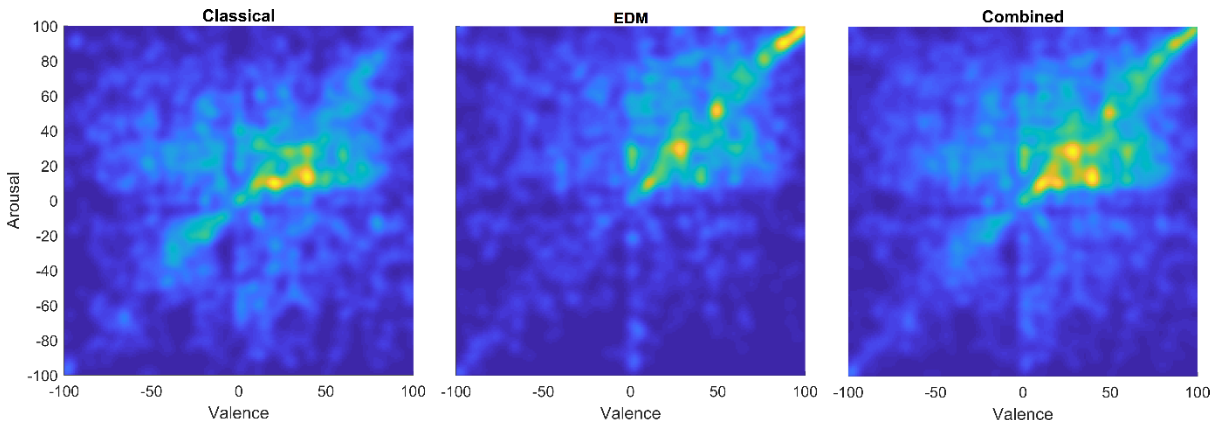


Figure 3-7

Heat Maps of Participants Recorded Responses within the 2-Dimensional Space of Valence and Arousal for Classical (Right), EDM (Middle), and Combined (Left) Break Routine Genres



Different amounts of previous exposure and familiarity to EDM and classical music could influence emotional differences. Correlations between three measures of past exposure (how often heard EDM, classical music, and break routines) were run to assess any relationships between how often participants had previously experienced each music type and emotional responses. Only the frequency of past exposure to EDM and break routines significantly and positively correlated, suggesting a relationship between hearing break routines and EDM. Correlations between EDM and break routines with classical music were not significant (see Table 3-5).

Table 3-5

Correlations between the Frequency of Past Exposure to Classical Music, EDM, and Break Routines

	Classical	**EDM**	**Break Routines**
Classical	-	r = .040, p = .751	r = .115, p = .367
EDM		-	r = .430, p < .001*
Break Routines			-

Note. *: significance of p <.05; r: effect sizes; N = 64.

Paired-sample t-tests also showed a similar pattern, with significant differences in recorded frequency of past exposure between classical music and EDM, as well as between classical music and break routines (see Table 3-6).

Table 3-6

Three Paired-sample t-tests Between the Frequency of Previous Exposure to Classical Music, EDM, and Break Routines

Music Genre	***t*(63)**	***p***
Classical and EDM	-6.24	<.001*
Classical and Break Routines	-5.83	<.001*
EDM and Break Routines	0.60	.551

Note. *: significance of p <.05; N = 64.

As frequency of past exposure to the two genres was significantly different within our sample, multi-level analysis for each emotional response was repeated with frequency of past exposure to EDM, classical music, and break routines as covariates. Including these covariates reduced the main effect of genre, making it insignificant for valence. For emotional strength, valence, and arousal there were significant interactions between the break routine genre and past frequency of exposure to classical music and EDM. For emotional strength, emotional response, valence, and arousal there were significant interactions between break routine genre and past frequency of exposure to break routines (see Table 3-7).

Table 3-7

Results from the Linear Multi-level Analysis Assessing the Impacts of Break Routine Genre on Valence, Arousal, Emotional Strength, and Emotional Response, Including the Covariates of Previous Genre Exposure Frequency (How Often Participants Had Heard Classical Music, EDM, and Break Routines)

Effect	***F***	***p***	**CI**
Valence			
Main Effect Genre	*F*(3713.52) = .44	0.507	[-10.60, 21.44]
Main Effect Classical Exposure	*F*(60.07) = .17	0.679	[-17.76, -5.26]
Main Effect EDM Exposure	*F*(59.96) = 4.30	.043†	[12.33, 26.41]
Main Effect BR Exposure	*F*(60.01) = 1.56	0.216	[-13.28, 0.10]
Genre × Classical Exposure	*F*(3713.01) = 128.14	<.001*	[16.98, 24.09]
Genre × EDM Exposure	*F*(3711.17) = 147.55	<.001*	[-28.72, -20.74]
Genre × BR Exposure	*F*(3712.20) = 7.05	.008*	[1.35, 8.95]
Arousal			
Main Effect Genre	*F*(3713.23) = 16.14	<.001*	[-44.48, -15.30]
Main Effect Classical Exposure	*F*(60.08) = 2.34	0.131	[-12.96, -0.85]
Main Effect EDM Exposure	*F*(59.98) = 1.90	0.173	[3.61, 17.25]
Main Effect BR Exposure	*F*(60.02) = .002	0.963	[-10.97, 1.99]
Genre × Classical Exposure	*F*(3712.79) = 8.76	.003*	[1.65, 8.13]
Genre × EDM Exposure	*F*(3711.16) = 40.41	<.001*	[-15.42, -8.15]
Genre × BR Exposure	*F*(3712.07) = 27.61	<.001*	[5.81, 12.73]
Emotional Strength			
Main Effect Genre	*F*(3707.41) = 9.18	.002*	[-23.94, -5.13]
Main Effect Classical Exposure	*F*(60.04) = 0.01	0.908	[-8.22, 1.62]
Main Effect EDM Exposure	*F*(59.97) = 0.83	0.366	[0.83, 11.92]
Main Effect BR Exposure	*F*(60.01) = 0.28	0.599	[-6.45, 4.10]
Genre × Classical Exposure	*F*(3707.13) = 32.21	<.001*	[3.95, 8.13]
Genre × EDM Exposure	*F*(3706.10) = 42.71	<.001*	[-10.15, -5.46]
Genre × BR Exposure	*F*(3706.68) = 19.93	<.001*	[2.85, 7.31]

Emotional Response			
Main Effect Genre	*F*(3710.30) = 21.26	<.001*	[-99.63, -40.18]
Main Effect Classical Exposure	*F*(60.19) = 0.09	0.767	[-10.51, 7.77]
Main Effect EDM Exposure	*F*(59.99) = 0.27	0.605	[-10.54, 10.03]
Main Effect BR Exposure	*F*(60.08) = 0.48	0.49	[-15.02, 4.56]
Genre × Classical Exposure	*F*(3709.46) = 0.003	0.954	[-6.40, 6.79]
Genre × EDM Exposure	*F*(3706.37) = 1.41	0.235	[-11.89, 2.92]
Genre × BR Exposure	*F*(3708.14) = 21.86	<.001*	[9.76, 23.86]

Note. EDM Exposure: measurement of how often participants had heard EDM; Classical Exposure: measurement of how often participants had heard classical music; BR Exposure: measurement of how often participants had heard break routines with drop passages; CI: 95% confidence interval; †: uncorrected $p \leq .05$; *: FDR adjusted $p \leq .023$.

Post-hoc tests, where the data was split by genre and the linear multi-level analysis repeated on significant interactions between break routine genre and previous classical, EDM, and break routine exposure showed that the amount of exposure to EDM and classical music particularly influenced music-evoked peak-pleasurable emotion ratings in EDM break routines (see Table 3-8).

Table 3-8

Estimates from the Linear Multi-level Analysis when Data had been Split by Genre for Emotional Strength and Emotional Response, Including Previous Exposure to Genre Covariates

	Effect	***t***	***p***	**Est.**	**CI**
Valence					
Classical	Classical Exposure	*t*(59.91) = 2.30	.025†	8.96	[1.16, 16.76]
	EDM Exposure	*t*(59.94) = -1.21	0.229	-5.34	[-14.15, 3.46]
	BR Exposure	*t*(59.88) = -0.35	0.729	-1.46	[-9.82, 6.91]
EDM	Classical Exposure	*t*(60.41) = -3.51	.001*	-11.61	[-18.23, -4.99]
	EDM Exposure	*t*(59.97) = 5.21	<.001*	19.43	[11.98, 26.89]
	BR Exposure	*t*(60.21) = -1.90	.063††	-6.72	[-13.82, 0.37]
Arousal					
Classical	Classical Exposure	*t*(59.89) = -0.61	0.545	-2.02	[-8.66, 4.62]

	EDM Exposure	$t(59.93) = -0.36$	0.718	-1.36	[-8.85, 6.14]
	BR Exposure	$t(59.86) = 1.35$	0.184	4.78	[-2.33, 11.90]
EDM	Classical Exposure	$t(60.35) = -1.94$	.057††	-6.84	[-13.90, 0.22]
	EDM Exposure	$t(60.04) = 2.62$	.011†	10.43	[2.47, 18.39]
	BR Exposure	$t(60.21) = -1.18$	0.242	-4.47	[-12.03, 3.10]
Emotional Strength					
Classical	Classical Exposure	$t(59.96) = 1.01$	0.315	2.74	[-2.67, 8.16]
	EDM Exposure	$t(59.97) = -0.48$	0.633	-1.46	[-7.58, 4.65]
	BR Exposure	$t(59.95) = 1.36$	0.18	3.94	[-1.87, 9.74]
EDM	Classical Exposure	$t(60.26) = -1.23$	0.224	-3.23	[-8.48, 2.03]
	EDM Exposure	$t(59.97) = 2.15$	.036†	6.35	[0.43, 12.27]
	BR Exposure	$t(60.13) = -0.40$	0.688	-1.13	[-6.76, 4.49]
Emotional Response					
Classical	Classical Exposure	$t(59.98) = -0.19$	0.851	-1.17	[-13.67, 11.34]
	EDM Exposure	$t(59.99) = -0.67$	0.506	-4.72	[-18.83, 9.39]
	BR Exposure	$t(59.95) = 1.73$	0.089	11.57	[-1.83, 24.98]
EDM	Classical Exposure	$t(60.64) = -0.23$	0.818	-1.06	[-10.22, 8.10]
	EDM Exposure	$t(60.05) = -0.05$	0.958	-0.27	[-10.58, 10.04]
	BR Exposure	$t(60.38) = -1.03$	0.309	-5.03	[-14.84, 4.78]

Note. EDM Exposure: measurement of how often participants had heard EDM; Classical Exposure: measurement of how often participants had heard classical music; BR Exposure: measurement of how often participants had heard break routines with drop passages; Est.: estimates; CI: 95% confidence interval; ††: uncorrected $p < .07$; †: uncorrected $p < .05$; *: FDR adjusted $p \leq .004$.

EEG Analysis

Drop & Inter-Genre Drop Activity

Drop and Inter-genre Drop EEG analyses showed the differences in brain activity across build-up and drop break routine passages, as well as between EDM and analogue classical break routines. Analysis of difference-activity volumes replicated previous findings from Chapter 2 with significant differences in brain activity between build-up and drop break routine passages across the two (classical and EDM) genres (Turrell et al., 2021). There were greater differences in right PMC and left MFG activity during drop passages, as well as greater bilateral superior temporal gyrus (STG) activity differences within build-up passages (Table 3-9).

We then split the data by genre and looked at brain activity differences between build-up and drop passages for analogue classical and EDM break routines independently. Both break routine genres correlated with greater STG activity differences during build-up passages and increased posterior angular gyrus (PAnG) activity differences within drop passages (Table 3-9). Inter-genre drop analysis showed greater activity differences within bilateral superior frontal gyrus, lateral part (SFGL) during classical break routines, as well as increased activity differences in the left PAnG, and bilateral STG during EDM break routines (Table 3-9). Specifically, left MFG and right SFGL activity differences between build-up and drop passages were greater during classical break routines compared to EDM (Table 3-9).

Table 3-9

Summary of the Drop and Inter-Genre Drop 3D Source Reconstruction Analysis of the EEG Data

						MNI		
Comparison	**Brain Area**	K_E	T	Z	P_{uncorr}	**x**	**y**	**z**
Drop Activity								
Drop > Build-up	r-Premotor Cortex	173	1.69	1.69	0.046	18	-24	68
	l-Mid Frontal Gyrus	501	1.54	1.55	0.061	-36	20	40
Drop < Build-up	l-Sup Temporal Gyrus	100	1.60	1.61	0.054	-48	-14	-14
	r-Sup Temporal Gyrus	100	1.51	1.52	0.064	56	-10	-10
Class - Drop > Build-up	l-Mid Frontal Gyrus	738	2.20	2.19	0.014	-44	20	36
	r-Sup Frontal Gyrus-Lateral Part	54	1.72	1.73	0.042	16	0	68
	r-Post Angular Gyrus	139	1.56	1.57	0.058	42	-72	34
Class - Drop < Build-up	l-Sup Temporal Gyrus	114	1.66	1.67	0.048	-48	-14	-14
	r-Sup Temporal Gyrus	118	1.61	1.61	0.053	56	-10	-10
EDM - Drop > Build-up	l-Post Angular Gyrus	68	1.65	1.66	0.049	-42	-72	38

EDM - Drop < Build-up	l-Sup Temporal Gyrus	49	1.77	1.77	0.039	-60	-48	26
Inter-Genre Drop Activity								
EDM > Class	l-Post Angular Gyrus	127	2.18	2.17	0.015	-42	-72	38
	r- Sup Temporal Gyrus	199	1.85	1.85	0.032	60	-44	28
	l- Sup Temporal Gyrus	90	1.78	1.78	0.038	-60	-48	26
EDM < Class	l-Sup Frontal Gyrus-Lateral Part	265	1.76	1.77	0.039	-16	0	66
	r-Sup Frontal Gyrus-Lateral Part	24	1.52	1.53	0.062	16	0	68
EDM Build-up-EDM Drop < Class Build-up-Class Drop	l-Mid Frontal Gyrus	402	1.66	1.66	0.048	-48	20	32
	r-Sup Frontal Gyrus-Lateral Part	40	1.60	1.61	0.054	16	0	68

Note. K_E refers to the number of neighbouring voxels with *p* value greater than the defined threshold of 0.05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; EDM: Electronic Dance Music; Class: Classical; Inf: Inferior; Mid: Middle; Sup: Superior; Post: Posterior; Trans: Transverse.

Correlations with Emotion Ratings

Correlational and inter-genre correlational analysis examined changes in brain activity across build-up and drop break routine passages in relation to peak-pleasurable emotion ratings and between EDM and analogue classical beak routines in these correlations. Analysis between difference-activity volumes and subjective ratings of valence (Table 3-10), arousal (Table 3-11), emotional strength (Table 3-12), and emotional response (Table 3-13) showed brain activity differences between build-up and drop passages.

Valence ratings correlated with increased bilateral MFG, left SFGL, and right PAnG activity differences during EDM break routines. Classical break routine valence ratings correlated with increased right PAnG and left MFG activity differences during build-up passages. While EDM valence ratings correlated with increased right SFGL and left superior frontal gyrus, medial part (SFGM) activity differences during build-up passages, as well as increased bilateral parietal operculumactivity (POp) and left SMG activity differences within drop passages. Specifically, differences in right PAnG, left MFG, and right PMC activity between build-up and drop passages that correlated with valence ratings were greater in EDM break routines (Table 3-10 and Figure 3-8).

Table 3-10

Summary of the Correlational and Inter-Genre Correlational 3D Source Reconstruction Analysis of Valence Ratings

						MNI		
	Brain Area	K_E	*T*	*Z*	P_{uncorr}	**x**	**y**	**z**
Correlational Activity								
Drop < Build-up	l-Sup Frontal Gyrus-Lateral Part	196	1.97	1.96	0.025	-16	0	66
	r-Sup Frontal Gyrus-Lateral Part	14	1.65	1.66	0.048	18	-2	68
	l-Mid Frontal Gyrus	161	1.40	1.41	0.079	-36	20	40
	r-Sup Temporal Gyrus	25	1.36	1.38	0.084	56	-44	14
Class - Drop < Build-up	r-Post Angular Gyrus	480	1.71	1.71	0.043	44	-72	32
	l-Mid Frontal Gyrus	397	1.69	1.70	0.045	-40	20	38
EDM - Drop < Build-up	r-Sup Frontal Gyrus-Lateral Part	29	1.89	1.89	0.029	18	-2	68
	l-Sup Frontal Gyrus-Medial Part	145	1.75	1.75	0.040	-8	4	68
EDM - Drop > Build-up	l-Par Operculum	40	1.87	1.87	0.031	-56	-20	26
	l-Sup Marginal Gyrus	126	1.83	1.83	0.034	-60	-26	36
	r-Par Operculum	15	1.68	1.68	0.046	56	-22	26
Inter-Genre Correlational Activity								
EDM > Class	l-Mid Frontal Gyrus	565	2.09	2.09	0.018	-28	26	34
	r-Mid Frontal Gyrus	203	1.84	1.84	0.033	28	26	38
	l-Sup Frontal Gyrus-Lateral Part	125	1.73	1.73	0.042	-18	0	66
	r-Post Angular Gyrus	167	1.34	1.36	0.086	42	-74	34
EDM < Class	l-Sup Frontal Gyrus-Lateral Part	95	2.11	2.07	0.019	-18	0	66
EDM Build-up-EDM Drop > Class Build-up-Class Drop*	r-Post Angular Gyrus	507	2.05	2.04	0.021	42	-74	34
	l-Mid Frontal Gyrus	438	1.80	1.80	0.036	-44	20	36
	r-Premotor Cortex	39	1.60	1.61	0.054	40	-16	38

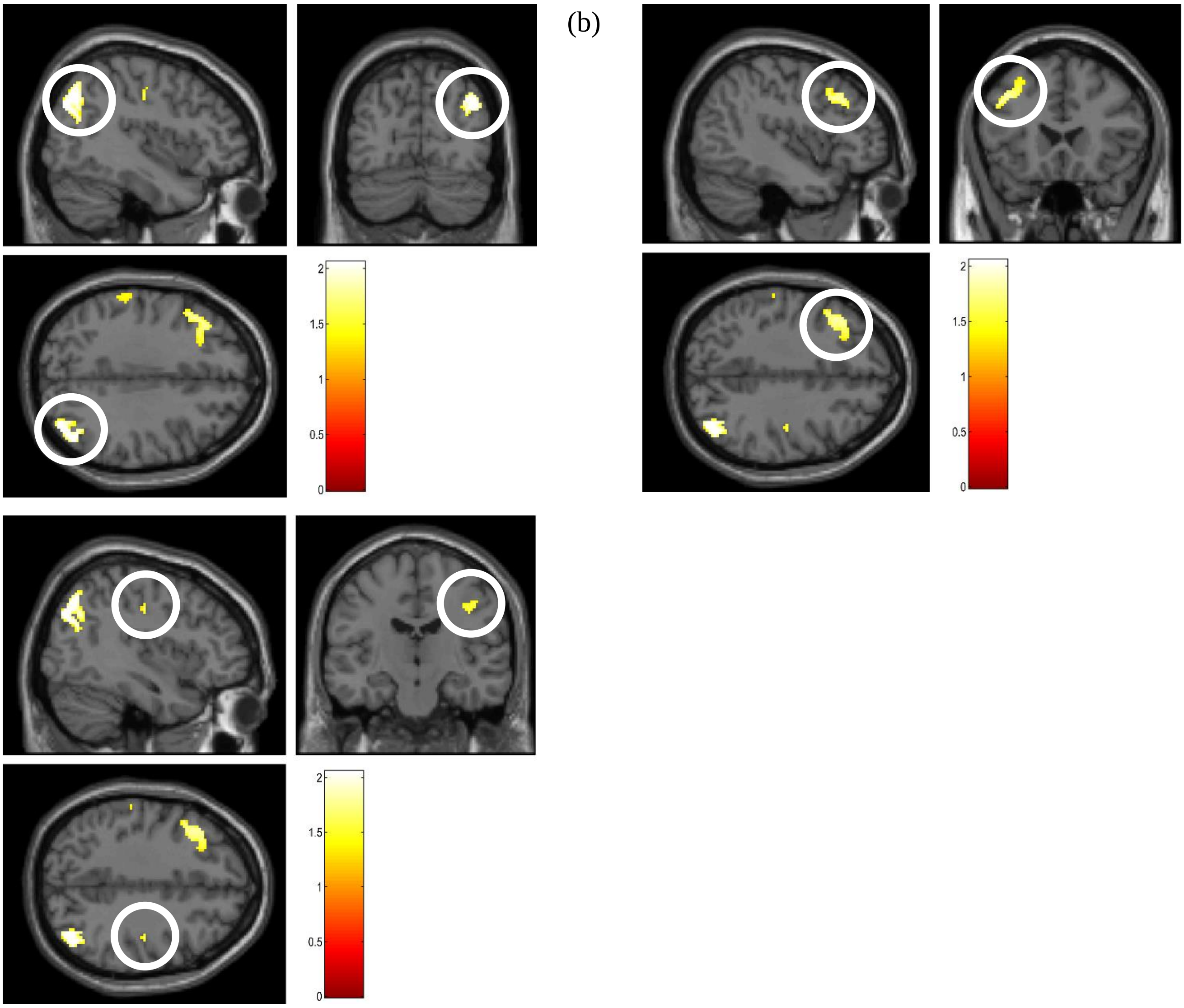
Note. K_E refers to the number of neighbouring voxels with *p* value greater than the defined threshold of 0.05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; EDM: Electronic Dance Music; Class:

Classical; Inf: Inferior; Mid: Middle; Sup: Superior; Post: Posterior; Trans: Transverse; Par: Parietal. *see Figure 3-8.

Figure 3-8

Brain Areas Correlated with Valence Ratings Showing Greater Differences Between EDM Build-up and Drop Passages (Cluster Size k > 5 Voxels) are the (a) Right PAnG (y = -74, z = 34), (b) Left MFG (y =20, z = 36), and (c) Right PMC (y = -16, z = 38). The Colourbar Indicates the T Statistical Values

(a) (b) (c)



Correlational brain activity differences for *arousal ratings* included increased left inferior temporal gyrus (ITG) activity differences during classical break routines, and greater right STG and left post transverse temporal gyrus (TTG) activity differences within EDM break routines. Specifically, arousal ratings correlated with greater right SFGL and left PMC activity differences during classical break routine drop passages and greater left PAnG activity differences during EDM drop passages. Left PAnG activity differences between build-up and drop passages correlated with arousal were also greater during EDM break routines compared to classical (Table 3-11 and Figure 3-9).

Table 3-11

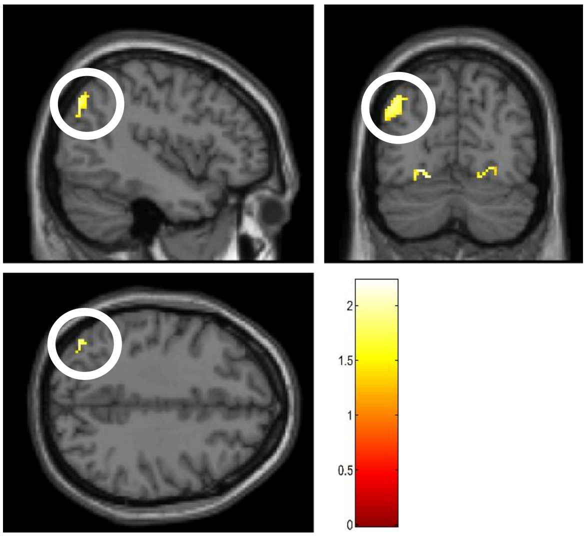
Summary of the Correlational and Inter-Genre Correlational 3D Source Reconstruction Analysis of Arousal Ratings

						MNI		
	Brain Area	K_E	T	Z	P_{uncorr}	**x**	**y**	**z**
Correlational Activity								
Drop > Build-up	l-Premotor Cortex	94	1.95	1.95	0.026	-10	-24	74
	r-Sup Frontal Gyrus-Lateral Part	127	1.93	1.93	0.027	8	-20	72
Class - Drop > Build-up	r-Sup Frontal Gyrus-Lateral Part	142	2.13	2.12	0.017	8	-20	72
	l-Premotor Cortex	107	2.10	2.09	0.018	-10	-24	74
EDM - Drop > Build-up	l-Post Angular Gyrus	54	1.68	1.68	0.046	-42	-72	38
Inter-Genre Correlational Activity								
EDM > Class	r-Sup Temporal Gyrus	103	1.98	1.97	0.024	56	-44	14
	l-Post Trans Temporal Gyrus	14	1.49	1.50	0.067	-54	-36	24
EDM < Class	l-Inf Temporal Gyrus	879	1.79	1.79	0.037	-46	-72	0
EDM Build-up-EDM Drop > Class Build-up-Class Drop*	l-Post Angular Gyrus	85	1.93	1.93	0.027	-42	-72	38

Note. K_E refers to the number of neighbouring voxels with p value greater than the defined threshold of 0.05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; EDM: Electronic Dance Music; Class: Classical; Inf: Inferior; Mid: Middle; Sup: Superior; Post: Posterior; Trans: Transverse. *See Figure 3-9.

Figure 3-9

Brain Areas Correlated with Arousal Ratings Showing Greater Activity Differences Between Build-up and Drop Passages in EDM Break Routines; the Left PAnG Activity (y = -72, z = 38) (Cluster Size k > 5 Voxels). The Colourbar Indicates the T Statistical Values



Emotional strength ratings correlated with greater right SFGL, bilateral PMC, and left MFG activity differences during classical break routines. Greater left PAnG activity differences correlated with emotional strength ratings in EDM build-up passages. Yet, greater activity differences in the left PAnG between build-up and drop passages correlated with emotional strength were seen in classical break routines compared to EDM (Table 3-12 and Figure 3-10).

Table 3-12

Summary of the Correlational and Inter-Genre Correlational 3D Source Reconstruction Analysis of Emotional Strength Ratings

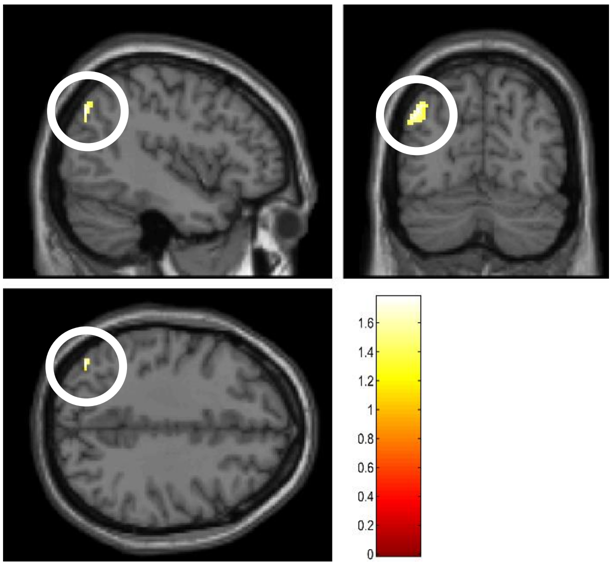
						MNI		
	Brain Area	***K*E**	***T***	***Z***	***P*uncorr**	**x**	**y**	**z**
Correlational Activity								
EDM - Drop < Build-up	l-Post Angular Gyrus	32	1.63	1.63	0.051	-42	-72	38
Inter-Genre Correlational Activity								
EDM < Class	r-Sup Frontal Gyrus-Lateral Part	97	1.64	1.64	0.050	30	28	40
	r-Premotor Cortex	85	1.56	1.57	0.058	12	-24	70
	l-Premotor Cortex	44	1.49	1.50	0.067	-10	-24	74

	l-Mid Frontal Gyrus	21	1.40	1.42	0.078	-26	26	34
EDM Build-up-EDM Drop < Class Build-up-Class Drop*	l-Post Angular Gyrus	45	1.78	1.78	0.038	-42	-72	38

Note. K_E refers to the number of neighbouring voxels with *p* value greater than the defined threshold of 0.05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; EDM: Electronic Dance Music; Class: Classical; Inf: Inferior; Mid: Middle; Sup: Superior; Post: Posterior; Trans: Transverse. *See Figure 3-10.

Figure 3-10

Brain Areas Correlate with Emotional Strength Ratings Showing Greater Activity Differences Between Classical Build-up and Drop Passages in Left PAnG (y = -72, z = 38) (Cluster Size k > 5 Voxels). The Colourbar Indicates the T Statistical Values



Emotional response ratings correlated with increased right SFGL activity differences during build-up passages within EDM and classical break routines, as well as greater differences in right PAnG and left inferior temporal gyrus (ITG) activity during classical drop passages. Greater right SFGL and left MFG activity differences correlated with emotional response ratings to a greater extent in classical compared to EDM break routines (Table 3-13 and Figure 3-11).

Table 3-13

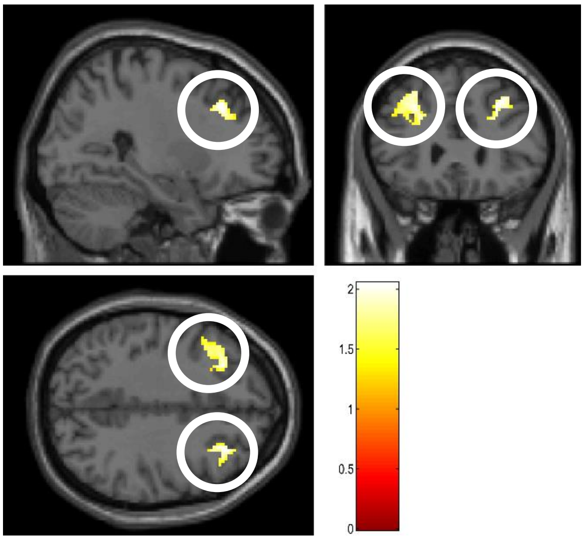
Summary of the Correlational and Inter-Genre Correlational 3D Source Reconstruction Analysis of Emotional Response Ratings

						MNI		
	Brain Area	K_E	T	Z	P_{uncorr}	**x**	**y**	**z**
Correlational Activity								
Drop < Build-up	r-Sup Frontal Gyrus-Lateral Part	229	2.67	2.65	0.004	32	28	42
	l-Inf Frontal Gyrus-Triangular Part	29	1.94	1.93	0.027	-50	32	0
	r-Inf Frontal Gyrus-Triangular Part	15	1.67	1.68	0.047	50	36	4
	l-Mid Frontal Gyrus	96	1.56	1.57	0.058	-26	26	34
Class - Drop < Build-up	r-Sup Frontal Gyrus-Lateral Part	155	2.04	2.04	0.021	30	28	40
Class - Drop > Build-up	r-Post Angular Gyrus	266	1.47	1.48	0.069	42	-74	34
	l-Inf Temporal Gyrus	461	1.34	1.36	0.086	-50	-68	-16
EDM - Drop < Build-up	r-Sup Frontal Gyrus-Lateral Part	86	1.68	1.68	0.046	32	28	42
Inter-Genre Correlational Activity								
EDM < Class*	r-Sup Frontal Gyrus-Lateral Part	167	2.04	2.04	0.021	28	28	38
	l-Mid Frontal Gyrus	424	1.95	1.94	0.026	-26	26	34

Note. K_E refers to the number of neighbouring voxels with p value greater than the defined threshold of 0.05 forming one cluster; Rows without K_E indicate a peak voxel activity belonging to the same cluster as the above row; EDM: Electronic Dance Music; Class: Classical; Inf: Inferior; Mid: Middle; Sup: Superior; Post: Posterior; Trans: Transverse. *See Figure 3-11.

Figure 3-11

Brain Areas Correlated with Emotional Response Ratings Showing Greater Activity Differences (Cluster Size k > 5 Voxels) in the Right SFGL (y = 28, z = 38) and Left MFG (y = 26, z = 34) During Classical Break Routines. The Colourbar Indicates the T Statistical Values



There were also no significant differences in the validation analysis, meaning no differences in brain activity between actual break routine and shifted build-up and drop break routine passages (*p's* > .24 uncorrected).

Discussion

Overview of results

This study offers a unique investigation into the extent music structure and acoustic features induce brain activity and peak-pleasurable emotions, using EDM and analogue classical break routines. Replicating findings from earlier chapters, break routines increased MFG and PMC activity differences across build-up and drop passages. Peak-pleasurable emotion ratings of valence, arousal, emotional strength, and emotional response, were also greater in EDM break routines, suggesting that music emotional effects are magnified by acoustic features, such as rhythm, pitch, and tempo (Brattico et al., 2011; Khalfa et al., 2008a; Lehne et al., 2014; Nusbaum et al., 2014; Thaut et al., 2014). Increased differences in MFG, SFGL, PAnG, and PMC activity correlated with greater peak-pleasure emotion ratings within EDM break routines, indicating that relating brain activity was also magnified by acoustic features (Huron, 2006; Koelsch et al., 2006; Meyer 1956; Turrell et al., 2021; Turrell et al., in submission, c). However, similar patterns of peak-pleasurable emotion ratings and MFG, SFGL, PAnG, and PMC activity during analogue classical break routines supports our conclusions from previous chapters and suggests music structure also induces brain activity and peak-pleasurable emotions (Turrell et al., 2021).

EDM and Classical Break Routine Differences

Differences in peak-pleasurable emotion ratings between EDM and analogue classical break routines suggests that acoustic features are important to music-induced emotions. Higher, valence, arousal, emotional strength, and emotional response ratings, as well as significant differences in the polar distribution of these ratings at 45° (indicating emotions such as excitement), were predicted by the often-higher levels of acoustic features, such as timbre, brightness, and rhythm, within EDM compared to analogue classical break routines (see Table 3-2; Butler, 2006; Russell, 1980). Acoustic features, such as tempo, rhythm, beat, and melody, can evoke emotions and are also used to create music structures which induce peak-pleasurable emotions, including happiness and excitement (Gabrielsson & Juslin, 1996; Habibi & Damasio, 2014; Rolison & Edworthy, 2013; Solberg, 2014; Solberg & Dibben, 2019; Turrell et al., 2021). Thus, stronger acoustic features within EDM break routines enabled increased peak-pleasurable emotion ratings and magnified the emotional effect of music structures.

Acoustic features including, beat, mode, tempo, rhythm, timber, melody, brightness, tone, pitch, and meter, as well as their relationships, structures, and irregularities also predict MFG, and PAnG activity differences (Alluri et al., 2012*;* Bogert et al., 2016; Brattico et al., 2011; Chen et al., 2006; Grahn & Brett, 2007; Grahn & Rowe, 2009; 2013; Jerde et al., 2011; Koelsch, 2011; Penhune & Zatorre, 2019; Thaut et al., 2014; Turrell et al., in submission, c). Different MFG and PAnG activity between EDM and analogue classical break routines could therefore result from acoustic feature differences. Specifically, greater MFG and PAnG activity was involved in processing more intense acoustic features in EDM break routines, such as major modes, faster tempos and rhythms, as well as louder intensities which also predict peak-pleasurable emotions, including excitement, happiness, and ‘chills’ (Butler, 2006; Brattico et al., 2011; Khalfa et al., 2008a; Kim et al., 2010; Koelsch, 2014; Laurier et al., 2009; Limb et al., 2006; Nusbaum et al., 2014; Patel, 2014; Salimpoor et al., 2009; Solberg 2014; Solberg & Dibben, 2019; Thaut et al., 2014). This suggests that greater EDM break routine acoustic features can increase peak-pleasurable emotions, such as happiness, liking, and nostalgia, as well as related MFG and PAnG activity (Altenmüller et al., 2014; Barrett & Janata, 2016; Brattico et al., 2011; Kim et al., 2017; Koelsch et al., 2006; Koelsch, 2014).

Different MFG, SFGL, PAnG, and PMC activity during EDM compared to analogue classical break routines also correlated with higher valence ratings. Increased activity during EDM break routines could have resulted from processing acoustic features, such as dissonance, key, pitch, tone, rhythm, mode, and tempo, which evoke positive valence and emotions, like joy and happiness (Bravo et al., 2017; Brattico et al., 2011; Butler, 2006; Grekow, 2017; Koelsch et al., 2018; Roda et al., 2014; Solberg & Dibben, 2019). This further suggests that differences in acoustic features between EDM and analogue classical break routines can evoke greater peak-pleasurable emotions and related MFG, SFGL, PAnG, and PMC activity during EDM break routines.

Greater arousal ratings correlated with PMC, SFGL, and PAnG activity differently across EDM and analogue classical break routines. Specifically, higher arousal ratings predicted increased SFGL and PMC activity within classical break routine drop passages, and with greater PAnG activity during EDM build-up passages. Different acoustic features between EDM and analogue classical break routines may influence arousal differently. For instance, higher arousal ratings with greater SFGL and PMC activity during classical drop passages may result from processing acoustic features, such as rhythm, tempo, and sound intensity as they change from build-ups, as well as to increased levels of unpredictability in analogue classical drop passages (Aryani et al., 2018; Chapin et al., 2010; Rogenmoser et al., 2016; Trost et al., 2012). Meanwhile, higher arousal ratings during EDM build-up passages alongside greater PAnG activity could have been induced by acoustic feature processing as they build back up to the main groove and highly expected drop passages (Bowling et al., 2019; Butler, 2006; Greene et al., 2014; Meyer, 1956). Thus, acoustic features evoke arousal and relating brain activity in EDM and classical break routines, but at different moments and with different functions.

The highest peak-pleasurable emotion ratings within EDM break routines did not always correlate with greater levels of brain activity, which sometimes occurred in analogue classical break routines. This suggests that greater acoustic features and increased emotional brain activity does not always induce greater peak-pleasurable emotions. For example, overall increased differences in MFG activity, as well as greater PMC, SFGL, and MFG activity differences in analogue classical break routines, correlated with higher emotional response and emotional strength ratings, respectively. PMC, SFGL, and MFG activity predicts aesthetic judgments and peak-pleasurable emotions, as well as strength, for emotions such as fear, happiness, joy, nostalgia, and tension, which can increase over music listening (Altenmüller et al., 2014; Barrett & Janata, 2016; Brattico et al., 2011; Kim et al., 2017; Koelsch et al., 2006; Koelsch et al., 2021; Okuya et al., 2017; Sachs et al., 2015; Trost et al., 2012). This suggests that acoustic feature differences between EDM and analogue classical break routines do not always fully correlate with differences in some peak-pleasurable emotion dimensions (namely emotional response and strength) and relating PMC, SFGL, and MFG activity, which may be more predictive of other dimensions, such as valence and the general negative or positiveness of emotions (Cunningham et al., 2004; Bogert et al., 2016; Kim et al., 2020).

Instead, similarly to contrastive valence where preceding negative emotions amplify positive ones, differential brain activity during break routine listening may enhance music-evoked emotions (Huron, 2006; Sorinas et al., 2020; Turrell et al., in submission, a; in submission, c). This suggests that EDM break routines can induce greater contrasting MFG, SFGL, PMC, and PAnG activity across build-up and drop passages, due to higher levels of acoustic features and more predictable music structures. This then results in greater valence, arousal, emotional strength, and emotional response peak-pleasurable emotion ratings compared to analogue classical break routines (Alluri et al., 2013; Brattico et al., 2011; Casey, 2017; Hoenig et al., 2011; Kim et al., 2017; Turrell et al., 2021).

EDM and Classical Break Routine Similarities

However, there were also notable similarities between EDM and analogue classical break routines. Both EDM and analogue classical break routines altered peak-pleasurable emotion ratings of valence, arousal, emotional strength, and emotional response, suggesting that their similar structures induced emotions. Music structures, like break routines, express recognizable, specific, and strong emotions in listeners by creating expectations and intensifying tension, according to the prediction effect and contrastive valence (Gabrielsson & Juslin, 1996; Juslin, 2013; Huron, 2006; Krumhansl, 2002; Solberg, 2014). Thus, break routine structures can increase tension during build-ups prior to predicted drop passages, evoking peak-pleasurable emotions, such as excitement, and suggesting why both EDM and analogue classical break routines are similarly emotive (Butler, 2006; Meyer, 1956; Solberg & Dibben, 2019; Turrell et al., 2021).

EDM and analogue classical break routines induced similar patterns of brain activity which also resulted in elevated ratings of peak-pleasurable emotion dimensions, including valence, arousal, emotional strength, and emotional response due to their structural similarities (Butler, 2006; Juslin & Sloboda, 2011; Krumhansl, 2002; Solberg & Dibben, 2019; Turrell et al., 2021). Greater MFG, SFGL, PMC and PAnG activity could have resulted from both break routines' syntax, structure, semantics, and expectations (Bogert et al., 2016; Casey, 2017; Donnay et al., 2014; Giordano et al., 2014; Heard & Lee, 2020; Koelsch, 2006; 2009; 2011; Koelsch & Siebel 2005; Osnes et al., 2012; Platel et al., 2003; Platel, 2005; Seghier, 2013; Turrell et al., 2021; Turrell et al., in submission, c). Specifically, similar MFG, SFGL, PMC, and PAnG activity in EDM and analogue classical break routines supports our previous findings and suggests brain activity results from structures of intensifying tension during build-up passages prior to expected drop passages, alongside evoked peak-pleasurable emotions when predictions were correctly fulfilled (Altenmüller et al., 2014; Brattico et al., 2011; Bravo et al., 2017; Cunningham et al., 2004; Huron, 2006; Kim et al., 2017; Shinkareva et al., 2020; Turrell et al., 2021). Therefore, similar peak-pleasurable emotions and emotional brain activity patterns during EDM and analogue classical break routines may have occurred due to their shared structures.

Future Directions

Peak-pleasurable emotion dimensions, such as valence, as well as relating MFG, SFGL, PMC, and PAnG activity, could have been influenced by familiarity. Greater familiarity reduces musical attention and processing demands, increases peak-pleasurable emotions, such as liking, preference, nostalgia, reward, and enjoyment, as well as, enhancing synchronization, emotional music engagement, emotional intensity, and anticipation for emotional acoustic features like rhythm, melody, and harmony (Ali, 2004; Ali & Peynircioğğlu, 2010; Altenmüller et al., 2014; Demorest et al., 2010; Freitas et al., 2018; Habibi & Damasio, 2014; Nan et al., 2008; Pereira et al., 2011; Plailly et al., 2007; Ritossa & Rickard, 2004; Salimpoor et al., 2011; Schubert, 2007). Participants rated EDM break routines as more familiar with higher levels of past exposure, influencing valence, arousal, emotional strength, and emotional responses ratings, which could have increased emotional engagement, preference, liking, drop passage expectedness, and peak-pleasurable emotions, as well as altering related MFG and PAnG activity (see Table 3-7 and Table 3-8: Ali & Peynircioğğlu, 2010; Altenmüller et al., 2014; Freitas et al., 2018; Koelsch, 2006; Pereira et al., 2011; Plailly et al., 2007; Turrell et al., 2021; Van Den Bosch et al., 2013). Future research should assess the impact of familiarity on break routines' ability to induce peak-pleasurable emotions and relating brain activity, using other music genres that are unfamiliar to western listeners, such as Chinese music (Bai et al., 2016; Nan et al., 2008).

Our findings suggest that both break routine structures and acoustic features can induce peak-pleasurable emotions, as there were significant similarities and differences in the number of emotional ratings and relating brain activity. However, the extent to which break routine structures and acoustic features evoke peak-pleasurable emotions is still difficult to determine, as similar musical moments were purposefully chosen for this study. Future research should elaborate by assessing other music moments that are within genres with different structures, yet similar acoustic features such as high energy, faster tempos, brighter timbre, and major tonality in jazz, pop, and rock which evoke peak-pleasurable emotions and MFG and PAnG activity (Alluri et al., 2012; Brattico et al., 2011; Brattico et al., 2016; Brattico & Pearce, 2013; Knutson et al., 2004; Nobile, 2014). This would clarify the extent to which break routines structures or acoustic features evoke peak-pleasurable emotions and relating emotional brain activity.

Conclusion

Differences in valence, arousal, emotional strength, and emotional response ratings and correlating MFG, SFGL, PAnG, and PMC activity between EDM and analogue classical break routines, indicate that acoustic features predict peak-pleasurable emotions and resulting brain activity. But also, similarities in evoked peak-pleasurable emotion ratings and induced brain activity patterns reinforces results from previous chapters and suggests that music structure induces peak-pleasurable emotions and resulting emotional brain activity. Thus, both acoustic features and music structures can induce peak-pleasurable emotions and may have an additive effect on each other. Future research should expand on the emotive and neurological responses to music structures using other music genres with various structures and acoustic features and assess the emotive and neurological impact of other music cognitive functions like familiarity.

Chapter 4 – How Tension Mediates Music-Evoked Emotions

Introduction

Music evokes a range of emotions, including peak-pleasurable emotions, defined as having high positive valence and arousal which mostly co-occur with physiological reactions, like ‘chills’ (Blood & Zatorre, 2001; Juslin & Sloboda, 2011; Habibi & Damasio, 2014; Mori & Iwanaga, 2017). Previous Chapters have established a key way music induces peak-pleasurable emotions is through continuous alterations in levels of tension and relaxation elicited through music structure and expectations (Lehne et al., 2012; Meyer, 1956). Tension levels during music have been linked to peak-pleasurable emotions, such as excitement and happiness (Granot & Eitan, 2011; Krumhansl, 2002; Robinson, 1994).

Electronic dance music (EDM) *break routines* may be particularly suited to creating tension prior to highly expected moments, resulting in strong peak-pleasurable emotions. (Turrell et al., 2021; for more details on break routines see ‘EDM Break Routines & Emotion’ in Chapter 1). EDM songs often contain multiple break routines, lasting around 20 s and featuring intense but highly expected changes in the song’s acoustic features and structure (Solberg, 2014; Solberg & Dibben, 2019). This enables listeners, even those who are unfamiliar with EDM, to expect drop passages and the reintroduction of the song’s main groove after being built up to a peak moment and held in suspense, increasing tension and peak-pleasurable emotions (Margulis, 2005; Meyer, 1956; Solberg, 2014; Solberg & Dibben, 2019; Solberg & Jensenius, 2017;2019).

Previously, Chapters 2 and 3 demonstrated that EDM break routine listening induces peak-pleasurable emotions, such as excitement (Turrell et al., 2021). The special structure of build-up passages delaying highly expected drop passages in EDM break routines can increase negatively valenced tension, as well as magnify peak-pleasurable emotions (Solberg, 2014; Solberg & Dibben, 2019). Music tension can refer to feelings of uncertainty, conflict, and instability over emotional motifs and approaching climaxes, where there is a desire for resolution and the formation of future expectations (Farbood, 2012; Lehne & Koelsch, 2015). Specifically, even listeners not very familiar with EDM break routines likely expect drop passages to occur but may be uncertain of exactly when and how, which increases the salience of delay and uncertainty, and thereby intensifies tension (Butler, 2006; Miller, 1967; Turrell et al., 2021). This increased negative tension prior to expected drop passages can magnify peak-pleasurable emotions when expectations are fulfilled (Huron, 2006; Turrell et al., 2021). EDM break routine structures of build-up and expected drop passages can therefore evoke strong peak-pleasurable emotions.

The extent to which break routine structures evoked peak-pleasurable emotions is also demonstrated in our research from the previous chapter (Chapter 3) comparing EDM break routines with analogue classical break routines, which had similar structures of tension and expectancy but distinct music elements, such as acoustic features (Turrell et a., in submission, c). Results showed that EDM and analogue classical break routines had similar patterns of tension ratings, with increasing tension during build-up passages and decreased tension as expected drop passages were fulfilled (Turrell et al., 2021; Turrell et al., in submission, c). Also, EDM and analogue classical break routines evoked similar peak-pleasurable emotions, suggesting break routine structures are particularly important to peak-pleasurable emotions over other music elements, like acoustic features. Thus, break routines are a good tool in assessing the extent to which music structures, expectations generated by structures, and negative tension created from expectations affect music-evoked peak-pleasurable emotions. However, the extent to which negative feelings, such as tension, can magnify positive emotions are not fully understood.

As discussed in earlier chapters, a central theory that can help explain why music structures, such as break routines, create expectations, tension, and peak-pleasurable emotions is ITPRA (Imagination, Tension, Prediction, Reaction, and Appraisal; Huron, 2006). Listeners learn structures and *predict* future music motifs, which they then *imagine* creating *tension* and uncertainty as the music can either violate or delay expectations (Hunter & Schellenberg, 2010; Huron, 2006; Margulis, 2005; Meyer, 1956). When expectations are fulfilled, listeners experience decreased tension and instead feel peak-pleasurable emotions, including excitement, satisfaction, and happiness as their immediate *reaction*, which they then *appraise* for future predictions (Egermann & McAdams, 2013; Huron, 2006; Meyer, 1956; Grewe et al., 2007a; 2007b: Lehne et al., 2012; Solberg & Dibben, 2019; Steinbeis et al., 2006; Turrell et al., 2021; Zentner et al., 2008). This suggests that break routine structures create expectancy, which results in tension that subsequently mediates peak-pleasurable emotions, such as excitement (Huron, 2006; Meyer, 1956; Turrell et al., 2021).

Tension's significant role in peak-pleasurable emotions is also potentially explained by *contrastive valence* in ITPRA (Huron, 2006). This captures the idea that greater prior tension levels lead to heightened peak-pleasurable emotions when expectations are fulfilled, as prior negative emotions, in this case tension, magnifies subsequent positive experiences (Huron, 2006; Lehne & Koelsch, 2015). Thus, higher levels of and more abrupt changes in tension within build-up passages prior to expected drop passages should correlate with increased peak-pleasurable emotions, including happiness and pleasure, when expectations are fulfilled (Huron, 2006; Lehne et al., 2012; Miller, 1967). Therefore, increased *tension* within build-up passages prior to expected or *predicted* drop passages, may induce *reactions* of greater peak-pleasurable emotions when break routine expectations are correctly fulfilled, due to contrastive valence.

Several researchers, as well as studies within this thesis, have applied ITPRA and contrastive valence when explaining tension's influence on peak-pleasurable emotions (Lehne & Koelsch, 2015; Pearce & Wiggins, 2012). Studies have shown tension can be evoked by acoustic features and expectancy, and correlates with a range of emotions, including happiness and fear (Krumhansl, 1997; Lehne et al., 2012). Yet, less research has assessed the extent of tension's impact on peak-pleasurable emotions using EDM break routines, which are particularly suited for this purpose because of how they induce greater tension levels during build-up passages prior to expected drop passages and peak-pleasurable emotions (Lehne et al., 2012; Lehne & Koelsch, 2015; Solberg & Dibben, 2019; Turrell et al., 2021). The current study examined whether increased tension during break routine build-up passages magnified peak-pleasurable emotions from expected and then fulfilled drop passages.

In this chapter, using a custom-built app, we measured tension levels across EDM break routines, in particular changes across build-up and drop passages, and assessed the research question as to whether tension mediated peak-pleasurable emotions as predicted by contrastive valence. Tension levels were measured on a continuous slider during break routine listening, and peak-pleasurable emotions ratings were elicited on the 2-dimensional space of valence and arousal, as both high positive valence and arousal are indicative of peak-pleasurable emotions. Correlations between tension and emotional ratings were examined to assess the relationship between higher tension levels and greater peak-pleasurable emotions. We hypothesised, first, that tension would increase during build-up passages prior to highly expected drop passages and then decrease during drop passages as expectations were fulfilled. We also predicted that higher average tension levels during break routines would correlate with increased peak-pleasurable emotion ratings.

Method

Participants

Fifty participants took part in this study. Following data collection, the PhD researcher and two undergraduate students (who were not naïve to the hypothesis) independently scored individual trials between 1 and 5, using silent video time lapses of participants continuous tension ratings. This was to ensure correct use of the tension scale according to predetermined instructions given to participants. Instructions included always keeping fingers on the screen and only moving fingers to show meaningful changes in tension levels. Participants with average scores of 2 or less were excluded from analysis. This resulted in the exclusion of 16 participants. These exclusions were mostly from repeatedly lifting fingers off the scale and 'doodling', as indicated by rapid and sharp changes in tension ratings.

This left 34 participants for the main analysis (31 females, age range [17-32], *M(SD)* = 19.21(1.30)). Participants ranged in experience with a musical instrument from not playing an instrument to 9 or more years of playing (*M(SD)* = 2.80(2.04); *Mdn* = 0-1 years) and sometimes heard similar music to EDM (*M(SD)* = 3.18(0.67); *Mdn* = 3 on the scale 1 'never heard' to 4 'often heard') and break routines (*M(SD)* = 3.15(0.70); *Mdn* = 3). Participants were required to have normal or corrected to normal vision and hearing, as well as have access to ear or headphones, and an iPhone or Android mobile device to run the study paradigm. The protocol of the study was approved by the ethics committee at the University of Kent and participants gave written informed consent in accordance with the Declaration of Helsinki.

Stimuli

Sixty EDM break routine clips were selected from a collection of 90 used in previous studies, including a range of EDM genres, such as Dub-step, House, and Trance (Turrell et al., 2021). Durations of EDM break routines varied between 18-22s with the moment of drop passages being between 12-16s and lasting 6s (see Figure 1-3). For a full list of songs used to create break routine clips and their details, see the associated data via DOI link https://doi.org/10.17605/OSF.IO/YS3QD.

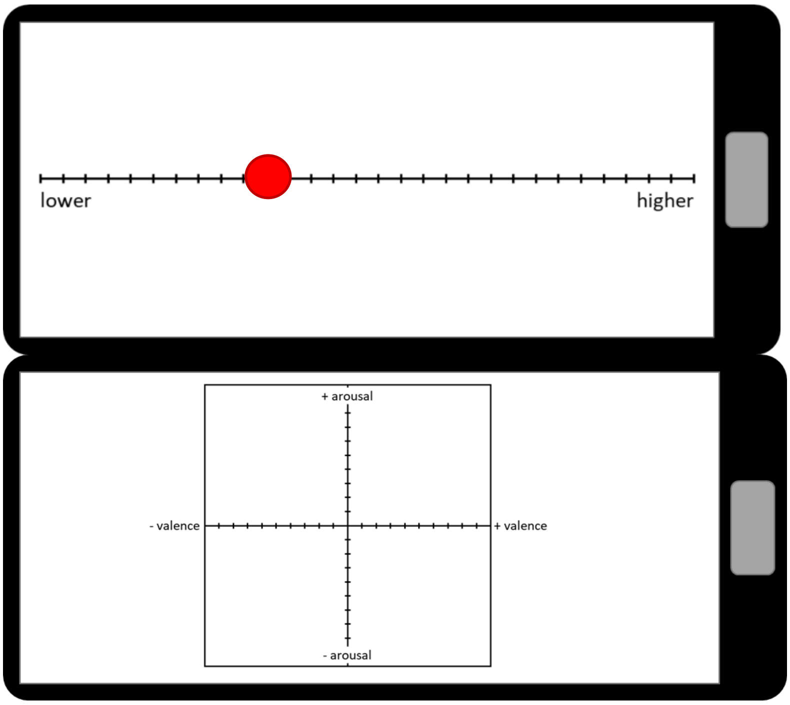
Tension & Emotion Recording

A continuous tension rating scale was used to record levels of felt tension throughout the break routine clips. It consisted of a vertical scale, ranging from low tension (left) to high tension (right; see Figure 4-1a).

Figure 4-1

The Custom-made Task Developed for iPhone and Android Devices. (a) The Continuous Tension Rating Scale as Displayed on Participants Mobile Devices. The Red Dot Appeared in the Location where Participants Placed their Finger to Respond. (b) The 2-Dimensional Space of Valence and Arousal as Displayed on Participants Mobile Devices

(a) (b)



Participants responded using one finger from their dominant hand to slide over the screen in response to their experienced tension levels as they listened to each break routine clip. Participants were instructed to keep their finger touching the screen throughout. Finger movements to the right showed an increase in tension, with maximum levels at the furthest right, and vice versa with low tension on the left. Participants were encouraged to use the full scope on the scale and kept their finger steady if they felt no alterations in tension levels.

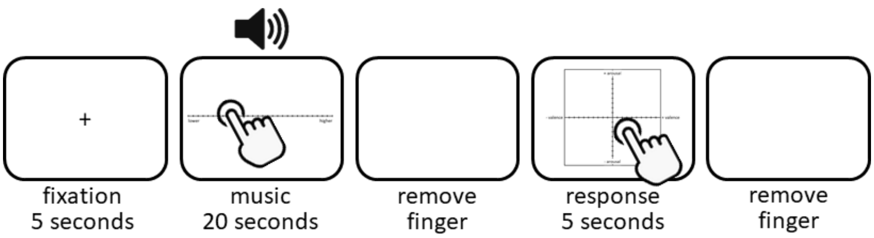
The 2-dimensional space of valence (the positivity or negativity of a feeling) and arousal (the alertness/stimulation of a feeling) was presented after each break routine clip, as soon as participants removed their finger from the continuous tension rating scale. Valence was on the horizontal axis and arousal on the vertical axis, both ranging from -100 to 100 as maximum scores around the outer edges of the space and 0 being the central point (see Figure 4-1b). Participants would then tap where in the 2-dimensional space represented how they felt during listening to the break routine clip. Participants were instructed to answer as quickly as possible within 5s.

Procedure

The study was conducted online: participants used their smartphone to respond and the instructions were delivered via video conference calling (see Appendix E). The webservice Pavlovia was used to deliver the task online. Each trial began with a 5s fixation cross, followed by a break routine clip. During the clip, participants continuously rated their felt levels of tension using their finger. Following that, participants indicated their felt valence and arousal on the 2-dimentional space (see Figure 4-2). Stimuli were randomly presented in two blocks with a minimum 30s break in between to prevent fatigue.

Figure 4-2

Visual Representation of Each Trial in the Music Paradigm with the Fixation Cross, Break Routine Clip and Continuous Tension Rating Scale, and 2-Dimensional Response Grid



Analysis

Participants' individual tension responses on the continuous slider rating scale were recorded and averaged across participants over the time course of each break routine clip. Valence and arousal ratings were also recorded and averaged for each break routine clip, which were then also used to calculate emotional strength (amplitude values) and emotional response (angle values) ratings and averages (see the 'Behavioural Analysis' of Chapter 3 for more details). To assess how tension differed across break routines, graphs of average tension ratings across time were created. Then Spearman's rho correlations between median tension ratings and time (whole break routine, 0 to 14s, and 14-20s) were run to assess the relationship between changes in tension and break routine segments. However, sudden changes in tension may be missed by correlations, so four Wilcoxon signed-rank tests were conducted on tension ratings: (1) comparing mean tension ratings for 1s at the beginning of break routines and 1s at the end of build-up passages, (2) comparing mean tension scores from the last second of build-up passages with the first second of drop passages, (3) comparing tension ratings at the first second of drop passages with the last second of break routines, and (4) comparing mean tension ratings at the first and last second of break routines.

To examine whether higher tension ratings were correlated with greater peak-pleasurable emotions, four Spearman's Rho correlations between average tension ratings and valence, arousal, emotional strength, and emotional response ratings were conducted. False discovery rate (FDR) correction for multiple comparison was used (Benjamini & Hochberg, 1995; Finner & Roters, 2001).

Results

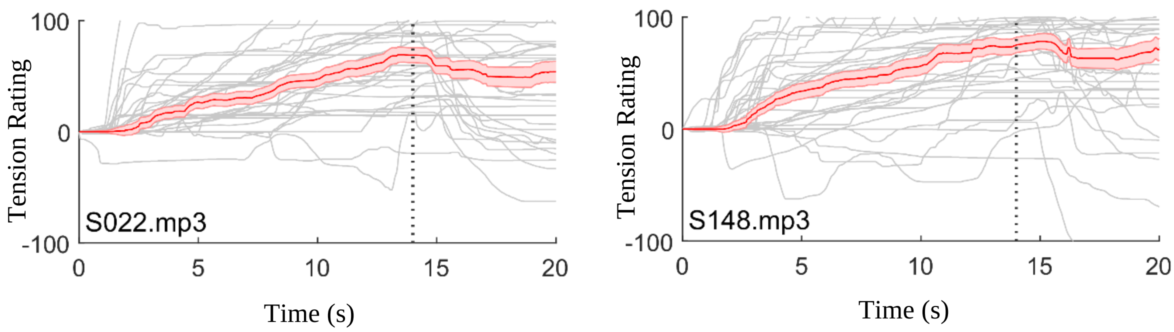
Tension Graphs

Each participant's tension response to each break routine was shifted to begin from zero. Individual and median continuous tension ratings were plotted on axes of minimum tension (-100) to maximum tension (100) by time (0-20s) for each break routine (see Figure 4-3 for examples of higher and lower individual and median tension ratings).

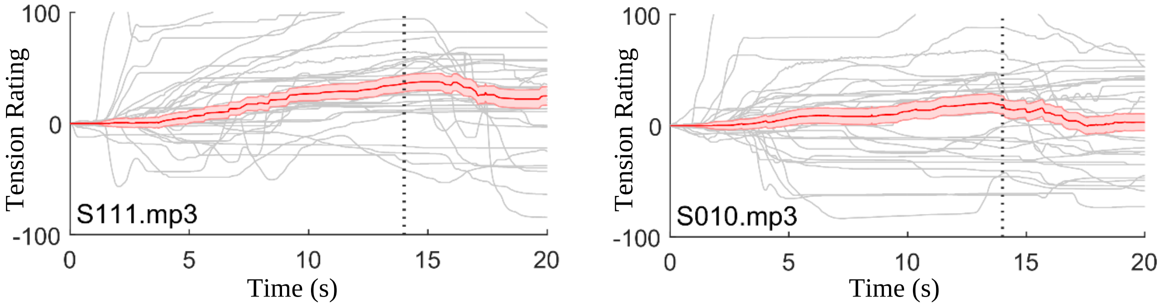
Figure 4-3

Participants' Individual and Median Continuous Tension Ratings for Four Example Break Routines: a) Two Break Routines with Higher Median Tension Ratings and b) Two Break Routines with Lower Median Tension Ratings

a)



b)

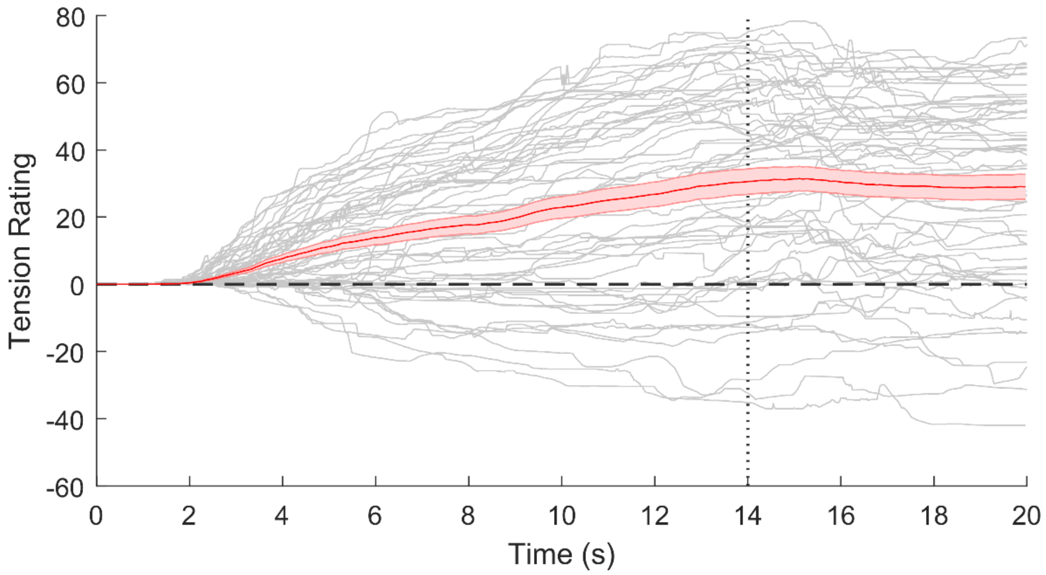


Note. Grey lines represent individual tension ratings. The solid red line represents median tension ratings across each break routine and the red shading shows standard error of the mean. The vertical dotted line indicates the beginning time of drop passages at 14s.

Then the median of all tension ratings to all break routines were plotted as an overall visual representation of how tension levels changed across break routine build-up and drop passages. This showed a steady increase in tension ratings during build-up passages to a peak moment at the beginning of drop passages (around 14 to 15s) followed by a slight reduction (see Figure 4-4 and Figure 4-5).

Figure 4-4

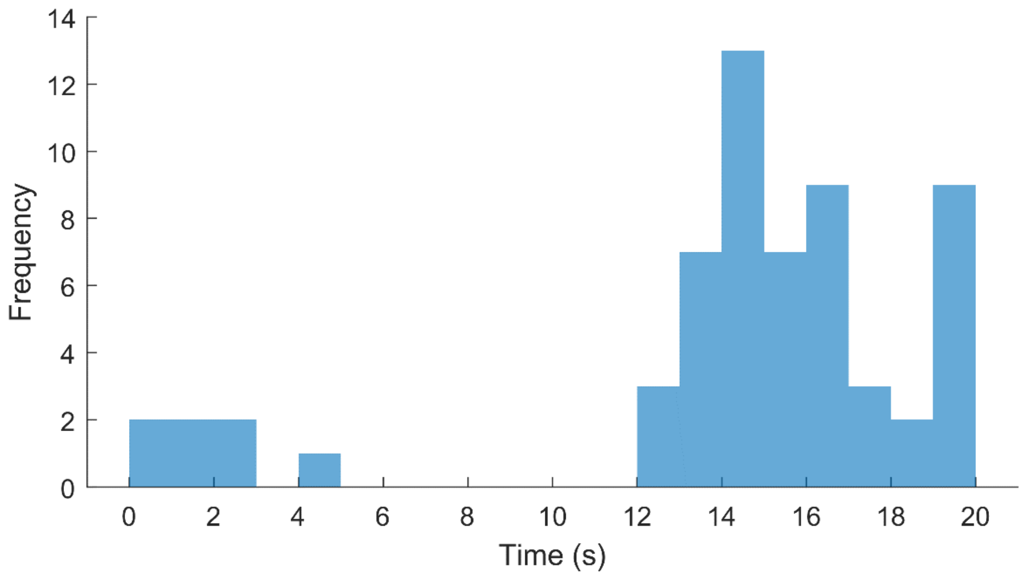
Median Continuous Tension Ratings Across all Participants and Break Routines



Note. Grey lines show individual tension ratings. The solid red line represents median tension ratings, and the red shading refers to standard error of the mean. The vertical dotted line indicates the beginning time of drop passages during break routines (14s).

Figure 4-5

Frequency of Peak Median Tension Ratings Across the Time of Break Routines. This Plot Shows that the Peak Tension Rating was Around 14s, where the Drop Passage Began



Tension and Time

Median tension ratings were correlated with time points at a sampling rate of 60 per second in each of the 60 break routines, to assess continuous changes in tension during break routine listening. Tension ratings significantly correlated with break routine time, $r_s(1198) = 0.942$, $p < 0.001$, reflecting that tension ratings increased over the course of break routines. To further assess how tension ratings changed over break routine time, separate correlations examining the relationship between tension ratings and break routine time for the build-up passage (from 0-14s) and during drop passages (14 to 20s) were conducted. Results showed a significant positive correlation between tension and time during build-up passages ($r_s(838) = 0.998$, $p < 0.001$) and a significant negative correlation between tension and time within drop passages ($r_s(358) = -0.853$, $p < 0.001$). Correlation results supported our hypothesis that tension would increase during build-up passages and then decrease within drop passages as musical expectations are fulfilled.

Non-parametric Wilcoxon tests enabled the comparison of mean tension ratings at significant time points during break routine structures. Mean tension ratings for 1s segments at the beginning, the last part of build-up passages, the start of drop passages, and at the end were compared. Results showed that mean tension ratings at the beginning of break routines (always measuring as 0 on the tension scale due to being corrected) were significantly lower than tension ratings at the end of build-up passages and at the end of break routines (see Table 4-1 and Table 4-2). This verified that tension ratings changed from 0 during break routines and showed that tension increased within build-up passages.

Tension ratings also significantly increased between the end of build-up passages and the beginning of drop passages (see Table 4-1 and Table 4-2). Mean tension ratings decreased between the start of drop passages and break routine endings but not significantly after correction, suggesting less of a reduction or release in tension during drop passages (Table 4-1 and Table 4-2, also see

Figure 4-6).

Table 4-1

Results from Wilcoxon Signed-rank Tests Comparing Tension Ratings at Different Time Points During Break Routines

Comparison	***Z***	***p***
Beginning vs Build-up	-5.54	<.001**
Build-up vs Drop	-2.40	.016*
Drop vs Ending	1.96	.050†
Beginning vs Ending	-5.54	<.001**

Note. Beginning: the first second of break routines; Build-up: the last second of build-up passages; Drop: the first second of drop passages; Ending: the last second of break routines; †: effect no longer significant after FDR correction for multiple comparison; *: $p \leq .05$; **: p <.001.

Table 4-2

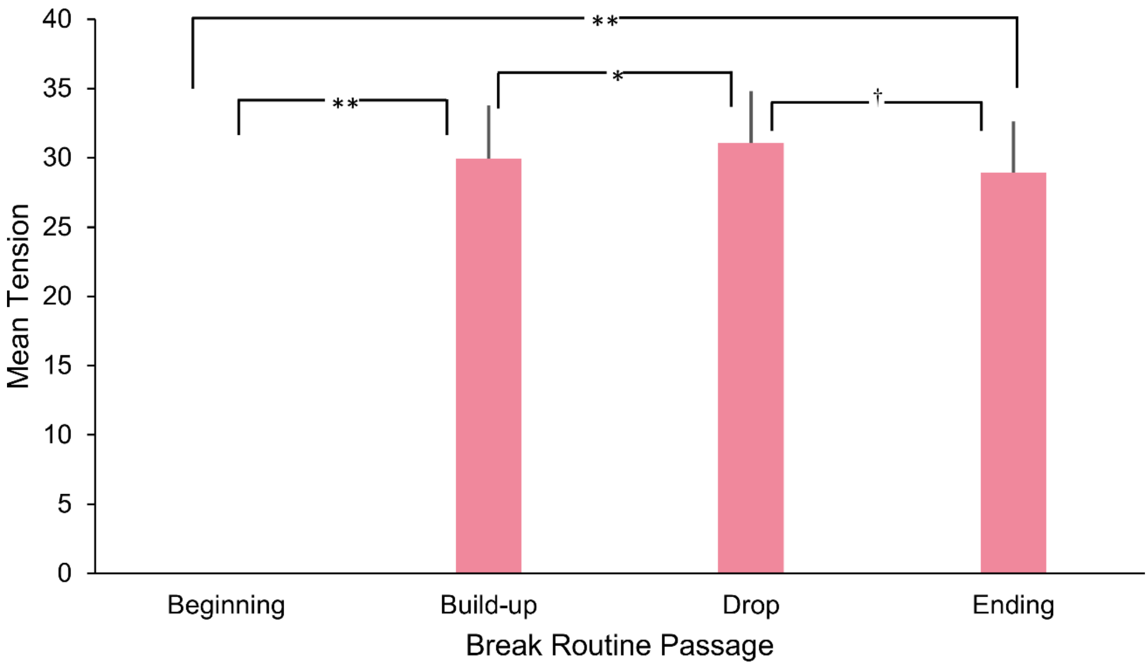
Means and Standard Deviations (SEM) of Tension Ratings for Different Times of Break Routines

Break Routine Time	***M***	***SEM***
Beginning	0	0
Build-up	29.94	3.84
Drop	31.07	3.75
Ending	28.94	3.69

Note. Beginning: the first second of break routines; Build-up: the last second of build-up passages; Drop: the first second of drop passages; Ending: the last second of break routines.

Figure 4-6

Bar Chart of Mean Tension Ratings for the 1s Segment of Each Break Routine Passage



Note. Error bars represent standard errors (SEM); †: effect no longer significant after FDR correction for multiple comparison; *: $p \leq .05$; **: $p < .001$.

Tension and Peak-Pleasurable Emotions

Correlations between average tension ratings with peak-pleasurable emotion dimension ratings (valence, arousal, emotional strength, and emotional response) indicated that tension levels significantly varied with emotions (see Table 4-3). Higher levels of tension correlated with higher arousal, emotional strength, and emotional response ratings. However, greater tension negatively correlated with valence ratings, indicating the higher tension predicted more negative emotions.

Table 4-3

Correlations Between Peak-Pleasurable Emotion Dimension Ratings (Valence, Arousal, Emotional Strength, and Emotional Response) with Average Tension Ratings During Break Routines

Emotion Ratings	**Average Tension**	
	r_s**(58)**	***p***
Valence	-.69	<.001**
Arousal	.92	<.001**
Emotional Strength	.62	<.001**
Emotional Response	.91	<.001**

Note. r_s: Spearman's Rho coefficient; **: *p* <.001.

Post-hoc Correlations Between Break Routines

Further Spearman's rho correlations assessed whether previous break routines had a cumulative influence on following break routines for tension, valence, arousal, emotional strength, and emotional response. Correlations were run between tension ratings at the last second of previous break routines and the first second of subsequent break routines. Results indicated that prior ratings did not influence ratings in subsequent break routines, as indicated by small correlation coefficients and insignificant *p* values (see Table 4-4).

Table 4-4

Correlations Between the Last Second of Previous Break Routines and the First Second of Subsequent Break Routines for Emotion Ratings (Tension, Valence, Arousal, Emotional Strength, and Emotional Response)

Emotion Ratings	r_s**(58)**	***p***
Tension	0.18	.177
Valence	<.001	.998
Arousal	0.16	.232

Emotional Strength	0.26	.047†
Emotional Response	0.18	.182

Note. r_s: Spearman's Rho coefficient; †: effect no longer significant after FDR correction for multiple comparisons; *: significant to p <.05.

Discussion

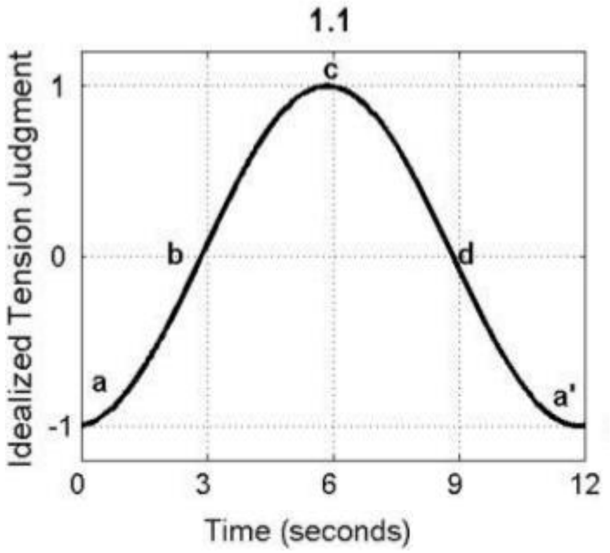
This study offered a novel exploration of tension and peak-pleasurable emotions during electronic dance music (EDM) break routines. Continuous tension ratings supported previous chapter assumptions, showing increasing tension during build-up passages prior to highly expected drop passages, where it decreased as expected drop passages were correctly fulfilled. Greater average tension positively correlated with arousal, emotional strength, and emotional response ratings, but negatively correlated with valence after each break routine. This suggested that higher tension during break routines correlated with negative emotions, such as continued tension, after break routines, rather than peak-pleasurable emotions (as indicated by greater arousal, emotional strength, emotional response, and positive valence ratings; Eerola & Vuoskoski, 2012; Russell, 1980; Salimpoor et al., 2009; Salimpoor et al., 2011). Therefore, tension changed across break routine structures as predicted but effects of increased and decreased tension across break routines on peak-pleasurable emotions were contradictory to contrastive valence.

Tension During Break Routines

This study demonstrated that tension levels altered around break routine expectations in tension resolution patterns, such as tension curves. These suggest an optimal pattern of tension is created from musical expectations, with increased tension alongside greater anticipation and uncertainty prior to expected musical events, such as EDM break routines (Huron, 2006; Koelsch et al., 2019). Greater tension is accompanied by an increased desire to complete the tension curve by decreasing and releasing tension when expected music events finally occur (Eerola & Vuoskoski, 2011; Sloboda & Juslin, 2001; Vines et al., 2005; You et al., 2021; see Figure 4-7). Tension curves that are fully resolved, with equal increases and decreases in tension, can then evoke peak-pleasurable emotions, such as reward, pleasure, and liking (Lehne & Koelsch, 2014; Lehne & Koelsch, 2015; Steinbeis & Koelsch, 2008). This suggests delay and elevated uncertainty created during break routine build-up passages in the current study, increased tension and the anticipation or desire to resolve and decrease intensified tension levels through fulfilling expected drop passages.

Figure 4-7

A Visual Example of an Optimal Tension Curve for Music Tension Judgements; Taken from Vines et al., 2005



However, mean tension ratings during break routines suggested a continued increase in tension between build-up and subsequent drop passages, contradicting the assumption that fulfilled music expectations would decrease or release tension. Yet, increased tension seemed to only occur for the first few seconds of drop passages, indicating a possible postponed decrease in tension when processing fulfilled expectations. Delays of anywhere from 3 and 8s can occur between music processing, emotional experiences, such as tension, and recording behavioural responses (Kim et al., 2010; Krumhansl, 1996; Schubert & Dunsmuir, 1999; Sloboda and Lehmann, 2001). Thus, although decreased tension from the fulfilment of expected drop passages were not represented in mean tension values taken from 1s into drop passages, decreased tension during drop passages, as reflected by correlations between tension and time, alongside median tension plots, did occur but after a delay of around 2 to 3s.

Tension and Peak-Pleasurable Emotions

Arousal

Higher average tension correlated with greater arousal ratings during break routines. Previous research suggests tension and arousal are similar constructs, some indicating that tension is equivalent to arousal. They are often used to describe or assess one another, such as 'tension arousal' and measuring muscle tension as indications of arousal (Dillman Carpentier et al., 2007; Eerola et al., 2012; Granot & Eitan, 2011; Huron, 2006; Kruhmansl, 1997; Rickard, 2004; Rozin et al., 2004; Trolio, 1976). Tension is often considered a sub-emotion of arousal, meaning greater tension always co-occurs with increased arousal but high arousal may not always occur with greater tension (Lehne & Koelsch, 2015; Trost et al., 2012). Highly significant correlations found here between tension and arousal could have derived from tension being a sub-emotion of arousal, suggesting they increased simultaneously during break routines, rather than greater tension influencing arousal.

The hierarchical organisation of acoustic features and break routine structure can similarly evoke arousal and tension (Butler, 2006; Meyer, 1956; Schäfer & Sedlmeier, 2011; Solberg, 2014; Turrell et al., 2021). Acoustic features present during EDM break routines, such as fast pace, faster tempo, higher timbral roughness, and greater loudness induce higher arousal and tension during music (Dean et al., 2011; Dillman Carpentier et al., 2007; Droit-Volet et al., 2013; Farbood & Price, 2017; Granot & Eitan, 2011). Such features can have a cumulative and interactive effect on arousal alongside break routine structures of delay and uncertainty prior to highly expected drop passages, enabling moments of tension and release (Butler, 2006; Farbood, 2012; Lehne et al., 2012; Lehne & Koelsch, 2015; Robinson, 1994). Thus, the strong correlation between tension and arousal ratings may have derived from having similar music mediators, such as acoustic features and break routine's structure.

Emotional Strength

Another peak-pleasurable emotion dimension that closely links, and is sometimes interchangeable, with tension is the calculated emotional strength (amplitude values; Luck et al., 2008; Vuoskoski & Eerola, 2011). Tension and emotional strength often simultaneously increase during music and mediate music-evoked emotions (Juslin & Sloboda, 2011; Hallam et al., 2011; Rozin & Rozin, 2008; Rickard, 2004). Emotional strength increases according to acoustic features, such as loudness, roughness, beat clarity, and spectral flux which combine into temporal music structures and often intensify during break routine build-up passages (Luck et al., 2008; Roda et al., 2014; Solberg, 2014; Turrell et al., 2021). Music expectancy also links to emotional strength, as tension for expected drop passages can be magnified if anticipated peak-pleasurable emotions from when expectations are fulfilled are stronger, such as excitement (Lehne & Koelsch, 2015; Steinbeis et al., 2006; Turrell et al., 2021). This suggests that emotional strength and tension are comparable and occurred simultaneously during break routine passages, rather than representing peak-pleasurable emotions mediated from greater tension within break routines due to contrastive valence.

Emotional Response

The combination of valence and arousal to create emotional response, referring to the angle of ratings within the 2-dimensional space, also correlated with tension. Combinations of high arousal and positive valence represents emotions such as happiness and excitement, which appear in the top right quadrant of the 2-dimenstional emotional space. Combinations of high arousal and negative valence indicates emotions like anger and tension appear in the top left quadrant of the emotional space (Eerola & Vuoskoski, 2012; Hunter & Schellenberg, 2010; Remington et al., 2000; Russell, 1980). Greater tension during break routines shifted the angle of emotional responses to areas measuring higher arousal and valence but more likely corresponded to emotions with high arousal and greater negative valence, including tension and intensity (Cohrdes et al., 2017; Greenberg et al., 2015; Remington et al., 2000; Russell, 1980). Therefore, increased angles of emotional response ratings could suggest higher feelings of tension after break routines, rather than predicted peak-pleasurable emotions mediated by tension and fulfilled expected drop passages (Butler, 2006; Huron, 2006).

Valence

Higher tension during break routines correlated with greater negative valence ratings, suggesting that higher tension does not always lead to peak-pleasurable emotions (Eerola & Vuoskoski, 2011; Garrido & Schubert, 2011). Break routine clips may have been more skewed to the perception of tension than peak-pleasurable emotions, like excitement, as they mostly included tension intensifying build-up passages (0-14s; Butler, 2006; Lehne & Koelsch, 2015; Meyer, 1956; Solberg, 2014). In contrast, drop passages, where peak-pleasurable emotions were proposed to be experienced, were shorter (14-20s; Butler, 2006; Solberg, 2014). Longer times listening to build-up passages, as well as participants rating how they felt during break routine listening, may have negatively skewed valence ratings, as participants predominately felt increasing tension. Therefore, more negative valence ratings at the end of break routine clips may have correlated with tension levels due to them both measuring tension during break routine listening, instead of peak-pleasurable emotions mediated by this tension.

Also, shorter drop passages may have prevented tension curves from being fully resolved and tension completely released. Researchers have suggested that for music tension to evoke peak-pleasurable emotions, tension curves need to be fully completed with equal amounts of increased and decreased tension before and after expected music events (Koelsch, 2014; Sun et al., 2020a; 2020b; Vines et al., 2005). When tension curves are not completed after fulfilled music expectations, there is not the full sense of resolution and negative emotions can occur, such as further tension and anticipation (Lehne & Koelsch, 2015; Meyer, 1956; Sun et al., 2020a; 2020b; Vines et al., 2005). Break routine clips used here may have not enabled the full completion of tension curves due to shorter drop passages, resulting in the continued experience of tension after break routine clips, and impeding peak-pleasurable emotions.

Future directions

Not all tension ratings followed tension resolution patterns (increases during build-up passages and decreases in drop passages) as some break routines had negative tension values, indicating listeners decreased tension ratings during build-up passages. This suggests that sustained tension from previous break routines may have influenced ratings of later clips, making participants begin tension ratings in the middle of the continuous tension rating scale. However, post-hoc correlations between previous and subsequent break routine ratings indicated no significant relationships between tension or other emotional dimensions. Thus, higher starting tension ratings may have occurred due to other tension inducing factors, such as anticipation for the next break routine clip, as well as other music elements present during break routines, including acoustic features (Farbood et al., 2012; Huron, 2006; Ilie & Thompson, 2006; Lehne et al., 2012). Future research could assess how tension levels are affected at the beginning of, across, and between break routines, using different stimuli such as silence or various music passages, like longer EDM break routine clips with equal times of build-up and drop passages or whole EDM tracks (Solberg & Dibben, 2019; Solberg & Jensenius, 2017).

While tension was continuously recorded throughout break routines, peak-pleasurable emotion dimensions of valence, arousal, emotional strength, and emotional response were recorded retrospectively after each EDM break routine clip, meaning any alterations in emotions over the course of break routine clips were not measured. This makes fully understanding the relationship between EDM break routine structures of increasing tension during build-up passages prior to expected drop passages and peak-pleasurable emotions more difficult, as emotional dimension ratings did not capture varying emotional levels across break routine passages. Future research could apply continuous measures of peak-pleasurable emotions, such as repeated 2-dimensional ratings, continuous sliders, or physiological measures (including heart rate and skin conductance) alongside continuous EEG, so relationships between changing tension and emotional dimensions can be assessed throughout break routine structures (Egermann et al., 2013; Rickard, 2004; Salimpoor et al., 2009; Schubert, 2013; Soleymani et al., 2011).

Conclusion

This study expands on previous chapters, examining the specific influence of tension elicited from EDM break routine structures on peak-pleasurable emotions, using continuous tension measures. Tension altered across break routines in accordance with their structure and tension resolution patterns: tension increased during build-up passages from the delay of expected drop passages, and then decreased within drop passages as expectations were finally fulfilled. However, tensions' correlations with arousal, emotional strength, emotional response and negative valence ratings suggested continued experiences of tension after break routine clips, perhaps due to increased tension not being fully decreased and mediating peak-pleasurable emotions. Future research could further assess peak-pleasurable emotions, using longer break routine clips to examine whether intensified tension levels required additional decreases to evoke peak-pleasurable emotions.

Chapter 5 – Electrical Brain Stimulation and Music-Evoked Emotions

Introduction

Music has been linked to a complex network of brain activity, present in the processing of music structures, acoustic features, music motor responses, and powerful music-evoked emotions (Habibi & Damasio, 2014; Koelsch, 2014; Kunert et al., 2015; Sloboda et al., 2001; Trost et al., 2014). For example, peak-pleasurable emotions, pitch, melody, and rhythm processing, as well as motor sensory responses, such as the desire to dance, all intertwine and correlate with extensive brain activity within the prefrontal cortex (PFC) and motor areas (Blood & Zatorre, 2001; Koelsch et al., 2006; Koelsch, 2014; Solberg & Jensenius, 2017; Trost et al., 2012; Turrell et al., 2021). Also, music structures which create expectations and tension can evoke peak-pleasurable emotions, as well as PFC and motor area activity (Lehne & Koelsch, 2015; Huron, 2006; Meyer, 1956; Thaut et al., 2014).

Two brain areas seen in our previous chapters, which are affected by music and emotions are the middle frontal gyrus (MFG) and primary motor cortex (PMC; Bogert et al., 2016; Green et al., 2012; Morrison et al., 2003; Turrell et al., 2021). Greater MFG and PMC activity can increase music liking, effect the processing of music structures, and influence the perception of acoustic features, such as rhythm and tempo (Bogert et al., 2016; Koelsch, 2014; Kornysheva et al., 2010; Kornysheva et al., 2011; Lehne et al., 2014; Lehne & Koelsch, 2015). The MFG and PMC also influence positive and peak-pleasurable music-evoked emotions, such as pleasantness, beauty, nostalgia, liking, happiness, and excitement (Altenmüller et al., 2014; Barrett & Janata, 2016; Flores-Gutiérrez et al., 2007; Kornysheva et al., 2010; Kim et al, 2017; Tabei, 2015; Turrell et al., 2021).

Experienced peak-pleasurable emotions positively correlate with increased MFG and PMC activity, suggesting a direct connection between these brain areas and positive music-evoked emotions (Turrell et al., 2021). However, the MFG and PMC have also been correlated with negative emotions, including dislike, unpleasantness, sadness, and fear (Altenmüller et al., 2002; Bogert et al., 2016; Brattico et al., 2016; Flores-Gutiérrez et al., 2007; Khalfa et al., 2005; Koelsch et al., 2006; Trost et al., 2015). Further assessment of the causal links between music and MFG and PMC activity with stimulation techniques is important to disentangling their functional roles in music-evoked emotions, yet little research has explored this (Heimrath et al., 2016). Here, we studied the causal links between these brain regions and peak-pleasurable music-evoked emotions using electronic dance music (EDM) break routines and anodal transcranial direct current stimulation (tDCS).

Emotion & Brain Stimulation

The causal effect of brain activity on emotions has been measured using brain stimulation techniques, such as stimulation during surgery, deep brain stimulation, TMS, and tDCS (see Figure 5-1 for a visual schematic of research). Stimulation to a wide variety of brain areas, including the cerebellum, cingulate cortex, amygdala, prefrontal cortex, temporal lobes, and subcortical areas, such as the subthalamic nucleus (STN) stimulation, can cause an array of negative and positive emotions like fear, anger, happiness, lightness, loneliness, depression, and hypomania (Caruana et al., 2018; Kuo & Nitsche, 2015; Lai et al., 2020; Schutter & van Honk, 2006; Selimbeyoglu & Parvizi, 2010). This demonstrates that numerous brain areas can have causational effects in a variety of emotional responses to music.

Researchers have assessed which brain areas may cause such specific emotions. For instance, DLPFC, medial frontal cortex, medial temporal, insular, and cerebellum stimulation increased negative emotions, such as fear, sadness, anger, and disgust or impaired negative emotion regulation (Abend et al., 2019; Ferrari et al., 2018; Harmer et al., 2001; Kuo & Nitsche, 2015; Leyman et al., 2009; Meletti et al., 2006; Motomura et al., 2019; Papagno et al., 2016; Pena-Gomez et al., 2011; Schutter & van Honk, 2009; Singh et al., 2020; Weigand et al., 2013; Zwanzger et al., 2014). Meanwhile, positive emotions such as happiness, pleasure, and mirth are influenced by stimulation in other brain areas, including the cerebellum, anterior cingulate, temporal pole, frontal operculum stimulation, as well as the ventrolateral and ventromedial PFC (Chick et al., 2020; Junghofer et al., 2017; Schutter et al., 2009; Selimbeyoglu & Parvizi, 2010; Winker et al., 2018). Thus, different music-evoked emotions, including positive and negative emotions, are caused by activity in numerous brain areas suggesting a complex neurological network.

Differential brain areas' causal effects on emotions have also been measured using the circumplex model's dimensions of valence and arousal (Russell, 1980). Arousal, which can be measured via behavioural and physiological measures, alters with surface and intracranial stimulation of the frontal cortex, orbitofrontal cortex, insula, and anterior cingulate cortex (Goldie et al., 2010; Mauri et al., 2015; Yih et al., 2019). Valence also changes with stimulation to similar brain areas, including the anterior cingulate cortex, as well as to different brain areas, including the ventromedial PFC and DLPFC (Roesmann et al., 2019; Winker et al., 2019; Yih et al., 2019). Therefore, emotions have also been causally linked to several similar brain areas according to their levels of valence and arousal. This further suggests a complex neurological network, consisting of multiple interconnected and overlapping brain areas, influences music-evoked emotions.

However, not all stimulation research successfully demonstrated a causal link between brain activity and emotions. For example, there are reports showing that different protocols of TMS and tDCS to the PFC can be helpful in depression but create no significant alterations in subjective experiences of emotions (Grisaru et al., 2001; Nitsche et al., 2012). Also, varying strengths of brain stimulation, such as deep brain stimulation, in areas including the amygdala and hippocampus, can have different influences on emotions, making stimulation effects less clear (Lai et al., 2020). Thus, there is still some uncertainty whether and how stimulation to certain brain areas truly effects emotion processing in a healthy population.

Music-Evoked Emotions & Brain Stimulation

Music's ability to evoke peak-pleasurable emotions make it useful in further assessing brain areas' emotive causational effects. Previous chapters have established that EDM break routines can be particularly emotive music segments, because of their distinct structures of tension and expectation (Butler, 2006; Solberg & Dibben, 2019). Specifically, intensifying tension during build-up passages prior to fulfilling expected drop passages, magnified peak-pleasurable emotions from fulfilled expectations due to contrastive valence and correlated with greater PMC and MFG activity, respectively (Turrell et al., 2021). This alluded to the PMC and MFG's involvement in music-evoked peak-pleasurable emotions through processing music structures of tension and expectancy.

Yet only a few recent papers have explored the causal role of brain areas within music-evoked emotions, specifically the DLPFC's causational effects in musical pleasure, using TMS. These suggest that music listening evokes mesolimbic striatal circuits which interact with cortical structures to create peak-pleasurable emotions, such as pleasure (Mas-Herrero et al., 2018). DLPFC stimulation engages a wider brain network, including the fronto-striatal pathways and dopamine production, and anodal stimulation increases pleasurable music-evoked emotions, physiological arousal, and music's monetary value (Goupil & Aucouturier, 2019; Koelsch, 2018; Mas-Herrero et al., 2018). Thus, peak-pleasurable music-evoked emotions can be causally linked to areas of the PFC, such as the DLPFC, which interconnect with emotional brain networks, like the mesolimbic striatal circuit. However, the shortage of research assessing causal roles of several other brain areas involved in music-evoked emotions (such as the PMC and MFG), indicates more such studies are needed.

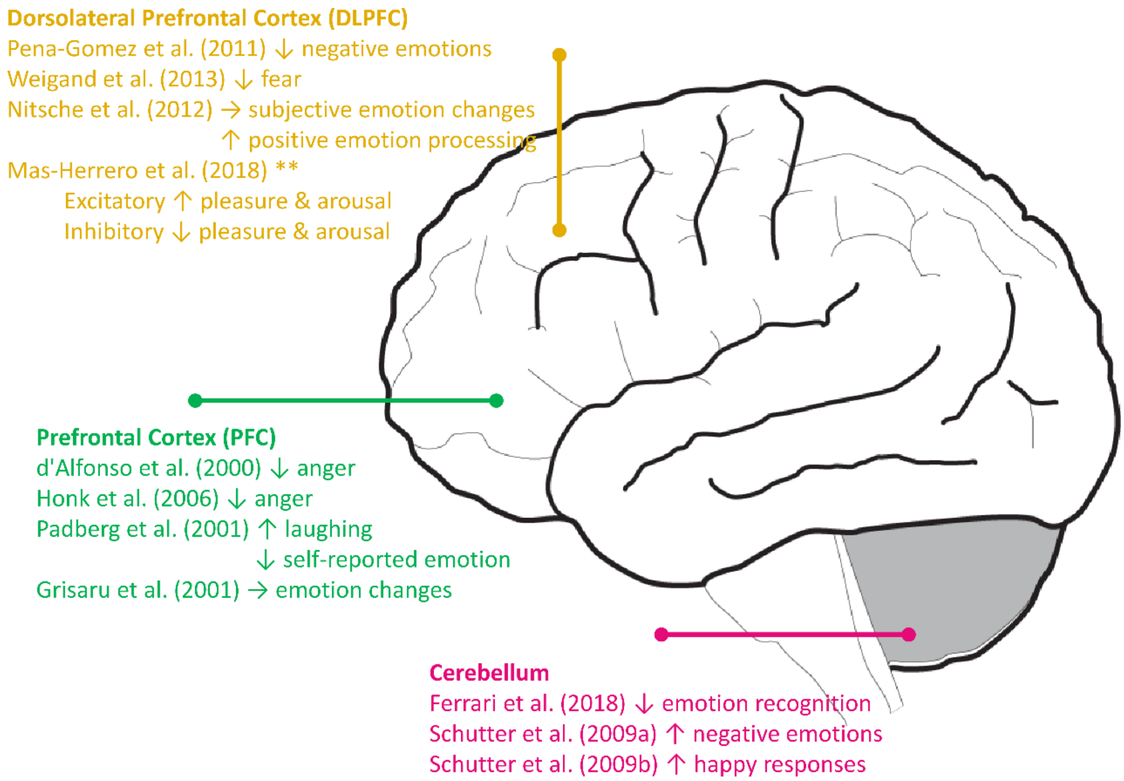
This Study

This chapter attempted to clarify the MFG and PMC's roles in the complex brain network involved in music-evoked emotions, using EDM break routines. Our previous chapters have shown the PMC and MFG are involved in EDM structure processing. Specifically, increased PMC activity during build-up passages suggested its involvement in intensifying tension levels prior to expected drop passages, where MFG activity increased as expectations were fulfilled (Turrell et al., 2021). EDM break routine structures, expectancy, and tension, as well as relating patterns of PMC and MFG activity positively correlated with greater peak-pleasurable emotions, such as excitement, due to contrastive valence (Bjork & Hommer, 2007; James et al., 2012; Huron, 2006; Lehne et al., 2014; Lehne & Koelsch, 2015; Meyer, 1956; Turrell et al., 2021; Vuilleumier & Trost, 2015).

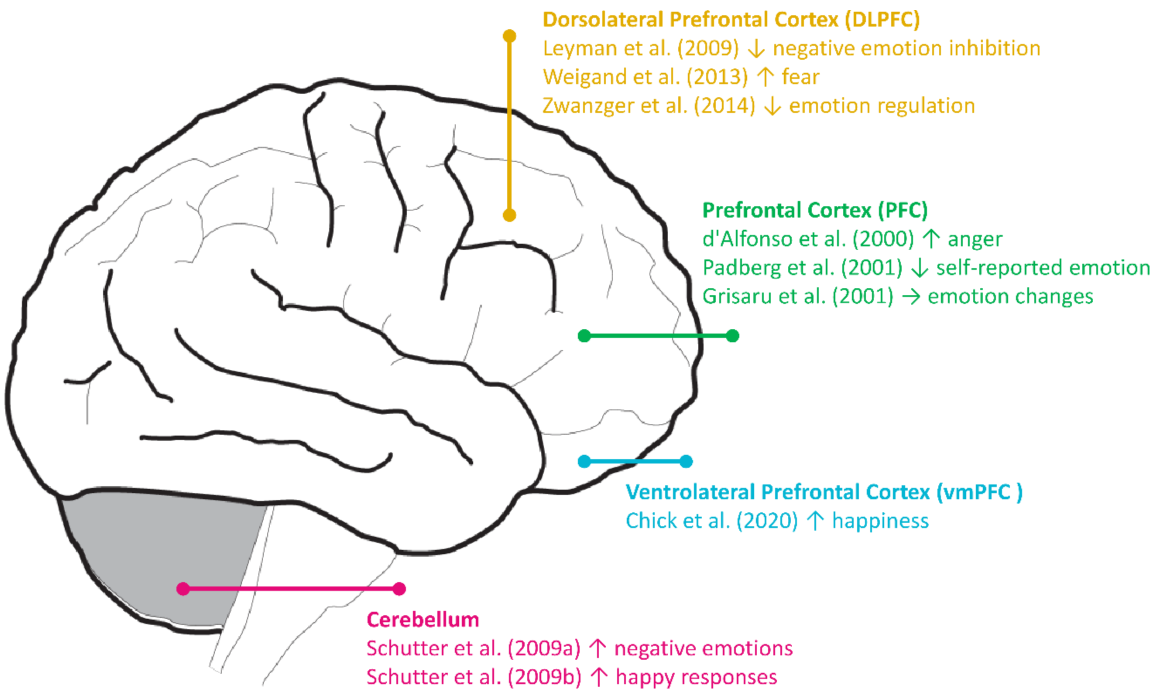
However, no studies have assessed the causational effects of MFG and PMC activity in music-evoked emotions and it is not yet determined whether greater MFG and PMC activity during EDM break routines causes increased peak-pleasurable emotions directly or indirectly through other mechanisms, such as structure and expectation processing. In this study, we assessed the causational role of the MFG and PMC in music-evoked emotions during EDM break routines, predicting anodal tDCS stimulation would magnify peak-pleasurable emotion ratings by altering the perception of build-up and drop passage structures.

Figure 5-1

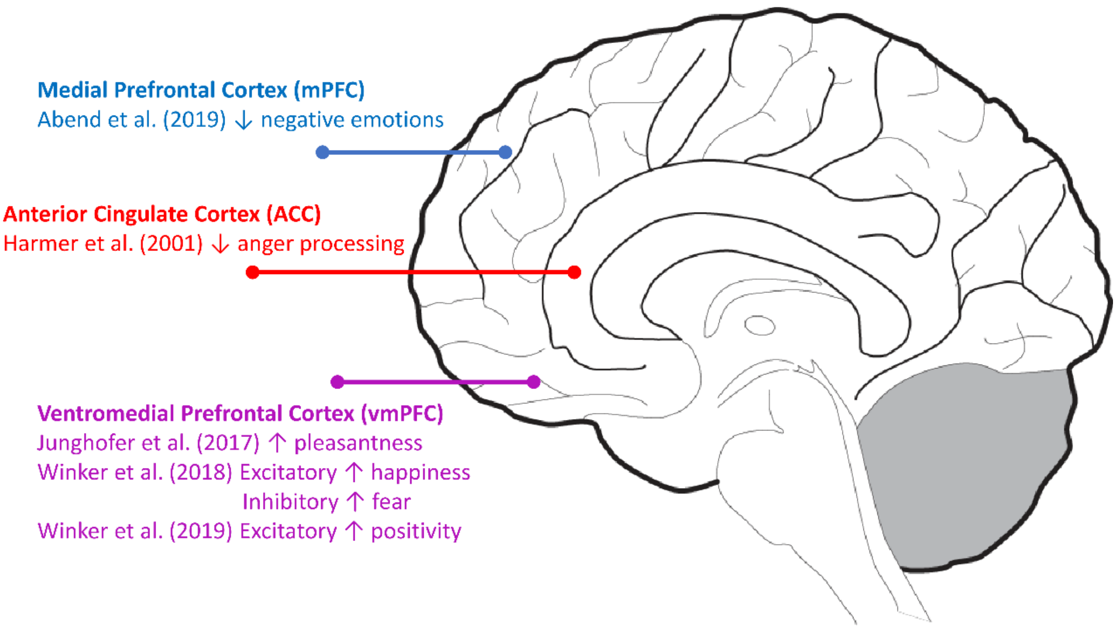
Visual Schematics of (a) Left Lateral, (b) Right Lateral, (c) Left Medial, and (d) Right Medial Brain Areas Influential to Emotions and Music-Evoked Emotions in Previous Research



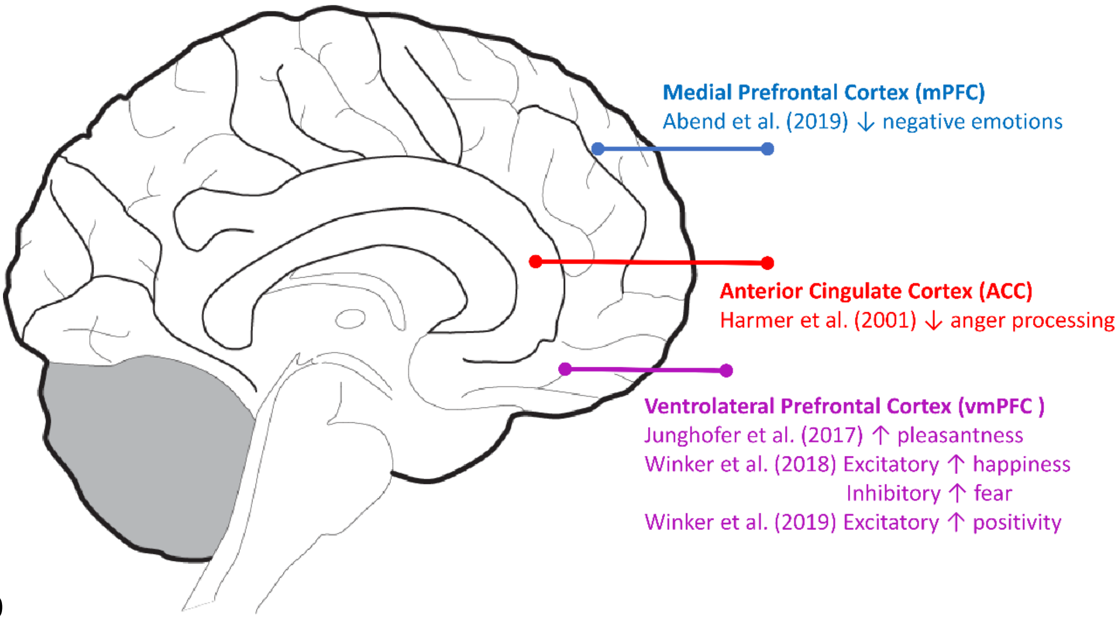
(a)



(b)



(c)



(d)

Note. ↑ increase, ↓ decrease, → no change, ** paper relevant to music-evoked emotions.

Method

Participants

Power calculation based on previous studies suggested a minimum required sample size of 43 (effect size F = 0.25, target power 0.95; G*Power 3.1.9.4; Faul et al., 2009). Forty-five University of Kent students participated in exchange for course credits as part of the research participation scheme, however four were excluded due to incomplete data. Therefore, the results of 41 participants are reported (34 (83%) females, age $M(SD)$ = 19.22(1.42)). Participants had a range of previous experience with a musical instrument from not playing at all to 9 or more years (*M(SD)* = 2.85(1.91), *Mdn* = 0-1 years of experience). Participants were required to have no neurological or family history of neurological illnesses, normal or corrected to normal vision and hearing, not be taking psychoactive or centrally acting medication, and be aged between 17 and 32. Participants gave written informed consent in accordance with the Declaration of Helsinki and the study protocol was approved by the local ethics committee at the University of Kent.

Stimuli & Measures

Forty electronic dance music (EDM) break routine clips were selected from a collection used in an earlier study (Turrell et al., 2021). These clips were from a range of EDM genres, including House, Dub-step, Dance, and Trance. Example songs which break routine clips were taken from include 'The Nights' by Avicii and 'Tour' by Macky Gee. The average familiarity (rating from 1-5) for these break routine clips was low (min = 1, max = 3.58, *M(SD)* = 1.99(0.65)) and they varied in acoustical features, such as loudness. Duration varied between 18-22s with drop passages being 6s and occurring between 12-16s following the beginning of the clip. For the complete list of songs and details of the stimuli see the associated data via DOI link https://doi.org/10.17605/OSF.IO/ZCYHR.

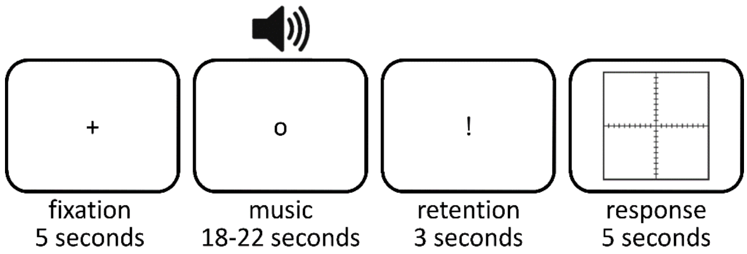
Participants recorded felt emotions when listening to break routines, using a 2-dimensional space of valence and arousal. This measure has been used extensively and is based on the Circumplex Model of Emotion (Russell, 1980). It plots emotions with valence and arousal on the horizontal and vertical axes, respectively. Please see the 'Procedure' section of Chapter 3 for more details on the 2-dimensional space, as well as on paper and computer 2-dimensional space training (Figure 3-4).

Procedure

Every participant attended three laboratory sessions, each with a different type of tDCS stimulation: MFG, PMC, and Sham. Sessions were held roughly one week apart (7±1 days) and stimulation conditions, as well as the order of break routine clips, were randomised. Psychtoolbox v3 (Brainard, 1997) on MATLAB was used to present auditory and visual stimuli, as well as record subjective ratings. Each trial began with a fixation cross for 5s, after which a break routine clip was presented alongside a fixation point for participants to keep their gaze. Following each break routine clip was a 3s retention period shown via an exclamation mark on the screen. Then the 2-dimensional space of valence and arousal was displayed, at which point participants had 5s to indicate their felt emotions while listening to the break routine clip with a mouse click (see Figure 5-2). Trials were divided into four blocks of 10 break routine clips with a 60s break in between each block, meaning a total of 40 break routine clips were presented in each stimulation session.

Figure 5-2

Visual Representation of Each Trial in the Music Paradigm Presented to Participants in Each Stimulation Session, Consisting of the Fixation Cross, Break Routine Presentation, Retention Period and 2-Dimensional Response Screen



Transcranial Direct Current Stimulation (tDCS)

tDCS stimulation was done using a DC Brain Stimulator Plus (NeuroConn, Ilmenau, Germany) and 35mm × 35mm saline soaked surface sponge electrodes. Stimulation was delivered with 1.5mA electrical current amplitude. Anodal stimulation was used as previous chapters indicated increased PMC and MFG activity during break routine build-up and drop passages correlated with greater peak-pleasurable music-evoked emotions. The MFG and PMC conditions consisted of 15 minutes of stimulation with 15s fade in and out. The Sham stimulation condition consisted of only 15s fade in and out. Locations of stimulation were identified using the 10-20 International System of Electrode Placement, with anodal electrodes being placed at F5 for MFG stimulation and C3 for PMC and Sham stimulation (see Figure 5-3 and Figure 5-4; Klem et al., 1999). The cathodal electrode was placed on the top of the left wrist for all stimulation conditions.

Figure 5-3

Visual Representation of the 10-20 International System of Electrode Placement, Coloured Electrodes Represent Areas of Stimulation: MFG Stimulation on F5 in Green and PMC and Sham Stimulation on C3 in Blue

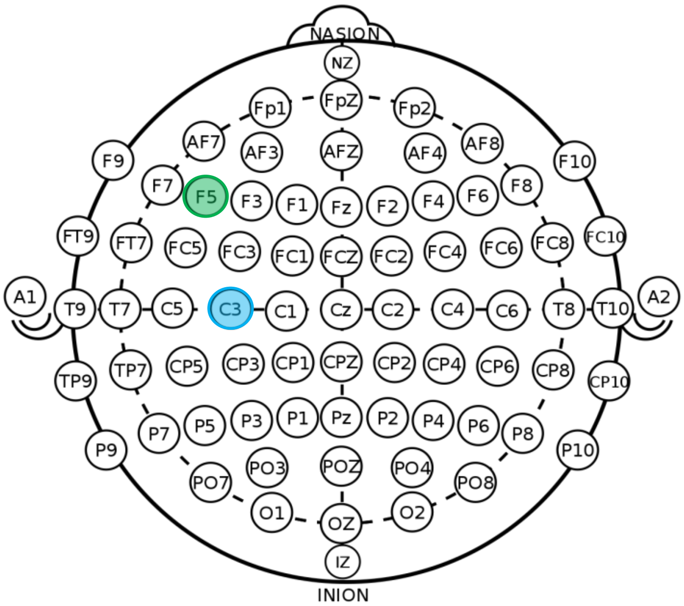
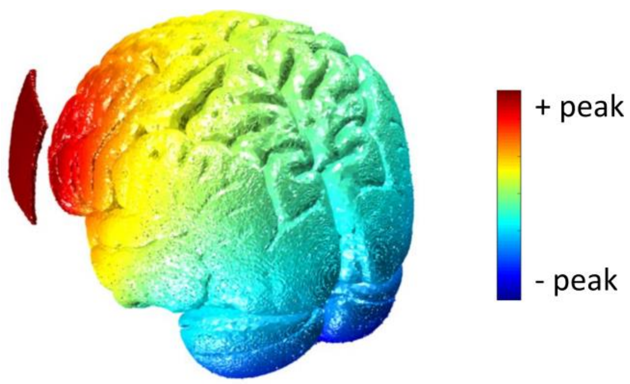


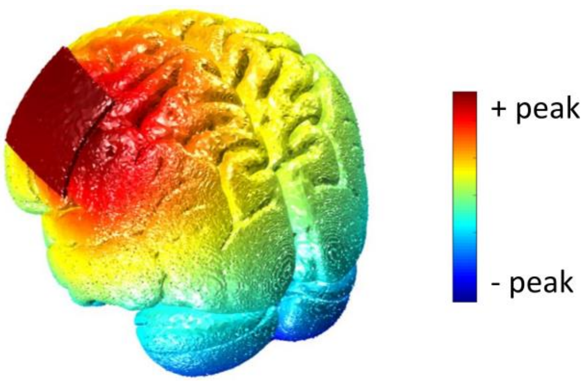
Figure 5-4

Simulation of the Current Flow for Transcranial Direct Current Stimulation (tDCS) of (a) Middle Frontal Gyrus (MFG; F5) and (b) Premotor Cortex (PMC; C3)

(a)



(b)



Note. The anode electrode was put on either MFG or PMC and the cathode electrode was put on the left wrist. Both electrodes were 35mm × 35mm and the current amplitude was 1.5mA. Modelling was done using open-source software ROAST (Huang et al., 2019).

Analysis

Participant's individual ratings of valence and arousal in the 2-dimensional space were recorded for each break routine clip. We also calculated amplitude (emotional strength) and angle (emotional response) values from the 2-dimensional space for each break routine (please refer to the 'Behavioural Analysis' section of Chapter 3 for more details on how emotional strength and emotional response were calculated). All these measures were considered as dependent variables (DV) in several multi-level mixed model analyses conducted on SPSS, controlling for random variation across participants while assessing differences between stimulation conditions on valence, arousal, emotional strength, and emotional response. A total of 13 multi-level analyses were conducted, four main effect analyses for each DV comparing all three stimulation groups. Then we report further post-hoc tests comparing two stimulation groups at a time for DV's with significant main effects. For example, one post-hoc multi-level analysis compared valence ratings for MFG and PMC stimulation. This was so that direct comparisons with meaningful estimates could be conducted between different stimulation groups.

Polar analysis was also conducted to investigate the combined measures of valence and arousal, displaying how ratings moved within the 2-dimensional space. Angle (emotional response) values were split across 60 bins (i.e., subsets of angles such that bin 1=]0,6]°, bin 2=]6,12]° and so forth) ranging from zero to 360°. Polar analysis was done using paired-sample t-tests on different bins to compare emotional responses across the three stimulation conditions. Paired-sample t-tests were run for each of the bins comparing the responses in different stimulation conditions. False discovery rate (FDR) correction for multiple comparison was used and alpha criteria were adjusted accordingly (Benjamini & Hochberg, 1995; Finner & Roters, 2001).

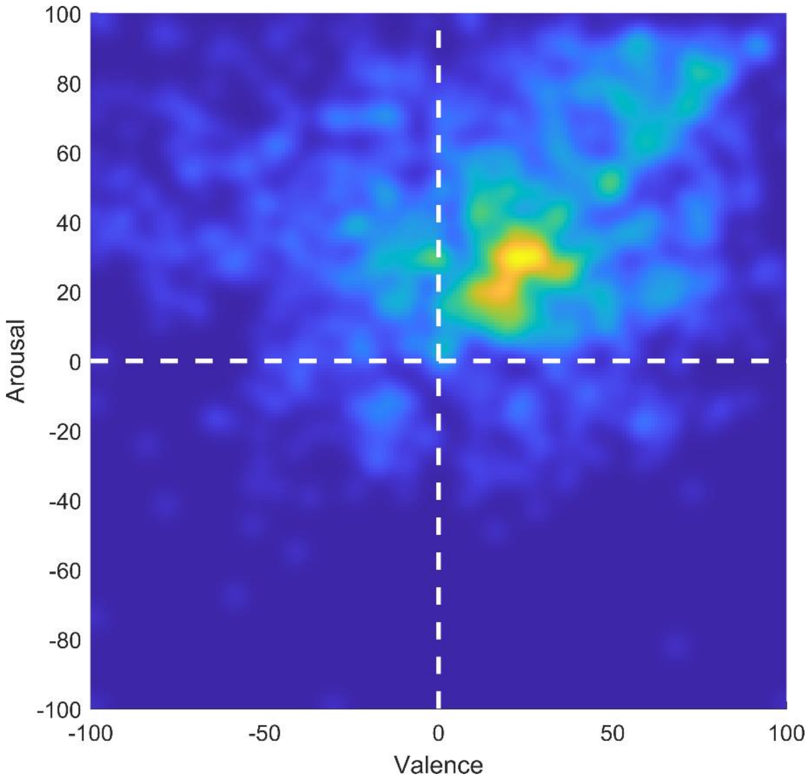
Results

The distribution of participants' emotional responses on the 2-dimensional space for each break routine clip within each stimulation condition was placed onto heat maps for visual comparison (see Figure 5-5).

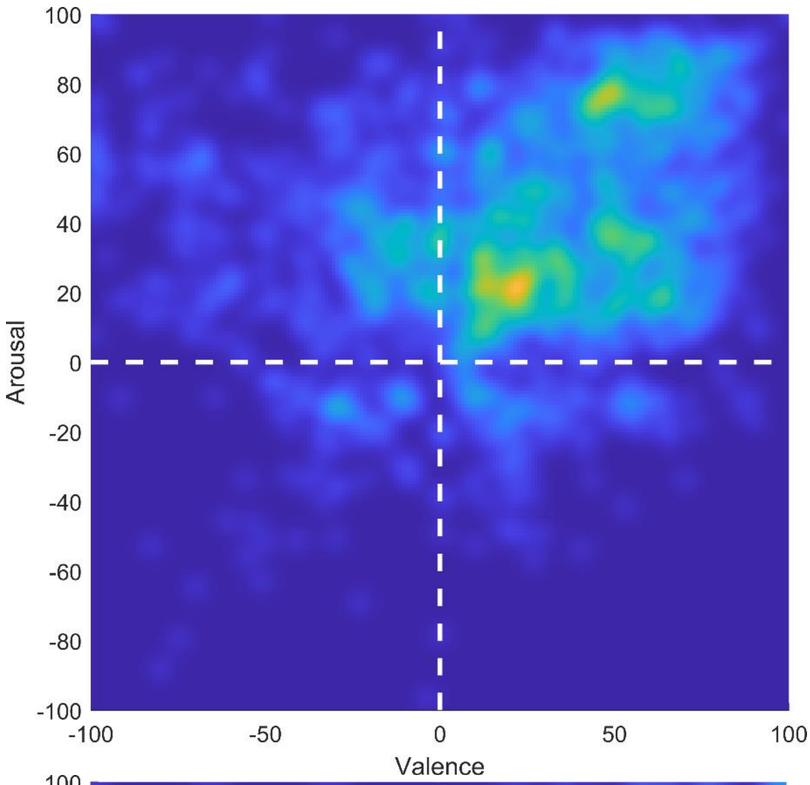
Figure 5-5

Heat Map Representation of the Distribution of the Responses for the Three Stimulation Conditions

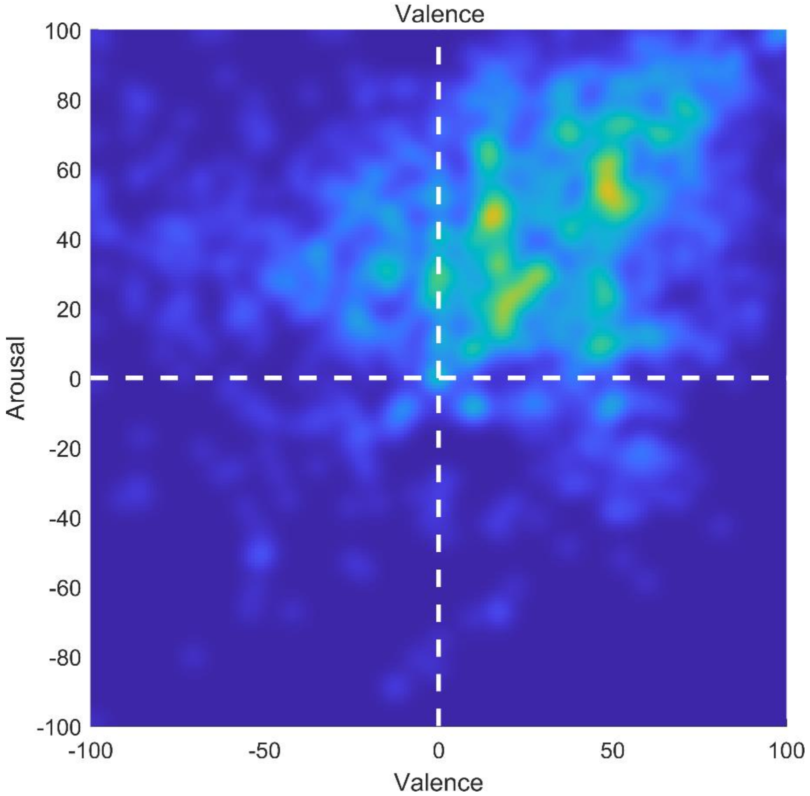
(a) MFG



(b) PMC



(c) Sham



Note. MFG: middle frontal gyrus stimulation; PMC: primary motor cortex stimulation; Sham: sham stimulation.

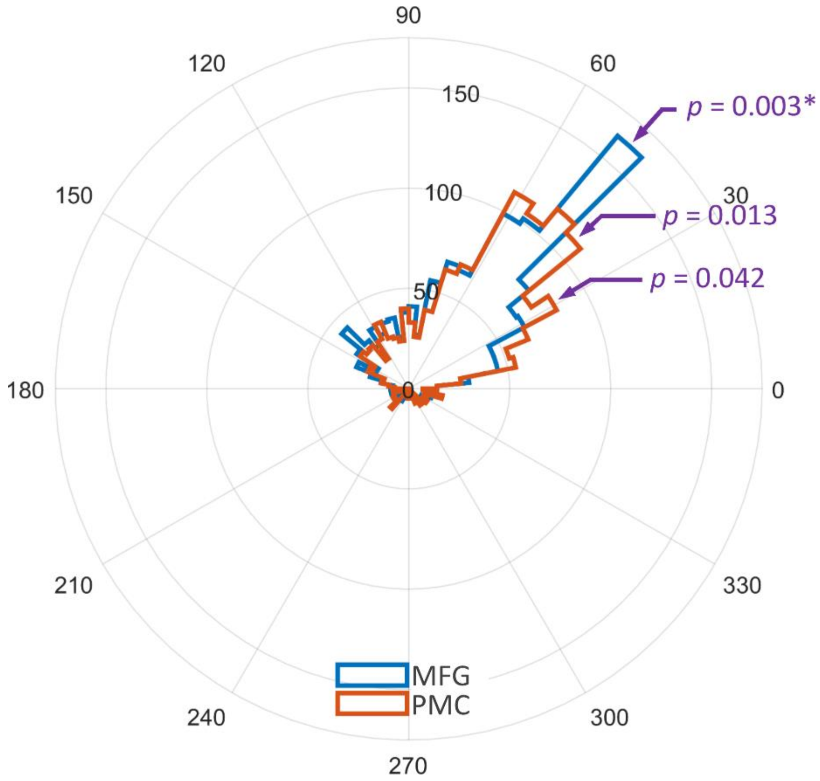
Polar Analysis

Polar analyses were conducted to investigate the effect of stimulation on emotional responses and amplitudes. Figure 5-6 shows the polar histogram of responses and the relevant *p* values across the 60 bins for different stimulation conditions.

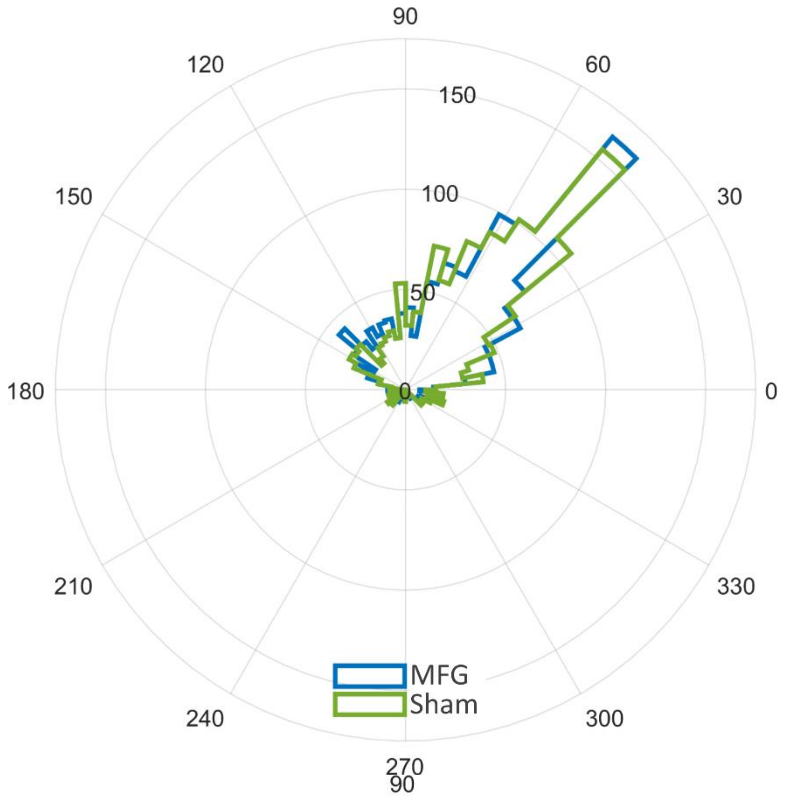
Figure 5-6

Polar Analysis of Responses, Comparing Different Stimulation Conditions

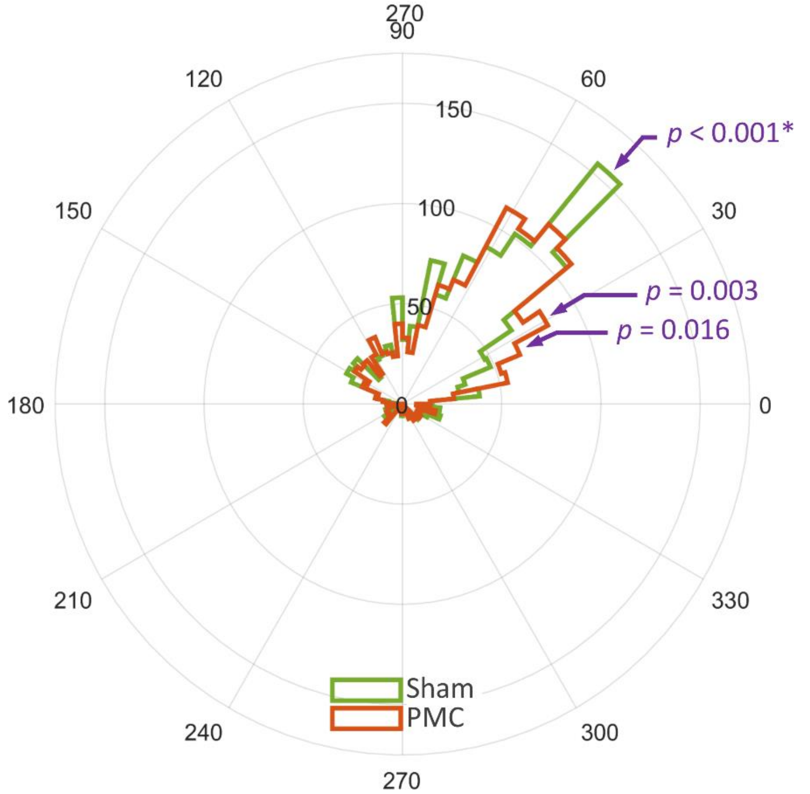
(a)



(b)



(c)



Note. *significant at adjusted α criterion following false discovery rate (FDR) correction for multiple comparison. MFG: middle frontal gyrus stimulation; PMC: primary motor cortex stimulation; Sham: sham stimulation.

Mixed-Model Multi-level Analysis

Mean ratings of valence, arousal, emotional strength, and emotional response were calculated for the 40 EDM break routine clips. On average, clips were experienced as positively valenced, arousing, strong and at an emotional response angle of around 50° in the 2-dimensional space (corresponding to emotional labels, such as astonished; valence *M(SD)* = 18.66(41.64), arousal 36.49(32.44), strength 60.42(28.53), angle 52.28(65.21)).

Separate linear multi-level mixed model analyses were run for each emotional dimension. There were significant main effects of stimulation condition on valence, emotional strength, and emotional response (see Table 5-1). However, the main effect of stimulation condition on arousal ratings was not significant.

Table 5-1

Multi-level Analysis Main Effect Results, Comparing all Stimulation Groups (MFG, PMC, and Sham), for Each Emotional Dimension Rating (Valence, Arousal, Strength, and Response)

Emotional Dimension	***F***	***P***
Valence	$F(4778.02) = 6.75$	0.001**
Arousal	$F(4778.02) = 1.66$	0.191
Strength	$F(4778.03) = 3.86$	0.021*
Response	$F(4778.03) = 5.61$	0.004**

Note. * $p < .05$; ** $p < .005$.

Post-hoc multi-level analyses comparing only two stimulation groups at a time, were run on variables with significant main effects (valence, strength, and response; see Table 5-2 for mean values). MFG stimulation induced significantly lower valence ratings than PMC and sham (see Table 5-3). MFG stimulation also induced significantly lower emotional strength ratings compared to sham, as well as marginally significant lower ratings compared to PMC stimulation. Meanwhile, within the PMC stimulation condition, there were significant differences in emotional responses compared to MFG and sham stimulation conditions, with ratings being closer to 45 degrees (Figure 5-7 for more details). Thus, MFG stimulation reduced felt valence and emotional strength during EDM break routines. While

PMC stimulation significantly moved the emotional response angle within the 2-dimensional space towards 45 degrees (towards the labelled emotion of excitement).

Table 5-2

Mean (SD) Values of Each Emotional Dimensions (Valence, Arousal, Emotional Strength, and Emotional Response) Across the Three Stimulation Conditions (MFG/PMC/Sham)

Emotional Dimension	MFG	PMC	Sham
Valence	16.06(41.84)	20.23(41.98)	19.69(40.98)
Arousal	36.66(31.38)	35.57(32.35)	37.24(33.55)
Strength	59.18(28.88)	60.64(28.37)	61.45(28.32)
Response	55.60(65.48)	48.54(65.88)	52.73(64.10)

Note. SD: standard deviation; MFG: middle frontal gyrus stimulation; PMC: primary motor cortex stimulation; Sham: sham stimulation.

Table 5-3

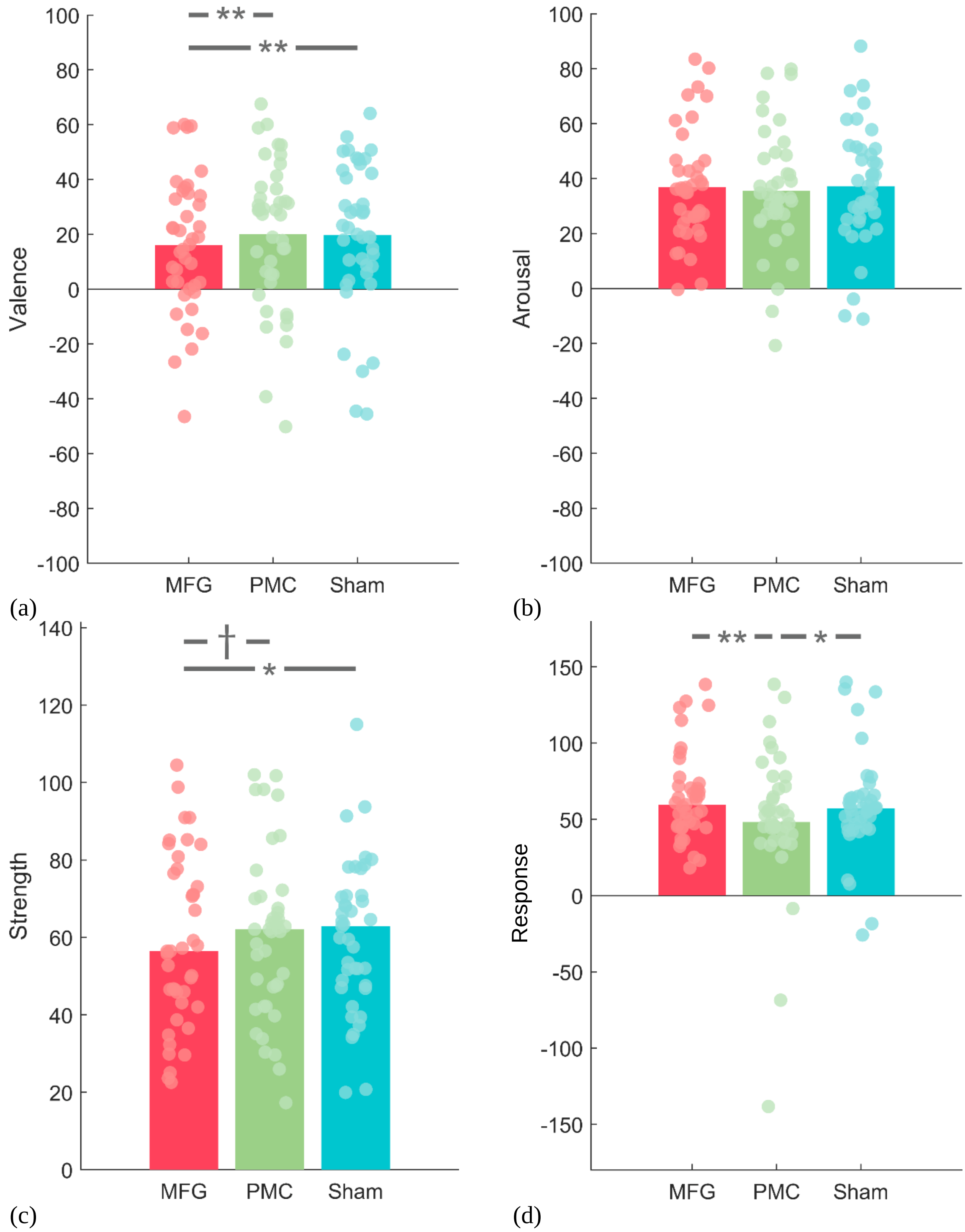
Post-hoc Multi-level Analyses Results, Comparing Two Levels of Stimulation on Each Emotional Dimension Rating with a Significant Main Effect (Valence, Strength, and Response)

Emotional Responses	Comparison	*F*	*P*	E
Valence	MFG vs PMC	$F(3180.04) = 11.01$	0.001**	-4.01
	MFG vs Sham	$F(3163.04) = 8.98$	0.003**	-3.59
	PMC vs sham	$F(3173.02) = 0.13$	0.723	0.42
Strength	MFG vs PMC	$F(3180.03) = 3.34$	$0.068^{\dagger}$	-1.38
	MFG vs Sham	$F(3163.04) = 7.53$	0.006*	-2.18
	PMC vs sham	$F(3173.05) = 0.95$	0.329	-0.77
Response	MFG vs PMC	$F(3180.07) = 10.71$	0.001**	6.92
	MFG vs Sham	$F(3163.09) = 1.96$	0.161	2.90
	PMC vs sham	$F(3173.01) = 3.93$	0.048*	-4.00

Note. * $p < .05$; ** $p < .005$; † marginal significant $p < .10$; E: estimates of the difference in response for each unit of measurement; MFG: middle frontal gyrus stimulation; PMC: primary motor stimulation; Sham: Sham stimulation.

Figure 5-7

Summary of Average Emotional Responses for (a) Valence, (b) Arousal, (c) Strength, and (d) Response Across Different Stimulation Conditions



Note. Bars represent mean response. *$p < 0.05$, **$p < 0.01$, †$p = 0.068$.

Discussion

This study offers a novel exploration into the middle frontal gyrus (MFG) and premotor cortex's (PMC) causational involvement in peak-pleasurable music-evoked emotions, using particularly emotive EDM break routines. We showed that most emotional dimensions of peak-pleasurable experiences (valence, emotional strength, and emotional response) can be influenced differently by anodal transcranial direct current stimulation (tDCS) of the left MFG and left PMC. Specifically, MFG stimulation reduced subjective ratings of valence and emotional strength, while PMC stimulation shifted the emotional response angle towards excitement. Yet, arousal ratings were not affected by either stimulation condition as compared to Sham stimulation.

There are several possible explanations as to why anodal left MFG and PMC stimulation reduced emotional experiences. Direct effects suggest that tDCS of these brain areas cause alterations in peak-pleasurable emotional dimensions, such as valence, emotional strength, and emotional responses. However, indirect effects suggest that increased MFG and PMC stimulation influenced music-evoked emotions through other processes, such as cognition, movement, and physiological responses (Koelsch, 2018). Specifically, in support of previous chapters, peak-pleasurable emotions could have been influenced indirectly through PMC and MFG stimulation altering the perception of EDM break routine structures of intensifying tension during build-up passages prior to expected drop passages.

Direct Causes

Anodal MFG and PMC stimulation reducing valence, emotional strength, and emotional responses infers a causational role of activity in peak-pleasurable emotions. Previous research has shown the MFG and PMC's involvement in music processing, as well as the perception and experience of music-evoked emotions and emotional dimensions, such as valence (Shinkareva et al., 2020; Tabei, 2015). Greater MFG activity has been shown to increase emotional dimensions, such as intensity or strength, alongside specific peak-pleasurable music-evoked emotions, including liking, happiness, and excitement (Altenmüller et al., 2014; Brattico et al., 2011; Koelsch et al., 2006; Okuya et al., 2017; Turrell et al., 2021). Thus, the MFG can directly increase peak-pleasurable music-evoked emotions, including excitement. However, anodal MFG stimulation in this study decreased emotional ratings of valence and strength, suggesting reduced peak-pleasurable emotions and contradicting previous research.

The PMC is also connected to peak-pleasurable music-evoked emotions through similar direct causes as the MFG. The PMC is less often associated with emotions and its primary function is thought to be in organising, preparing, and conducting movements (Chouinard & Paus, 2006; Schubotz & von Cramon, 2003). Yet, greater PMC activity can also increase emotional dimensions like valence, emotional strength, and emotional response angles corresponding with peak-pleasurable emotions such as liking, pleasantness, joy, and wonder (Cunningham et al., 2004; Kim et al., 2020; Okuya et al., 2017; Pereira et al., 2011; Sammler et al., 2007; Trost et al., 2012). Thus, PMC activity also directly increases peak-pleasurable emotion dimensions, establishing why anodal PMC stimulation moved emotional response angles within the 2-dimensional space to areas representing peak-pleasurable emotions, such as excitement.

Indirect Causes

Direct links between MFG and PMC activity with music-evoked emotions suggests greater activity would have increased peak-pleasurable emotions. Yet, valence, emotional strength, and emotional response ratings all decreased with anodal stimulation in this study. Possible indirect causes may better explain these unexpected effects of MFG and PMC stimulation on peak-pleasurable music-evoked emotions.

Neural Interconnectivity

For example, MFG and PMC’s *interconnectivity with other emotive neural networks* could explain anodal stimulation’s effects on valence, emotional strength, and emotional response ratings. For instance, the auditory cortex, orbitofrontal cortex, inferior frontal gyrus, precuneus, amygdala, insular, ventral striatum, and anterior cingulate cortex have all been linked with the MFG and PMC as part of intricate music-evoked emotion brain networks (Koelsch, 2014; Rogenmoser et al., 2016; Schaefer, 2017). Integrated activity within such networks enables the processing, experience, and expression of music- evoked emotions, such as happiness, tension, and pleasure (Koelsch, 2018; Koelsch et al., 2006; Lehne et al., 2014). Anodal MFG and PMC stimulation may have modulated activity within interconnected brain areas during EDM break routine listening. This may have reduced activity in other interconnected brain areas involved in peak-pleasurable emotions, such as the orbitofrontal and inferior frontal cortices, which then decreased peak-pleasurable emotion ratings of valence, emotional strength, and emotional responses.

Acoustic Feature Processing

MFG and PMC activity may have also decreased peak-pleasurable emotions indirectly through *acoustic feature processing* (Habibi & Damasio, 2014; Rolison & Edworthy, 2013). Greater MFG and PMC activity can alter the processing, integration, and working memory of acoustic features, such as rhythm, pitch, loudness, beat, melody, and tone (Grahn & Rowe, 2009; Koelsch, 2011; Penhune & Zatorre, 2019; Schulze et al., 2011). For example, increased PMC activity correlates with greater rhythm synchrony, louder tones, and higher beat perception (Chen et al., 2006; Grahn & Rowe, 2009). Meanwhile, greater MFG activity correlates with the working memory and higher order processing of music structures, such as melodies (Jerde et al., 2011; Turrell et al., 2021).

Such acoustic features are important to creating EDM break routine structures: as they reduce to only a few remaining features during breakdown passages, then gradually increase again to peak levels during build-up passages and return to the song's main groove during drop passages (Butler, 2006; Solberg & Dibben, 2019; Turrell et al., 2021). These acoustic features also effect emotional dimensions of valence and arousal, peak-pleasurable emotions (including happiness and excitement), as well as physiological responses, such as increased heart rate, skin conductance, respiratory rates, and 'chills' (Geiser et al., 2009; Koelsch, 2014; Mori & Iwanaga, 2017; Salimpoor et al., 2009; Thaut et al., 2014). Anodal MFG and PMC stimulation may have indirectly reduced peak-pleasurable emotion dimensions of valence, emotional strength, and emotional response ratings by changing the perception of acoustic features that are relevant to establishing EDM break routine structures, such as mode and tempo (Rogenmoser et al., 2016).

Music Structure & Expectancy Processing

The MFG and PMC also influence *music structure and expectations processing* (Koelsch, 2009; Koelsch, 2011; Turrell et al., 2021). Specifically, increased MFG and PMC activity is involved in the identification of sequenced auditory information, calculating relationships between acoustic features, identifying music structural relationships and irregularities, as well as making predictions or expectations and rules of upcoming music events (Bogert et al., 2016; Giordano et al., 2014; Koelsch, 2006; 2009; 2011; Koelsch & Siebel 2005). As indicated in previous chapters, assessing music structure to create future expectations enables peak-pleasurable emotions when they are correctly fulfilled (the prediction effect; Koelsch, 2014; Meyer, 1956; Huron, 2006; Turrell et al., 2021). EDM break routines' distinctive structures of intensifying tension during build-up passages before fulfilling expected drop passages correlates with increased PMC and MFG activity, respectively (Turrell et al., 2021). Thus, anodal MFG and PMC stimulation could have altered the perception of EDM break routine structures and features, decreasing the extent drop passages were expected and reducing peak-pleasurable emotion dimensions of valence, emotional strength, and emotional response.

Increased PMC activity also correlates with EDM break routine structures, via intensifying tension levels prior to expectations (Koelsch, 2014; Lehne & Koelsch, 2015; Osnes et al., 2012; Turrell et al., 2021). EDM break routine structures increase tension and relating PMC activity during build-up passages prior to fulfilling expectations and increasing MFG activity within drop passages, which magnifies peak-pleasurable emotions when expected drop passages are correctly fulfilled due to contrastive valence (Huron, 2006; Meyer, 1956; Solberg & Jensenius, 2017; Turrell et al., 2021). Thus, anodal MFG and PMC stimulation could have influenced the processing of EDM break routine structures, decreasing levels of tension and expectancy, which can then reduced the amount of contrastive valence and decreased peak-pleasurable emotion dimensions of valence, emotional strength, and emotional response.

Other Emotive Cognitive Functions

Another indirect link between MFG and PMC activity and music-evoked emotions are their *roles in other emotionally relevant cognitive functions*, such as attention and familiarity (Blood & Zatorre, 2001; Koelsch, 2014; Västfjäll, 2001). Increased music recognition and familiarity can induce greater MFG and PMC activity, as well as emotional music engagement, increased music preference, and peak-pleasurable emotions (Freitas et al., 2018; Koelsch, 2006; Pereira et al., 2011; Van Den Bosch et al., 2013). Thus, anodal MFG and PMC stimulation may have influenced peak-pleasurable emotion dimensions of valence, emotional strength, and emotional response by increasing the recognition, familiarity, and engagement of EDM break routines. However, greater familiarity and recognition could have also made EDM break routine drop passages too predictable, reducing uncertainty and tension levels around expectations and inducing more negative emotions, such as boredom and dislike (Ali, 2004; Meyer, 1956; Schubert, 2010). This could explain why anodal MFG and PMC activity reduced peak-pleasurable emotion ratings of valence, emotional strength, and emotional response.

Direction of Emotional Changes

Most previous research suggests increased brain activity evokes greater musical emotions. However, the direction of emotional change seen here suggests that increased MFG and PMC activity does not always evoke greater peak-pleasurable emotions. One explanation could be that differential (rather than greater) brain activity influences emotion, similarly to the theory of contrastive valence (Huron, 2006; Sorinas et al., 2020). This suggests music inducing greater differences in brain activity would evoke higher peak-pleasurable emotions. Anodal stimulation increased baseline activity within the MFG and PMC, reducing the extent of differences between baseline and peak level brain activity during EDM break routines. Such reduced differences in MFG and PMC activity could have then decreased valence, emotional strength, and emotional response ratings for peak-pleasurable emotions (Kim et al., 2017).

No Arousal Effects

Music arousal and emotions with higher arousal (such as excitement) correlate with numerous brain areas, including the amygdala, insula, auditory cortex, anterior cingulate cortex, right parietal and parieto-temporal areas, the prefrontal cortex, MFG, and PMC (Daly et al., 2019; Khalfa et al., 2008b; Rogenmoser et al., 2016; Sachs et al., 2020; Shany et al., 2019; Touroutoglou et al., 2012; Trost et al., 2012; Turrell et al., 2021). It is therefore surprising that anodal MFG and PMC stimulation did not influence arousal ratings within in our study.

There are several reasons why stimulation may have had no influence on arousal ratings. First, the MFG and PMC may be more loosely associated with arousal and other brain areas involved in music-evoked emotions, such as the amygdala, insula, and anterior cingulate cortex may be more influential to arousal (Koelsch et al., 2013; Lehne et al., 2014). Secondly, the 2-dimensional space of valence and arousal may not accurately measure arousal independently. When considered alone, MFG and PMC stimulation induced no significant changes in arousal but when combined with valence to create emotional response angles, stimulation had an effect. This suggests that anodal MFG and PMC stimulation may influence the combination of valence and arousal to create specific emotional experiences such as joy, nostalgia, excitement, and sadness (Russell, 1980; Trost et al., 2012; Turrell et al., 2021). Other physiological measures, such as ECG and skin conductance, may be more accurate and indicative of independent alterations in arousal during music (Kim & André, 2008; Sorinas et al., 2020).

Future Research

Quite large electrodes (35mm × 35mm) were used to stimulate the MFG and PMC, meaning other brain regions could have been influenced by the anodal stimulation. Future research should repeat our study using other and more targeted MFG and PMC stimulation methods, such as smaller electrodes, high definition tDCS, and focal TMS, which can provide acute and sensitive stimulation with the possibility to combine other imaging techniques, like EEG (Ferreri & Rossini, 2013; Roy et al., 2014). This would enable better indications of how the MFG and PMC contribute to peak-pleasurable emotions during EDM break routines.

As discussed above, anodal MFG and PMC stimulation effects on peak-pleasurable emotions may have occurred indirectly through altering the processing of acoustic features and music structure. Future research should establish these mediating effects by assessing how MFG and PMC anodal stimulation influences the perception of acoustic features, like rhythm, tempo, brightness, and beat, which are important in creating EDM break routine structures of build-up and drop passages (Solberg & Dibben, 2019; Turrell et al., 2021). If stimulation influences acoustic feature and EDM structure processing, levels of expectancy and tension could have been reduced, which better explains why anodal MFG and PMC stimulation decreased peak-pleasurable emotion ratings.

The 2-dimensional space ratings of valence and arousal were recorded retrospectively after each EDM break routine clip. Ratings, therefore, may not be accurate measures of emotional responses during EDM break routines, and valence and arousal ratings may differ across build-up and drop passages. Future research should explore continuous ratings of valence and arousal during intensifying tension within build-up passages and peak-pleasurable emotions from fulfilled expected drop passages, using other emotion measures, such as repeated 2-dimensional responses, continuous ratings, and physiological measures, like skin conductance and respiration rates (Egermann et al., 2013; Schubert, 2013).

Conclusion

Our previous chapters used EEG to show that EDM break routines are particularly emotive due to their structure creating expectations and tension, and that such effects correlate with activity in frontal (MFG) and motor brain areas (PMC; Turrell et al., 2021). In this chapter, we provide a novel insight into the causational role of the MFG and PMC in peak-pleasurable emotions, using the particularly emotive structure of EDM break routines and anodal tDCS. Our results showed that anodal left MFG stimulation decreased peak-pleasurable emotion dimensions of valence and strength, while anodal left PMC stimulation shifted emotional response angles lower and towards excitement, and neither stimulation group influenced arousal. This suggests a complicated and interconnected experience of peak-pleasurable music-evoked emotions, which includes acoustic features, various brain areas, and several cognitive processes. Specifically, results support findings from previous chapters, suggesting that EDM break routine structures of intensifying tension during build-up passages (correlating with greater PMC activity) before fulfilling expected drop passages (correlating with higher MFG activity) induces peak-pleasurable emotions. Anodal PMC and MFG stimulation could have changed the perception of tension and expectations during build-up and drop passages, which then influenced the extent of peak-pleasurable emotions. Future research should elaborate on the nature of peak-pleasurable emotions, using different neuroimaging techniques to clarify the mediating role of music structure and interconnectivity between different brain areas.

Chapter 6 – General Discussion

Overview

This thesis investigated how music can induce powerful peak-pleasurable emotions, assessing the roles of structure, expectancy, and tension, as well as relating brain activity, in unique and short musical motifs called break routines. Our first study assessed whether electronic dance music (EDM) break routines could evoke peak-pleasurable emotions and what brain areas correlated (Chapter 2). Results showed that EDM break routines induced peak-pleasurable emotions, specifically excitement, as well as MFG, IFG, and PMC activity according to their structure of increased tension during build-up passages prior to expected drop passages. To clarify the extent break routine structures influenced peak-pleasurable emotions and relating brain activity, our second study examined the emotional impact of structurally similar break routines from EDM and classical music (Chapter 3). Comparable peak-pleasurable emotion ratings and patterns of MFG, SFGL, PMC, and PCUN activity suggested break routine structures are important to peak-pleasurable emotions and relating brain activity.

However, the extent tension prior to expected drop passages within break routine structures influenced peak-pleasurable emotions was still ambiguous. Our third study, therefore, measured continuous tension levels across break routines and peak tension's correlations with peak-pleasurable emotions (Chapter 4). This confirmed that tension increased during build-up passages and reduced within expected drop passages but was less clear on whether higher tension increased peak-pleasurable emotions. Lastly, to further understand the causational role of relating brain activity during EDM break routine peak-pleasurable emotions, the MFG and PMC were stimulated, which decreased peak-pleasurable emotions (Chapter 5). This suggested MFG and PMC activity indirectly effected peak-pleasurable emotions through break routine structure processing. The following chapter will discuss findings of this thesis, as well as future directions and applications.

When Music is Exciting

Music can undoubtedly evoke emotions but exactly how it does this is complex and difficult to untangle. One explanation proposes expectancy and tension derived from music structures, leading to theories such as ITPRA (Imagination, Tension, Prediction, Reaction, and Appraisal: Huron, 2006; Meyer, 1956; Miller, 1967; see 'Music-Evoked Emotions, Expectancy & Predictions' in Chapter 1). However, assessment of music structures, expectations, and tension's influence on music-evoked emotions and relating brain activity is still lacking (Lehne & Koelsch, 2015). The aim of Chapter 2 was to examine EDM break routines' influence on peak-pleasurable emotions and relating brain activity, according to their structure of intensifying tension during build-up passages prior to highly expected drop passages (Solberg & Dibben, 2019).

A study was conducted using continuous electroencephalography (EEG) across break routine listening to assess brain activity changes and their correlation with higher peak-pleasurable emotions (i.e., excitement). Findings showed that several brain regions significantly differed across break routine passages including greater bilateral premotor cortex (PMC), and precuneus (PCUN) activity during build-up passages, as well as increased bilateral inferior frontal gyrus (IFG), and right middle frontal gyrus (MFG) activity within drop passages. Also, greater IFG and MFG activity correlated with excitement ratings during drop passages, linking them to peak-pleasurable emotions as music expectations were fulfilled.

Break Routine Structure

Music structure is the temporal, semantic, and layered combination of numerous smaller blocks including acoustic features, such as pitch, tempo, melody, and rhythm, that create music-evoked emotions (Jones, 1982; Koelsch, 2014; Komosinski & Mensfelt, 2016; Kunert et al., 2015; Tervaniemi et al., 2014; Vuust & Witek, 2014; Weidema et al., 2016). Within EDM break routines, acoustic features including rhythm, timbre, and tonality increased to create build-up passages and then returned to the song's expected and established main groove during drop passages (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019; Turrell et al., 2021). These distinct EDM break routine passages referred to different ITPRA stages, as build-up passages increased tension, while drop passages fulfilled expectations or predictions (Huron, 2006). We proposed that it was EDM break routine's specific structure created through changing acoustic features, which then induced tension within build-up passages prior to fulfilling expected drop passages and evoked peak-pleasurable emotions, such as excitement.

EDM break routines' structure of increasing tension during build-up passages prior to expected drop passages also led to brain activity differences within the PMC, PCUN, IFG, and MFG. As discussed in the 'Brain Differences During Build-up Passages' section of Chapter 2, greater PMC and PCUN activity within build-up passages suggests their involvement in processing the gradual amplification of tension and acoustic features, such as tempo, rhythm, and pitch (Dohn et al., 2015; Ono, Nakamura, & Maess, 2015; Potes et al., 2012; Schön et al., 2010; Thaut et al., 2014). While increased IFG and MFG activity during drop passages was involved in the implicit processing of break routine structures, fulfilled expectations, and alterations in acoustic features like rhythm, pitch, and harmony (Bogert et al., 2016; Butler, 2006; Dohn et al., 2015; Koelsch, 2014; Lappe et al., 2013; Schön et al., 2010; Solberg, 2014; Solberg & Dibben, 2019; Thaut et al., 2014). Therefore, break routine structures changing from intensifying tension during build-up passages to expected drop passages also influenced brain activity.

Differential brain activity during EDM break routine build-up and drop passages additionally affected peak-pleasurable emotions. PMC and PCUN activity are involved in tension, suggesting greater activity within build-up passages occurred alongside intensifying tension as uncertainty and acoustic features increased before expected drop passages (Koelsch, 2014; Turrell et al., 2021; Vuilleumier & Trost, 2015). Meanwhile IFG and MFG activity influences peak-pleasurable emotions, including happiness, liking, and excitement which are evoked from fulfilled expectations during drop passages (Altenmüller et al., 2014; Brattico et al., 2011; Koelsch et al., 2006; Kornysheva et al., 2010; Tabei, 2015; Turrell et al., 2021). Thus, EDM break routine structures of intensifying tension during build-up passages prior to fulfilling expected drop passages correlated with PMC and MFG activity respectively, which then mediated peak-pleasurable emotions, including excitement (Turrell et al., 2021).

Expectancy

According to Huron’s (2006) ITPRA theory, tension and expectancy are important influencers on peak-pleasurable emotions. Specifically, higher tension levels prior to expected moments can magnify peak-pleasurable emotions from the correct fulfilment of expectations or predictions, due to contrastive valence (Huron, 2006; Lehne & Koelsch, 2015; Meyer, 1956). This suggests that peak-pleasurable emotions can be amplified if they are immediately preceded by negative emotions. In EDM break routines, ITPRA factors tension, prediction, and reaction happen alongside EDM break routine build-up and drop passages to produce peak-pleasurable emotions. Tension experienced during build-up passages was negative and occurred directly before expected drop passages, which then magnified peak-pleasurable emotions from correctly fulfilled drop expectations (Huron, 2006; Solberg & Dibben, 2019; Turrell et al., 2021). This demonstrated that EDM break routines are a useful tool in assessing the proposed importance of music structures that create tension prior to expectations, in peak-pleasurable emotions.

Expectancy and tension during EDM break routines also correlated with distinct brain activity patterns (which are reviewed in detail in discussion sections of Chapters 2, 3, and 5), suggesting they are separable factors of ITPRA. Greater PMC and PCUN activity within build-up passages indicated their role in assessing break routines' structure and experiencing elevated tension due to delayed expected drop passages (Alluri et al., 2017; Bjork & Hommer, 2007; James et al., 2012; Koelsch et al., 2006; Koelsch et al., 2021; Lehne et al., 2014; Lehne & Koelsch, 2015; Thaut et al., 2014; Trost et al., 2012; Trost et al., 2014; Vuilleumier & Trost, 2015). Increased IFG and MFG activity during drop passages was evoked by fulfilled drop passage expectations as tracks returned to the main groove, as well as resulting peak-pleasurable emotions from fulfilled expectations (Altenmüller et al., 2014; Barrett & Janata, 2016; Bogert et al., 2016; Gebauer et al., 2012; Kim et al., 2017; Kohn et al., 2014; Lehne et al., 2014; Pecenka et al., 2013; Tillmann et al., 2003; Wallmark et al., 2018a; 2018b). This suggests that ITPRA factors tension, prediction, and reaction happen alongside EDM break routine structures of build-up and drop passages, producing peak-pleasurable emotions and specific patterns of brain activity, including the PMC, PCUN, IFG, and MFG.

Music structure seems to be more than just the hierarchical combination of smaller units, such as acoustic features, but also involves higher cognitive processes of predicting future music motifs (Jones, 1982; Koelsch, 2014; Vuust & Witek, 2014). Chapter 2 showed that EDM break routines are particularly efficient at establishing predictions and expectations for drop passages after intensifying tension within build-up passages (Butler, 2006; Solberg & Dibben, 2019). Such patterns of tension and expectation derived from EDM break routine structures and acoustic features elicited peak-pleasurable emotions and distinct brain activity within the PMC, PCUN, IFG, and MFG (Daly et al., 2015; Koelsch, 2014; Tillmann et al., 2014; Turrell et al., 2021; Warren, 2008). Increased tension, alongside PMC and PCUN activity, within build-up passages from greater uncertainty and delay of expected drop passages magnified peak-pleasurable emotions, as well as MFG and IFG activity, when drop passages were correctly fulfilled. This demonstrated how expectancy in music structures can evoke peak-pleasurable emotions and relating brain activity, as well as the enhancing role of tension.

The Role of Structure

So far, this thesis has demonstrated that EDM break routine structures can create specific peak-pleasurable emotions and brain activity patterns across build-up and expected drop passages. However, there is still some uncertainty as to what extent break routine structures, which create expectancy and tension, impact peak-pleasurable emotions. The aim of Chapter 3 was to clarify the extent to which EDM break routine structures influenced peak-pleasurable emotions compared to other emotional music factors, such as acoustic features.

Continuous EEG during EDM and analogue classical break routines was assessed across build-up and drop passages, as well as between EDM and analogue classical break routines. Peak-pleasurable emotion ratings on the 2-dimensional space of valence and arousal were also compared between EDM and analogue classical break routines. Similarities in peak-pleasurable emotions and patterns of MFG, SFGL, PAnG, and PMC activity suggested break routine structures of tension and expectancy, were stronger influencers on peak-pleasurable emotions than other music factors. However, greater peak-pleasurable emotions during EDM break routines also implied that other music factors, including acoustic features, mediated expectancy and tension’s effect on music-evoked emotions.

Other Music Factors, Emotions, and Brain Activity

EDM and classical music differ in acoustic features and such differences can have various emotional and neurological effects. As mentioned in Chapter 3, higher acoustic features, including tempo, rhythm, pitch, key, tone, mode, dissonance, and sound intensity, can increase MFG, SFGL, PMC, and PAnG activity, as well as heighten peak-pleasurable emotion ratings on valence, arousal, emotional strength, and emotional response, suggesting increased feelings of joy, happiness, and excitement (Aryani et al., 2018; Bravo et al., 2017; Brattico et al., 2011; Butler, 2006; Chapin et al., 2010; Grekow, 2017; Koelsch et al., 2018; Roda et al., 2014; Rogenmoser et al., 2016; Solberg & Dibben, 2019; Trost et al., 2012; Turrell et al., 2021). Acoustic features, such as faster rhythm, major modes, and louder intensities were more frequent in EDM compared to analogue classical break routines, suggesting that higher peak-pleasurable emotion ratings and correlating MFG, SFGL, PMC, and PAnG activity during EDM break routines occurred due to genre differences in acoustic features (Butler, 2006; Khalfa et al., 2008a; 2008b; Kim et al., 2010; Koelsch, 2014; Laurier et al., 2009; Limb et al., 2006; Nusbaum et al., 2014; Patel, 2014; Salimpoor et al., 2009; Solberg 2014; Solberg & Dibben, 2019; Thaut et al., 2014;Turrell et al., 2021).

EDM break routine structures, enabling tension and expectancy, induced peak-pleasurable emotions and relating MFG, SFGL, PMC, and PCUN activity, but acoustic features also magnified these emotional and neurological effects. This suggests music-evoked peak-pleasurable emotions derive from complex interconnections between numerous individual factors, including structure, expectancy/prediction, and tension factors in ITPRA, as well as acoustic features (Altenmüller et al., 2014; Huron, 2006; Kornysheva et al., 2010; Kim et al., 2017; Turrell et al., 2021). Such interdependence between factors alludes to their connections, where differences in one may alter another, affecting resulting peak-pleasurable emotions (Juslin et al., 2008; Huron, 2006; Meyer, 1956). Therefore, greater peak-pleasurable emotions during EDM break routines may have been influenced by greater acoustic features altering listeners perceptions of break routine structure, expectancy, and tension.

However, EDM break routines, with greater acoustic features, did not always correlate with maximum peak-pleasurable emotions and MFG, SFGL, PMC, and PAnG activity, which sometimes occurred within analogue classical break routines. This suggests that acoustic features are not the only mediators of peak-pleasurable emotions and relating brain activity. Other higher cognitive processes, such as semantic and structure processing, are also involved in seen brain activity and peak-pleasurable emotions (Casey, 2017; Donnay et al., 2014; Giordano et al., 2014; Heard & Lee, 2020; Koelsch, 2006; 2009; 2011; Koelsch & Siebel 2005; Osnes et al., 2012; Platel et al., 2003; Platel, 2005; Seghier, 2013; Turrell et al., 2021; Turrell et al., in submission, c). Thus, differences between EDM and analogue classical break routines in peak-pleasurable emotions and MFG, SFGL, PMC, and PAnG activity are not solely caused by variations in acoustic features, but rather a combination of factors, such as acoustic features and music structures.

Break Routine Structure, Emotions, and Brain Activity

Similarities between EDM and analogue classical break routines indicate the extent to which break routine structures influence peak-pleasurable emotions and relating brain activity. EDM and analogue classical break routines had similar structures of intensifying tension during build-up passages before fulfilling expected drop passages, where tension decreased and peak-pleasurable emotions, such as excitement, were experienced (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019). Both EDM and analogue classical break routines increased valence, arousal, emotional strength, and emotional response ratings, alongside similar MFG, SFGL, PMC, and PAnG activity (Turrell et al., 2021). This suggested, regardless of music genres and their differences in music factors (such as acoustic features), similar music structures which increase tension before fulfilling expected music motifs are able to evoke peak-pleasurable emotions and relating brain activity (Huron, 2006; Kunert et al., 2015; Osnes et al., 2012; Turrell et al., in submission, c; West & Lamere, 2006). This demonstrated that break routine structures of expectancy and tension are more important in evoking peak-pleasurable emotions and relating brain activity, over other potential emotional factors, such as acoustic features.

The Role of Tension

Our earlier studies demonstrated that EDM break routines can evoke peak-pleasurable emotions due to their structure. However, increased and decreased tension within break routine build-up and drop passages, as well as correlations with peak-pleasurable emotions needed verification and further exploration. Chapter 4 examined tension; how it is evoked by EDM break routine structures and its specific role in peak-pleasurable emotions. Continuous slider and single 2-dimensional space ratings were used to measure tension and peak-pleasurable emotions. Findings showed a significant correlation between tension and break routine time, indicating that tension increased across build-up passages and decreased within drop passages.

Peak tension levels correlated with 2-dimnesional space ratings of arousal, emotional strength, emotional response, and negative valence, suggesting less peak-pleasurable emotions with greater tension. Instead, 2-dimensional space ratings measured continued feelings of tension after break routines, suggesting tension did not fully decrease in drop passages and peak-pleasurable emotions were not evoked. Therefore, tension levels altered across EDM break routines as expected, with increases during build-up passages and decreases within expected drop passages. However, how tension mediates peak-pleasurable emotions from fulfilled drop passage expectations is less clear.

Tension Patterns

As discussed in earlier chapters, expectancy and tension are linked through music structure in key peak-pleasurable emotion theories, including ITPRA (Farbood, 2012; Huron, 2006; Meyer, 1956). Regular structures in music enable expectations, which can be delayed, violated, or fulfilled to induce tension and peak-pleasurable emotions (Egermann et al., 2013; Huron, 2006; Lehne et al., 2012; Lerdahl & Krumhansl, 2007; Meyer, 1956). Music creators (including EDM composers and DJ’s) manipulate structure and expectations to build or reduce tension levels (Butler, 2006; Solberg, 2014; Solberg & Dibben, 2019). Intensifying tension within EDM break routine build-up passages arises from delayed expectations and increasing uncertainty around how and when expected drop passages will occur. When drop passage expectations were correctly fulfilled tension then decreased (Butler, 2006; Huron, 2006; Meyer 1956; Solberg, 2014; Solberg & Dibben, 2019; Turrell et al., 2021). Therefore, EDM break routine structures were effective at manipulating expectations to alter tension levels, demonstrating that tension, structure, and expectations are interdependent.

Increased tension during EDM break routine build-up passages before decreases in drop passages also validated previous research suggesting tension resolution patterns, such as tension curves, around expectations in music (Vines et al., 2005; You et al., 2021; see 'Tension During Break Routines' in Chapter 4). Tension curves propose that tension increases to peak levels before expected moments, where it then decreases to baseline levels as expectations are fulfilled (Turrell et al., 2021; Vines et al., 2005; Figure 4-7). EDM break routines magnified tension to peak levels during build-up passages with delay, anticipation, and uncertainty around expected drop passages (Butler, 2006; Huron, 2006; Meyer, 1956). Magnified tension levels may have increased the desire to resolve and release tension from fulfilling expected drop passages, making it more pleasurable when drop passages finally occurred (Eerola & Vuoskoski, 2011; Herremans & Chuan, 2017; Koelsch, 2014; Koelsch, 2015; Meyer, 1956; Sloboda & Juslin, 2001; You et al., 2021). Thus, EDM break routine structures can predictably change tension levels according to tension resolution patterns around moments of expectation, with increases during build-up passages and decreases within expected drop passages.

Tension & Emotion

Changes in tension levels across EDM break routines demonstrated the interconnectedness between structure, expectancy, and tension, but their influences on peak-pleasurable emotions needs more exploration. Previous research has shown expectancy and tension affect music-evoked emotions, as fulfilment of music expectations can evoke peak-pleasurable emotions, such as happiness, pleasure, and excitement (Butler, 2006; Egermann et al., 2013; Grewe et al., 2007; Huron, 2006; Lehne & Koelsch, 2015; Meyer, 1956). Chapters in this thesis have additionally suggested peak-pleasurable emotions evoked from fulfilled expectations can also be magnified by proceeding tension, according to contrastive valence (Huron, 2006; Solberg & Dibben, 2019; Turrell et al., 2021). Therefore, EDM break routines with greater tension during build-up passages should have increased peak-pleasurable emotions within expected drop passages.

However, increased tension did not evoke higher peak-pleasurable emotions in this study. Instead, greater arousal, emotional strength, emotional response, and valence ratings negatively correlated with increased tension, suggesting more negative emotions, such as further tension, after break routines. This demonstrated that tension can induce both positive and negative music-evoked emotions, including fear, stress, happiness, and excitement (Eerola & Vuoskoski, 2011; Lehne & Koelsch, 2015; Turrell et al.,2021). While tension may alter across break routines in accordance with expectancy (increases before and decreases after), this does not guarantee peak-pleasurable emotions. This makes music structures, expectations, and tensions' influence on peak-pleasurable emotions more ambiguous.

Negative correlations between tension levels and peak-pleasurable emotion ratings were suggested to represent continued tension during EDM break routine drop passages, implying tension did not fully decrease to baseline levels after drop passage expectations were fulfilled. Tension resolution patterns indicate that for peak-pleasurable emotions to occur, tension needs to be fully resolved and decrease back to baseline levels (Koelsch, 2014; Sun et al., 2020a; Vines et al., 2005). Due to shorter EDM break routine drop passages (6 seconds), tension may not have been fully resolved in our stimuli, meaning it did not decrease to baseline levels and was still present after break routine clips (explaining peak-pleasurable emotion ratings for more negative emotions; Lehne & Koelsch, 2015; Meyer, 1956; Sun et al., 2020a; see Figure 4-4). Thus, resolved tension resolution patterns may be necessary for peak-pleasurable emotions, suggesting decreased tension after expected drop passages are just as influential as increased tension before expectations.

Chapter 4 attempted to show the extent of tension's individual effects on peak-pleasurable emotions. Results suggested tension can magnify peak-pleasurable emotions evoked by other ITPRA factors, including prediction and expectancy, but only when tension resolution patterns are fully resolved (Huron, 2006; Meyer, 1956). This further suggested an interdependence between music structure, expectations, and tension in evoking peak-pleasurable emotions. Thus, tension may impact peak-pleasurable emotions from EDM break routines, by magnifying pleasurable responses during fulfilled expected drop passages. However, peak-pleasurable emotions were not seen to the same extent as in Chapter 2 and 3, perhaps due to increased tension from greater focus during continuous tension scale ratings (Lehne & Koelsch, 2015; Williams et al., 2011). This made it less clear how expectations and tension created across EDM break routine structures interacted and influenced peak-pleasurable emotions.

Therefore, Chapter 4 demonstrated that EDM break routine structures facilitated drop passage expectations, which increased tension during build-up passages before reducing tension during expected drop passages. This again indicated EDM break routines' usefulness in assessing structure's, expectancy's, and tension's, influence of peak-pleasurable emotions. However, exactly how tension levels across EDM break routine structures correlated with peak-pleasurable emotions was less clear, as results suggested continued tension during drop passages rather than magnified peak-pleasurable emotions.

The Role of Brain Activity

As previous chapters have indicated, break routine structures of intensifying tension during build-up passages prior to expected drop passages regulate MFG and PMC activity and can evoke peak-pleasurable emotions (Huron, 2006; Koelsch, 2014; Lehne & Koelsch, 2015; Meyer, 1956; Osnes et al., 2012; Solberg & Dibben, 2019; Solberg & Jensenius, 2017; Turrell et al., 2021). However, they did not determine how MFG and PMC activity caused peak-pleasurable emotions during EDM break routines. Chapter 5 used transcranial direct current stimulation (tDCS) to investigate the causational role of MFG and PMC activity on EDM break routine structure processing and peak-pleasurable emotions. Findings showed that anodal PMC stimulation decreased peak-pleasurable emotion ratings of emotional response, while anodal MFG stimulation decreased valence and emotional strength ratings. This suggested MFG and PMC activity influenced peak-pleasurable emotions during EDM break routines, but that effects were indirect and mediated by music factors, including structure, expectations, and tension.

Direct Role of the MFG & PMC

Previous research suggested direct links between MFG and PMC activity and peak-pleasurable emotions and their dimensions, such as happiness, liking, excitement, joy, and valence (Altenmüller et al., 2014; Brattico et al., 2011; Koelsch et al., 2006; Pereira et al., 2011; Sammler et al., 2007; Shinkareva et al., 2020; Tabei, 2015; Trost et al., 2012; Turrell et al., 2021). However, anodal MFG and PMC stimulation reduced ratings of valence, arousal, and emotional angle away from peak-pleasurable emotions during EDM break routines. Therefore, greater MFG and PMC activity may not directly cause peak-pleasurable emotions. Instead, other music factors, such as structure, expectancy, and tension, may mediate MFG and PMC activity's emotional effects during EDM break routines, suggesting more indirect links between brain activity and peak-pleasurable music-evoked emotions.

Indirect Role of the MFG & PMC

Discovered patterns of PMC and MFG activity during EDM break routines alluded to their involvement in different ITPRA factors across build-up and drop passages. As discussed in previous chapters, greater PMC activity during build-up passages increased tension levels prior to expected drop passages, whereas higher MFG activity induced peak-pleasurable emotions when drop expectations were fulfilled (Turrell et al., 2021; Turrell et al., in submission, c). Both anodal MFG and PMC stimulation influenced peak-pleasurable emotions but perhaps through different ITPRA factors during different EDM break routine passages.

PMC stimulation could have reduced tension levels during build-up passages, decreasing the contrastive valence between prior negative tension and peak-pleasurable emotions during expected drop passages (Huron, 2006; Meyer, 1956). Meanwhile, MFG stimulation could have altered break routine structure processing, reducing the expectancy of drop passages and decreasing peak-pleasurable emotions from their fulfilment (Butler, 2006; Margulis, 2005; Meyer, 1956; Osnes et al., 2012; Solberg & Dibben, 2019). Therefore, MFG and PMC activity may causally but indirectly influence EDM break routine structures, altering expectancy and tension levels that then mediate peak-pleasurable emotions

The MFG and PMC are also interconnected and part of a wider neural network, meaning their activity may influence each other during EDM break routines and peak-pleasurable emotions (Koelsch, 2014; Rogenmoser et al., 2016; Schaefer, 2017; Turrell et al., 2021; Turrell et al., in submission, c). This suggests that PMC activity alongside increasing tension during build-up passages then altered MFG activity during fulfilled expected drop passages. Stimulation to the PMC may have not only decreased tension levels during build-up passages, but also changed the amount of MFG activity and consequently the perception of expected drop passages. Therefore, in addition to the interconnectedness between EDM break routine structures, expectations, and tension, connections between induced PMC and MFG activity may have intertwined to affect the processing of structures, expectations, and tension, which then mediated peak-pleasurable emotions.

Neural interconnections between the PMC and MFG during EDM break routines also involves numerous other brain areas, including the amygdala, orbitofrontal cortex, PCUN, and IFG (Koelsch, 2014; Rogenmoser et al., 2016; Schaefer, 2017; Turrell et al., 2021). This suggests the involvement of a larger, interconnecting brain network when processing music structure, expectancy, tension, and ensuing peak-pleasurable emotions, which is considered further in Chapter 5’s discussion section (Koelsch, 2018; Koelsch et al., 2006; Lehne et al., 2014). For example, arousal ratings did not differ between MFG and PMC stimulation conditions but did change across EDM break routine passages as tension and expectancy altered. This may suggest activity in other interconnected brain areas, such as the amygdala, PFC, and nucleus accumbens influenced EDM break routine structures and arousal (Rogenmoser et al., 2016; Shany et al., 2019; Trost et al., 2012; Trost et al., 2015; Turrell et al., 2021). Therefore, MFG and PMC activity could indirectly influence peak-pleasurable emotions through their interconnectivity with other brain areas involved in the processing of EDM break routine structures.

Greater MFG and PMC activity are also involved in higher-level cognitive functions influential to peak-pleasurable emotions, such as attention, recognition, and engagement (Blood & Zatorre, 2001; Koelsch, 2006; Koelsch, 2014; Västfjäll, 2001; Van Den Bosch et al., 2013). Higher EDM break routine attention and engagement could mediate drop passage expectations, altering tension levels during build-up passages and ensuing peak-pleasurable emotions from fulfilled drop expectations (Huron, 2006; Margulis, 2005; Meyer, 1956; Solberg, 2014; Solberg & Dibben, 2019). Anodal MFG and PMC stimulation could have influenced listeners attention and engagement with EDM break routines, changing the processing of break routine structures, expectancy, and tension, as well as resulting peak-pleasurable emotions. This again suggests MFG and PMC’s influence on peak-pleasurable emotions is indirectly through the altered processing of EDM break routine structures, expectancies, and tension.

Anodal PMC and MFG stimulation reduced peak-pleasurable emotions, confirming their causational role, but suggesting greater activity does not directly increase peak-pleasurable emotions. Rather PMC and MFG activity indirectly influenced peak-pleasurable emotions by altering the perception of EDM break routine structures. Previous studies from earlier thesis chapters alluded to the PMC’s and MFG’s causational roles in EDM break routine processing and peak-pleasurable emotions. Greater PMC activity during build-up passages points to its involvement in altering tension levels, which may have decreased with anodal stimulation (Koelsch, 2014; Osnes et al., 2012; Turrell et al., 2021). While higher MFG activity within drop passages suggests its involvement in processing and determining fulfilled expectations, which may have changed with anodal stimulation (Koelsch, 2011; Koelsch & Siebel 2005; Osnes et al., 2012; Turrell et al., 2021). This clarified that PMC and

MFG activity can indirectly evoke peak-pleasurable emotions, through the perception of EDM break routine structures that first intensify tension before fulfilling expectations.

Clinical Applications

As we have shown, EDM break routines can reliably induce peak-pleasurable emotions due to their structure of tension and expectancy, demonstrating their potential usefulness in therapeutic settings. This is particularly important considering the increase in mental health difficulties, with 43.4% of adults in the UK believing they have a disorder and 19.5% of males and 33.7% of females having a professional diagnosis (Mental Health Foundation, 2016; Stansfeld et al., 2016). Additionally, current mental health therapies are often inadequate, inaccessible, and ineffective (Carta et al., 2013; Mago et al., 2018; Tracy et al., 2016), suggesting a need for more effective and reachable forms of treatment, such as music (Mental Health Foundation, 2016; McCrone et al., 2008). Therefore, there is great potential for interventions that are accessible and easy to deliver, such as music-based interventions. Indeed, more than 69% of young adults and those with higher depression or anxiety, already report using music when managing emotions for significant events, such as loss and consolation, demonstrating music's usefulness (Achterberg et al., 2011; ter Bogt et al., 2017).

Pleasant musical melodies are already used as therapeutic tools in several mental health disorders, such as schizophrenia, obsessive compulsive disorder (OCD), and depression; reducing symptoms and improving overall rehabilitation for up to 3 months (Erkkilä et al., 2011; Fachner et al., 2013; Kavak et al., 2016; Kayashima et al., 2017; Lee et al., 2016; Silverman, 2016; Trimmer et al., 2016; Zhao et al., 2016). Music's beneficial effect in disorders, such as depression, can also be seen in longitudinal activity alterations in music-evoked emotion brain areas, including the amygdala, hippocampus, frontal cortex, and right temporoparietal alpha for up to 3 months (Fachner et al., 2013; Hou et al., 2017; Lee et al., 2016; Leonardi et al., 2018; Misuraca et al., 2017; Vik et al., 2018). EDM break routines' ability to evoke peak-pleasurable emotions, alongside MFG, SFGL, PMC, and PCUN activity, may make them particularly helpful within therapeutic settings for disorders, such as depression.

Future Directions

Definitions of emotional dimensions, such as tension, arousal, and emotional strength are often underdefined and less clear in research, with investigators relying on participants' own created descriptions, there being numerous commonalities between dimensions, and terms being used interchangeably (Farbood, 2012; Fredrickson & Coggiola, 2003; Juslin & Sloboda, 2011; Lehne et al., 2014). This makes music-evoked emotions more difficult to measure, including being able to separate and determine individual and combined effects (Juslin & Sloboda, 2011). Future research should attempt to establish more standardised definitions of emotion dimensions, such as tension, with clearer differentiations between them and further assessment of how they interact with one another.

The circumplex model was used throughout this thesis to measure peak-pleasurable emotions, as it was easily understood by participants and allowed for comparisons with previous music-evoked emotion research (Ilie & Thompson, 2006; Russell, 1980). However, as mentioned in Chapter 1, the circumplex model is also limited in its ability to capture all elements of emotions. For instance, it is less sensitive to changes in valence than arousal and has limited capacity to differentiate between distinct emotions which are close together in the space, thus potentially restricting conclusions to more easily measured and contrasting emotions (Eerola & Vuoskoski, 2012; Huq et al., 2010; Scherer, 2005; Song et al., 2016). Future research could apply more recent adaptations on the circumplex model, such as Scherer's circumplex model which include other dimensions, including tension and intensity to better understand how music structure affects specific peak-pleasurable emotions (Ilie & Thompson, 2006; Scherer, 2005; Schubert, 2007; Song et al., 2016; see Figure 1-2 for another dimensional model example).

Increased MFG and PMC activity, along with greater acoustic features during EDM break routines did not always evoke greater peak-pleasurable emotions. This suggests that relationships between EDM break routines, brain activity, and peak-pleasurable emotions are not always linear and positive, as greater levels in one does not mean higher responses in another. Instead, similarly to the theory of contrastive valence, differential acoustic features and brain activity may be more influential to peak-pleasurable emotions (Huron, 2006; Sorinas et al., 2020; Yamanishi et al., 2011). This suggests break routines with greater contrasts between baseline and peak levels of acoustic features, as well as MFG, SFGL, PMC, and PAnG activity increased peak-pleasurable emotion ratings of valence, arousal, emotional strength, and emotional response (Alluri et al., 2013; Brattico et al., 2011; Casey, 2017; Hoenig et al., 2011; Kim et al., 2017; Turrell et al., 2021). Future research could examine contrasts in music further, exploring the extent differential brain activity and acoustic features magnified subsequent peak-pleasurable emotions.

Links between music-evoked emotions and brain activity can also be clarified with the exploration of physiological responses. Brain activity in the amygdala, nucleus accumbens, insula, ventromedial prefrontal cortex, somatosensory cortex, hypothalamus, and orbitofrontal cortex influence music-evoked emotions, such as pleasure, and physiological changes, including heart rate variability and skin conductance (Johnsen et al., 2009; Huron, 2006; Menon & Levitin, 2005; Scherer & Zentner, 2001; Thayer et al., 2012). Research has shown increased heart rate variability evokes greater calmness, cheerfulness, and emotional regulation and well-being, as well as increased brain activity and connectivity within emotional areas, such as the medial prefrontal cortex, caudate nucleus, and insula (Geisler et al., 2010; Lane et al., 2009; Mather & Thayer, 2018). Thus, future research could assess the relationship between music-evoked emotions, specific brain activity, and physiological responses further using physiological measures.

Previous research has shown gender and individual differences in musical preference, familiarity, engagement, and training correlates with music-evoked emotions (such as happiness), emotional dimensions (including valence and strength), as well as brain activity in the MFG, PMC, and reward circuits (Altenmüller et al., 2014; Flannery & Woolhouse, 2021; Freitas et al., 2018; Hunter et al., 2011; Koelsch et al., 2003; Ladinig & Schellenberg, 2012; Lundqvist et al., 2009; Pereira et al., 2011; Schubert, 2010; Swaminathan & Schellenberg, 2015; also see ‘Future Directions’ in Chapter 3). These can also affect listeners perception of music structures, creating different levels of tension and expectancy, which can then alter resulting peak-pleasurable emotions (Huron, 2006; Lehne & Koelsch, 2015; Van Den Bosch et al., 2013). While such factors were arbitrarily measured in our studies, showing an overrepresentation of females in our sample, no in-depth analysis was conducted as it fell outside the scope of this thesis. Future research could clarify how gender and listener preferences for, and previous engagement with, EDM break routine structures influences peak-pleasurable emotions, as well as relating brain activity, by incorporating more balanced samples and measures like Goldsmiths Musical Sophistication Index and the Short Test of Music Preferences (STOMP; Müllensiefen et al., 2014; Rentfrow & Gosling, 2003).

EEG was our chosen neuroimaging method due to its ability to capture high temporal information; important for comparisons between one second during build-up and drop break routine passages, along with 3D source reconstruction analysis to enable explorations of structural brain activity (Nunez et al., 2016; Read & Innis, 2017). However, the single use of one neuroimaging method and analysis may have limited our conclusions. Further research could apply other neuroimaging techniques or a combination of techniques, such as functional magnetic resonance imaging (fMRI) and community structure analysis, other EEG analysis methods like independent component analysis, as well as additional stimulation studies looking at causal links between different brain areas and music-evoked emotions (Ferreri & Rossini, 2013; Hou et al., 2017; Wilkins et al., 2014; Lin et al., 2014a; 2014b; Roy et al., 2014). This would clarify the exact functioning of brain activity (including the MFG, SFGL, PMC, and PAnG) and how they are interconnected during music structure processing and emotions (Hou et al., 2017; Koelsch et al., 2014; Omar et al., 2011; Wilkins et al., 2014). Thus, further explaining the extent MFG and PMC activity influenced break routine structure processing, tension, and expectancy, which then mediated peak-pleasurable emotions.

EDM break routines' ability to consistently evoke similar peak-pleasurable emotions, alongside MFG, SFGL, PMC, and PCUN activity demonstrated their potential in music-evoked emotion research. This proved multiple music genres containing intensifying tension during build-up passages prior to highly expected drop passages can be used to successfully research peak-pleasurable emotions (Turrell et al., 2021; Turrell et al., in submission, c). This should encourage researchers to use wider music ranges in research, reducing the current overreliance on western, classical, and specifically created simple music (Omigie, 2016; Schutz, 2017; Seger, 2009; Seger et al., 2013). By exploring emotional effects in wider varieties of music, influences of structure, expectancy, and tension can be better understood, enabling a greater understanding of peak-pleasurable emotions.

Conclusions

Through a series of four studies, this thesis has further investigated music structure, expectation, and tension's effects on peak-pleasurable emotions. Findings support previous theories of expectancy and ITPRA, suggesting structure is central to establishing expectations and tension which then result in peak-pleasurable emotions (Huron, 2006; Meyer, 1956). EDM break routines were repeatedly shown to increase peak-pleasurable emotion ratings of valence, arousal, emotional strength, and emotional response, alongside relating brain activity due to their structure of build-up and drop passages (Solberg & Dibben, 2019; Turrell et al., 2021). Structures of EDM break routines delayed expected drop passages by intensifying tension and increasing PMC activity during build-up passages, before finally fulfilling expected drop passages and evoking peak-pleasurable emotions alongside MFG activity (Turrell et al., in submission, b; Turrell et al., in submission, a). Multiple music genres containing structures of intensifying tension before expectations induced peak-pleasurable emotions and specific patterns of MFG and PMC activity (Turrell et al., in submission, c). Results have clarified the extent music structures, creating expectancy and tension, influences peak-pleasurable emotions, using EDM break routines. We suggest an interdependence between factors, which can be mediated by MFG and PMC activity, evokes peak-pleasurable emotions. Future research should attempt to further unravel the influences of structure, tension, expectancy, and brain activity on peak-pleasurable emotions, as well as attempt to use break routines in therapeutic settings

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Appendices

Appendix A

An example of the online Qualtrics questionnaire used to collect demographic data.

University of Kent | School of Psychology

Please enter your participant code in the box provided below

This included the first three letters of your last name and the town you were born
For example, if your last name is Smith and you were born in Birmingham your participant code would be 'smibir'

Please state your gender

- Male
- Female
- Transgender
- Other
- Prefer not to say

Please state your ethnicity

- White
- White European
- Asian
- Black
- Black European
- Other
- Prefer not to say

Please state your age

How many years of experience (if any) do you have of playing a musical instrument?

- ◯ I do not play an instrument
- ◯ 0-1 years
- ◯ 1-3 years
- ◯ 3-5 years
- ◯ 5-7 years
- ◯ 7-9 years
- ◯ 9 years or more

What type(s) of instrument have you played?

How often on average do you hear classical music or songs similar to the clips heard today?

- ◯ I never hear classical songs like those in the clips
- ◯ I rarely hear classical songs like those in the clips
- ◯ I sometimes hear classical songs like those in the clips
- ◯ I often hear classical songs like those in the clips

How often on average do you hear dance music or songs similar to the clips heard today?

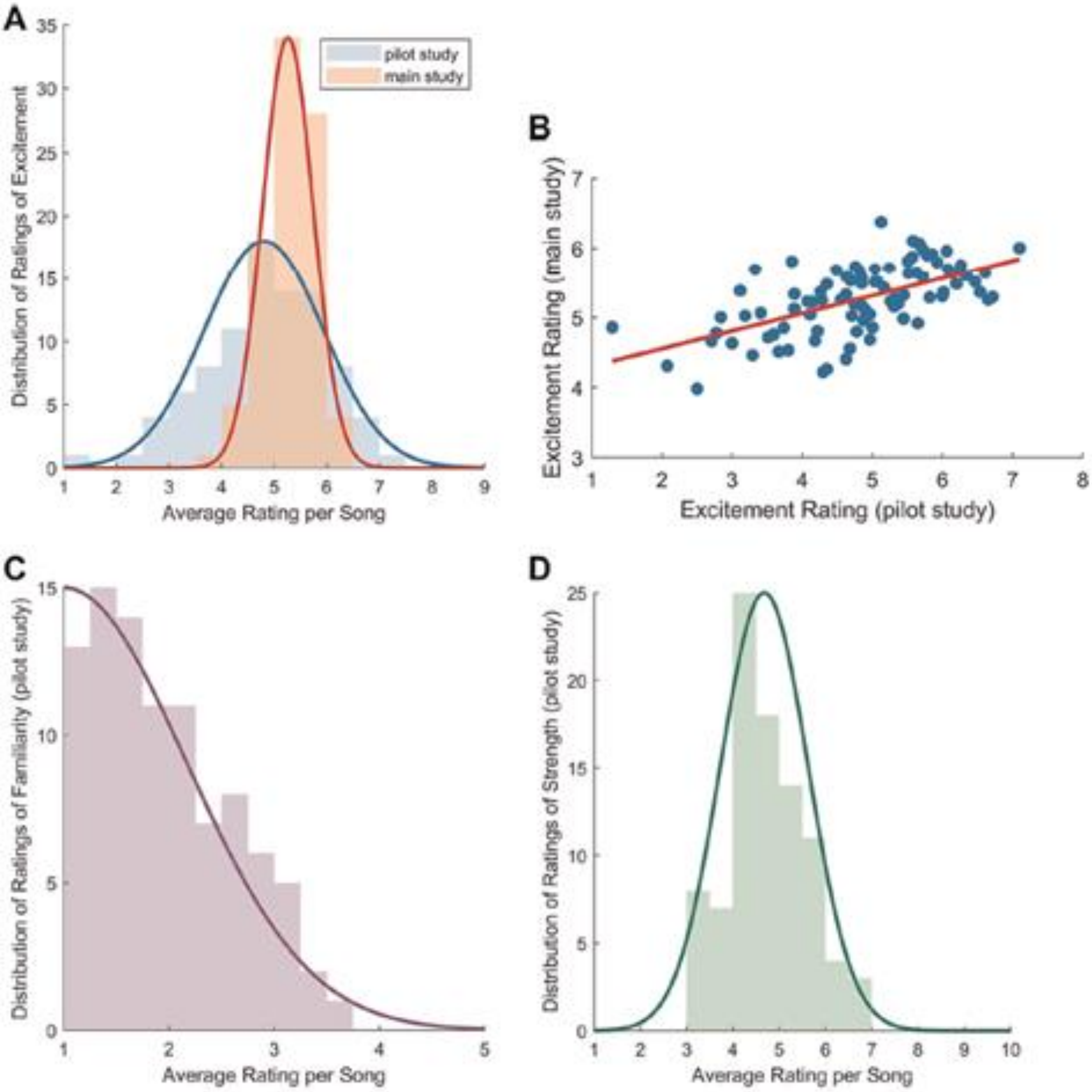
- ◯ I never hear dance songs like those in the clips
- ◯ I rarely hear dance songs like those in the clips
- ◯ I sometimes hear dance songs like those in the clips
- ◯ I often hear dance songs like those in the clips

How often on average do you hear Drops (*a moment of build in musical features, such as tempo, rhythm and frequency, then stop/slow and change*) similar to the clips heard today?

- ◯ I never hear Drops like those in the clips
- ◯ I rarely hear Drops like those in the clips
- ◯ I sometimes hear Drops like those in the clips
- ◯ I often hear Drops like those in the clips

Appendix B

The distribution plots of familiarity and strength ratings for the 180 piloted break routine clips (Figures C and D), as well as excitement ratings for the piloted 180 clips compared to the 90 break routine clips used in Chapter 2's main experiment (Figures A and B).

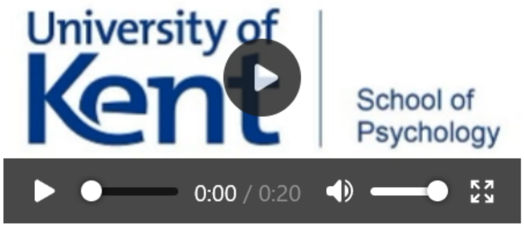


Appendix C

Sample of Questions from the online Qualtrics questionnaire used to pilot classical stimuli in Chapter 3.

University of Kent | School of Psychology

Please listen to the music clip below carefully and in its entirety **before** answering the questions



How familiar did you find the music in the clip you just heard?

- ○ Not familiar at all
- ○ Slightly familiar
- ○ Moderately familiar
- ○ Very familiar
- ○ Extremely familiar

How strong would you rate the musical change in the clip you just heard?

- ○ Not strong at all
- ○ Slightly strong
- ○ Moderately strong
- ○ Very strong
- ○ Extremely strong

How similar would you rate the musical change in the clip you just heard to a Drop in dance music?
A Drop refers to the moment in dance music where music features rapidly build and increase to a point where it stops and or slows to then dramatically change

- ○ Not at all like a Drop
- ○ Slightly like a Drop
- ○ Moderately like a Drop
- ○ Very much like a Drop
- ○ Extremely like a Drop

How aroused did you feel when you listened to the above clip?

- ○ Not aroused at all
- ○ Slightly aroused
- ○ Moderately aroused
- ○ Very aroused
- ○ Extremely aroused

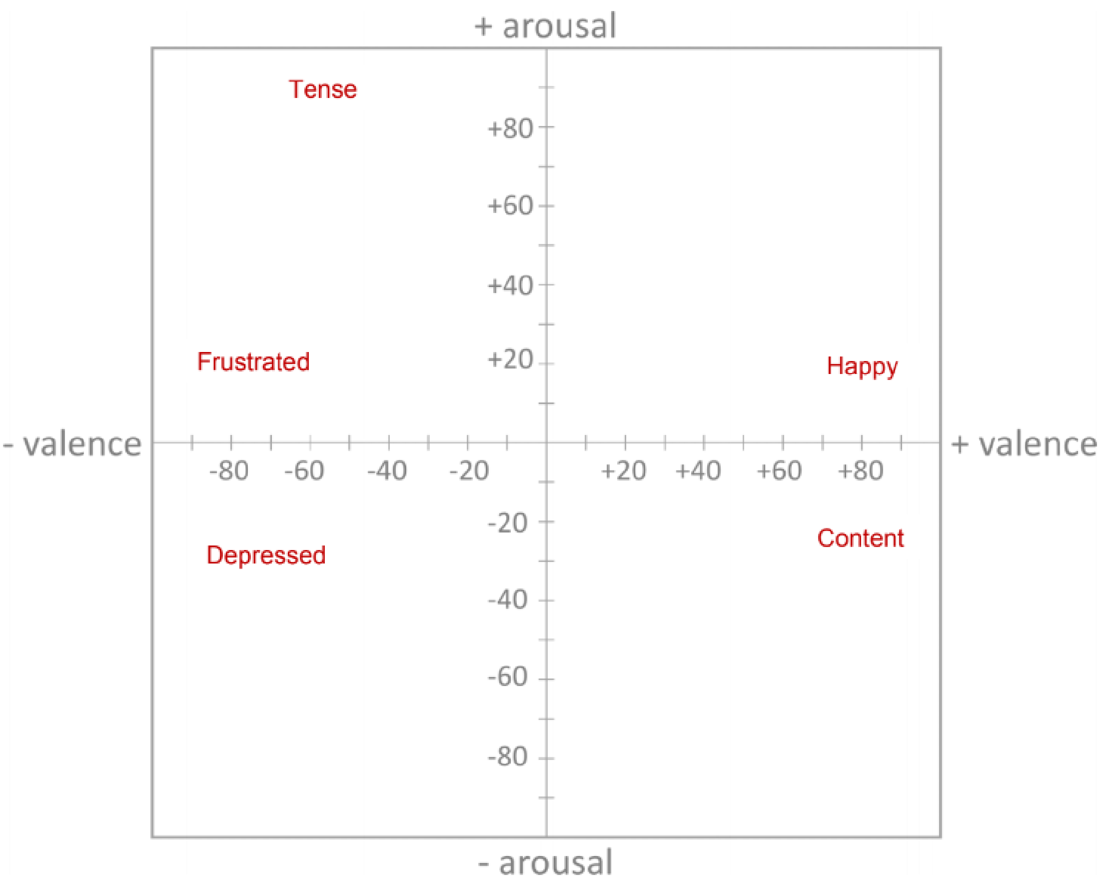
How positive did you feel when you listened to the above clip?

- ○ Very negative
- ○ Moderately negative
- ○ Neither negative or positive
- ○ Moderately positive
- ○ Very positive

Appendix D

The pen and paper training given to participants to better understanding of the 2-dimensional space response screen in Chapter 3.

Point 1	Valence 100	Arousal 0
Point 2	Valence 100	Arousal 100
Point 3	Valence 100	Arousal -100
Point 4	Valence -100	Arousal 100
Point 5	Valence 50	Arousal 50
Point 6	Valence -50	Arousal -100

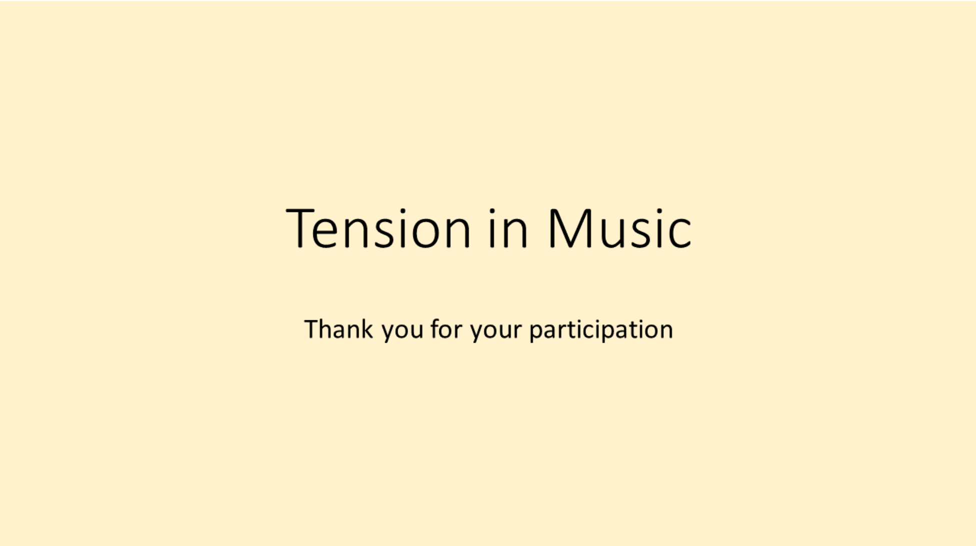


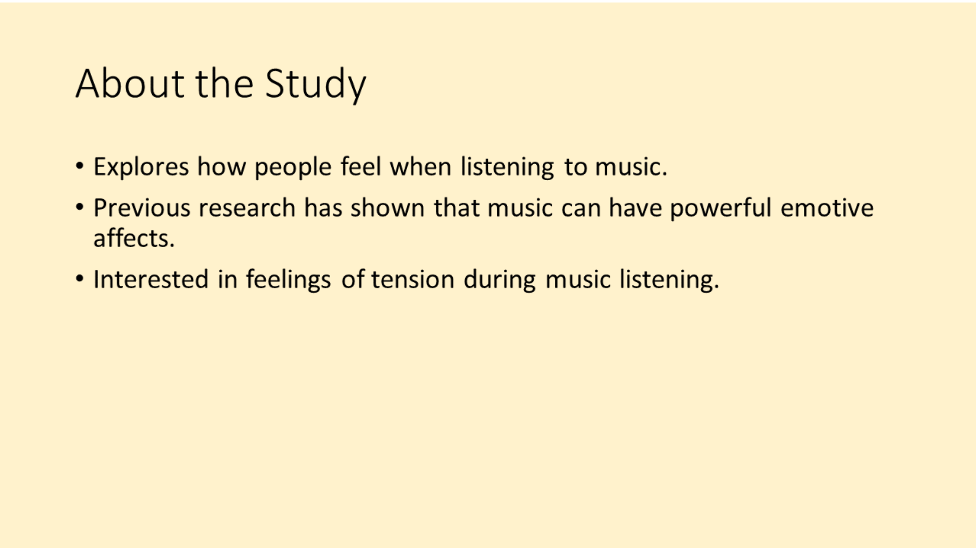
Where do you think the following emotions are in the 2-dimensional space above?

1. Excited
2. Tired
3. Calm

Appendix E

The PowerPoint instructions provided to each participant during the online study in Chapter 4.



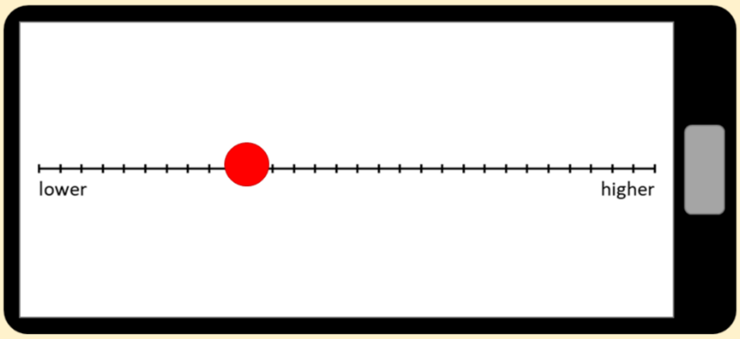


What you will need to do

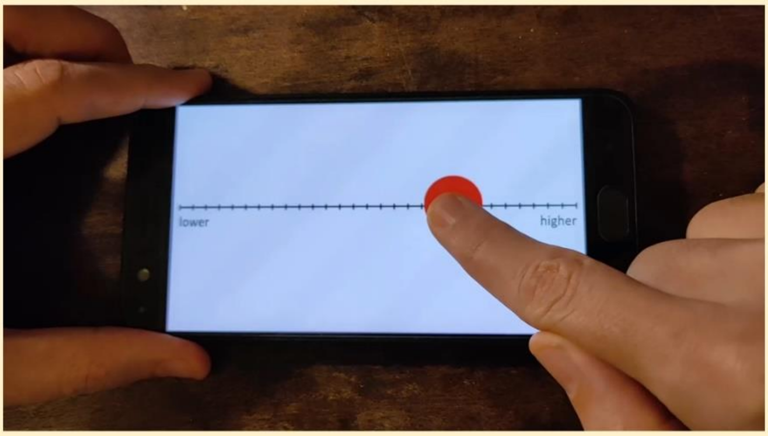
- A brief online questionnaire.
- The music task;
  - Listen to 60 music clips via ear/headphones and rate continuous levels of tension.
  - Record felt levels of valence and arousal using a 2-dimensional space.
- The whole experiment will take approximately 50-60 minutes.

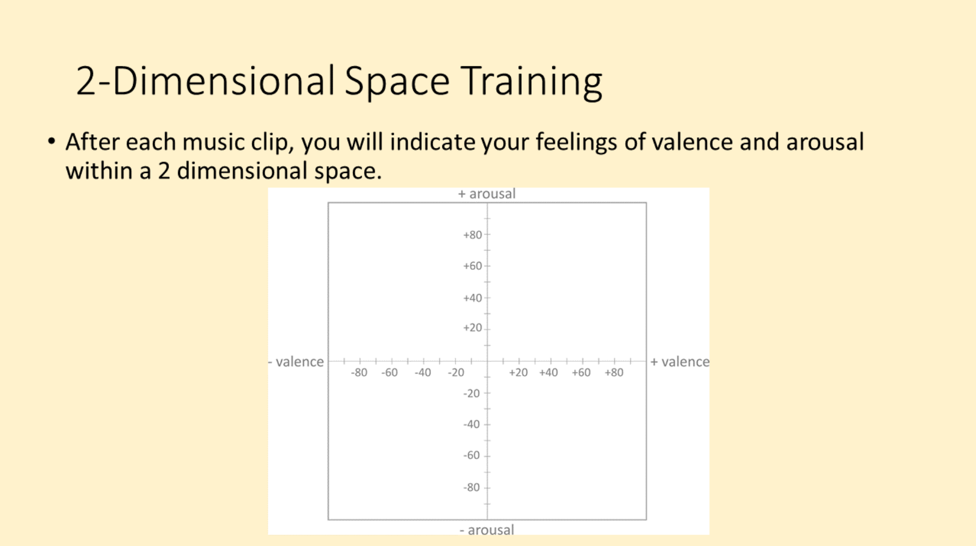
- Please stay on Zoom with your camera on for the entirety of the experiment.

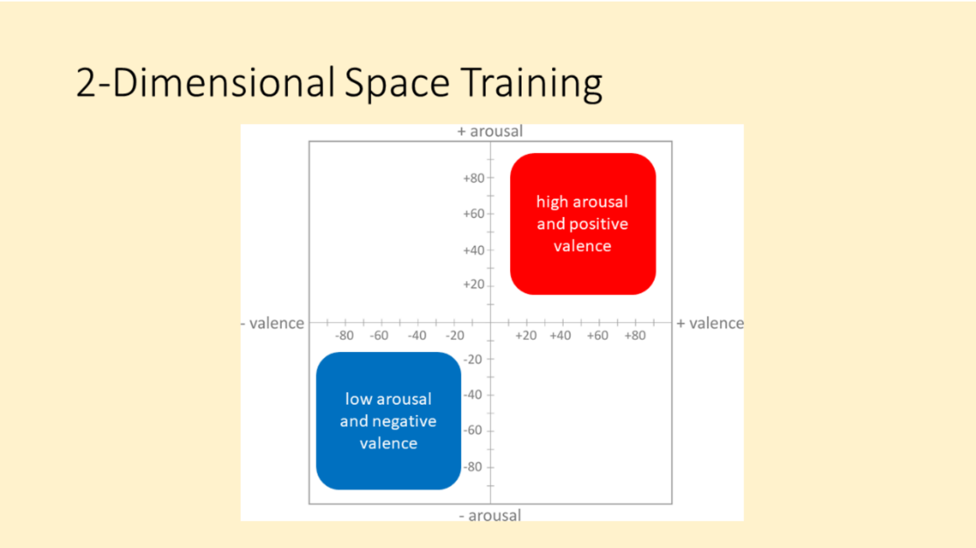
Continuous Tension Ratings Training

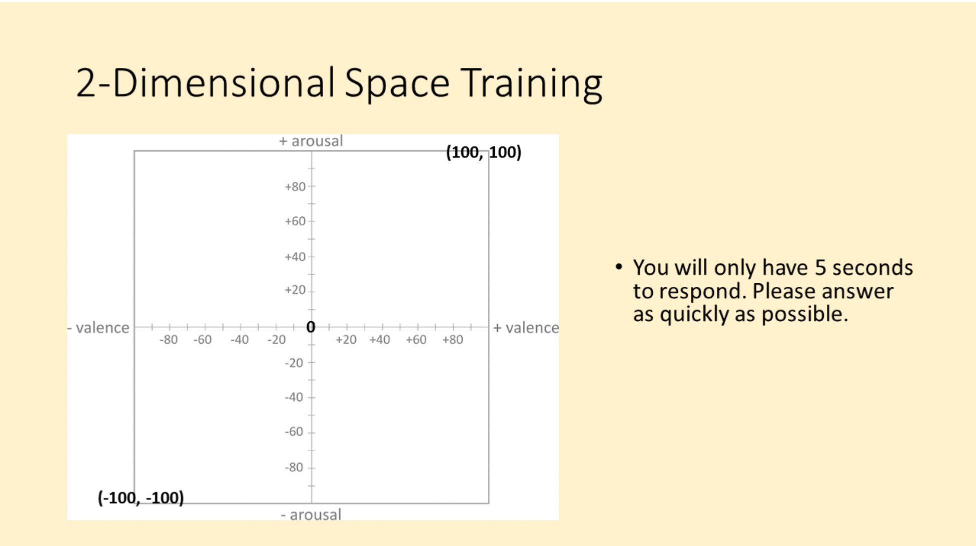


Continuous Tension Ratings Practice




2-Dimensional Space Training
• After each music clip, you will indicate your feelings of valence and arousal within a 2 dimensional space.
+ arousal
+80
+60
+40
+20
- valence
-80 -60 -40 -20
+20 +40 +60 +80
+ valence
-20
-40
-60
-80
- arousal

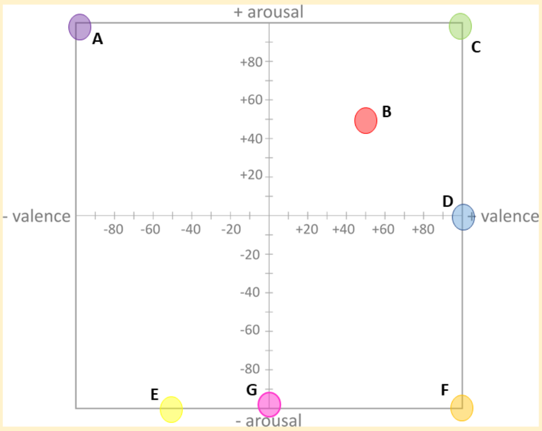

2-Dimensional Space Training
+ arousal
+80
+60
+40
+20
high arousal and positive valence
- valence
-80 -60 -40 -20
+20 +40 +60 +80
+ valence
-20
-40
-60
-80
low arousal and negative valence
- arousal


2-Dimensional Space Training
+ arousal
(100, 100)
+80
+60
+40
+20
- valence
0
-80 -60 -40 -20
+20 +40 +60 +80
+ valence
-20
-40
-60
-80
(-100, -100)
- arousal
• You will only have 5 seconds to respond. Please answer as quickly as possible.

2-Dimensional Space Practice

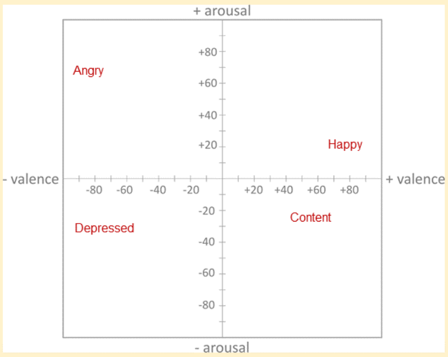
- Match each point of arousal and valence below with a lettered circle within the 2-dimensional space.

Point 1	Valence 100	Arousal 0
Point 2	Valence 100	Arousal 100
Point 3	Valence 100	Arousal -100
Point 4	Valence -100	Arousal 100
Point 5	Valence 50	Arousal 50
Point 6	Valence -50	Arousal -100



2-Dimensional Space Training

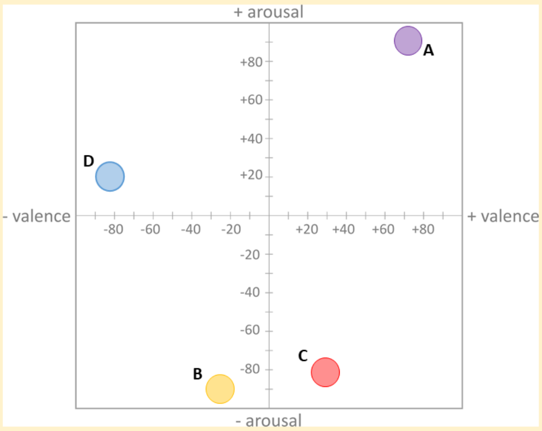
- Certain labels of emotion can be placed on the 2-dimensional space according to their levels of valence and arousal.



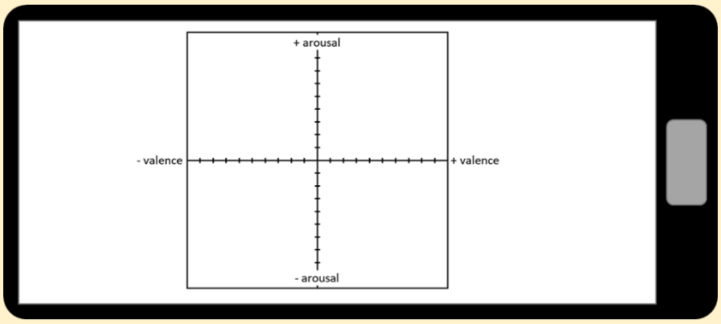
2-Dimensional Space Practice

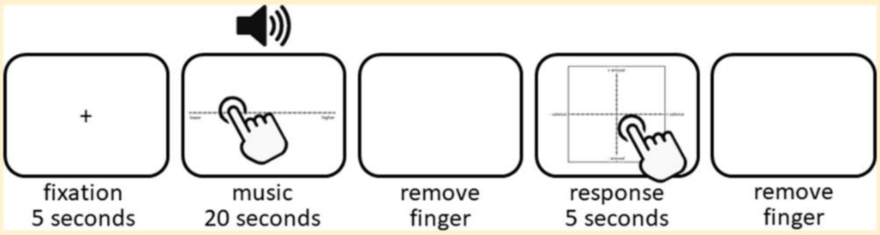
- Match each emotion below with a lettered circle within the 2-dimensional space, according to their values of arousal and valence.

1. Tired
2. Excited
3. Calm



2-dimensional Space





Any Questions?

Go to Qualtrics on your Mobile

Please open a web browser (Chrome, Safari, Firefox...)

Go to this address: tinyurl.com/tensionstudy

Once finished DON'T close the Qualtrics webpage

If you are ready, continue on your mobile

The link is displayed on the final page of the Qualtrics questionnaire. You need to tap on that.

Thank you

- A debrief will be emailed to you.