The Dynamic Functional Capacity Theory and Music-Evoked Emotions: A Temporal-Dynamic Neuroaffective Model For Understanding Music’s Ability to Elicit Intense Emotions

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Abstract

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The music-evoked emotion literature implicates many brain regions involved in emotional processing but is currently lacking a model that specifically explains how they temporally and dynamically interact to produce intensely pleasurable emotions. A conceptual model, The Dynamic Functional Capacity Theory (DFCT), is proposed that provides a foundation for the further understanding of how brain regions interact to produce intense intensely pleasurable emotions. The DFCT claims that brain regions mediating emotion and arousal regulation have a limited functional capacity that can be exceeded by intense stimuli. The prefrontal cortex is hypothesized to abruptly deactivate when this happens, resulting in the inhibitory release of sensory cortices, the limbic system, the reward-circuit, and the brainstem reticular activating system, causing ‘unbridled’ activation of these areas. This process produces extremely intense emotions. This theory may provide music-evoked emotion researchers and Music Therapy researchers a theoretical foundation for continued research and application and also to compliment current theories of emotion.
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Introduction

A growing body of neuroscience literature consistently shows that brain structures associated with emotions and motivation can be modulated by listening to music (Blood & Zatorre, 2001; Koelsch, 2006; Ball et al., 2007) and that their activity is correlated with varying levels of emotional intensity, also referred to as emotional arousal. Regions involved in this process include subcortical and limbic structures such as the amygdala and hippocampus; the ‘reward-circuit’ including the ventral tegmental area (VTA), the nucleus accumbens (nAC), the striatum, and the orbitofrontal cortex (OFC); and the temporal, parietal, and prefrontal cortices (Peretz, 2001). In the music-evoked emotion literature, reports of specific regions of cerebral activity are abundant, and recently, progress has been made to identify functional connections between them (Schmidt, & Trainor, Fritz & Koelsch, et al., 2007) using connectivity analyses such as electroencephalogram (EEG) coherence and functional magnetic resonance imaging (fMRI). While this has led to the proposal of several neural networks that mediate musical-emotions, current theories of emotion may fail to take a global and integrative theoretical approach to the dynamic relationship between music, emotion, and cerebral activation, across time as emotions develop and intensify. Additionally, current theories of emotion may fail to explain perhaps music’s most sustaining quality: its ability to profoundly impact our emotions by instilling intensely positive feelings of euphoria and bliss, often described as “chills” or “thrills” (see Blood and Zatorre, 2001).

Current emotion theories referred to in the music and emotion literature such as the Valence Hypothesis (Tomarken, Davidson, Henriques, 1990; see Demaree, Everhart, Youngstrom, & Harrison, 2005) and the Right Hemisphere model (Bowers, Bauer, Heilman, 1993), as well as neuropsychological theories of emotion in general, may not fully appreciate the
dynamics of cerebral interactions within a temporal domain that give rise to the most intense emotional experiences that often define the most pleasant experiences that an individual can experience (described as “peak emotions”, spiritual, and transcendental), and the most unpleasant emotions that often define psychological disorders. Specifically in regards to the intensely pleasurable emotions described as “chills” (see Blood & Zatorre, 2001) investigated in the music-evoked emotion research, the explanatory range and ability of the current emotion theories may be truncated for the following reasons: they appear to assume that emotional intensity and frontal lobe activation are linearly related (frontal lobe activation increases linearly with increasing emotional intensity) despite some evidence to the contrary (see Arnsten, 1998); these theories have been developed and are better suited to describe more stable, trait-like characteristics and mood rather than rapid, transient, and intense emotional development. The importance of temporal dynamics in that process is less emphasized or overlooked and they have generally used mild to moderate emotional provocation that is insufficient to evoke the intense emotions of interest here. Having evoked and observed these emotions less frequently, these theories may be ill suited to predict or explain the underlying brain mechanisms during their occurrence. Although some findings in the music-evoked emotion literature seem to fit the current emotion models, conflicting findings in regard to the cerebral lateralization of emotional valence and the relationship between emotional intensity and brain activation (Blood & Zatorre, 2001) indicate that the current theories may need revision in order to explain the full range of emotional intensity and experience. At this point in the development of music and emotion research, a neuropsychological theory of emotion that specifically addresses the previously mentioned theoretical short-comings may be beneficial to the growth of music and emotion research, music therapy (MT) research, and other potential clinical applications. The Dynamic
Functional Capacity Theory (DFCT; see Carmona, Holland, & Harrison, 2009; see also Harrison, 2015) described in this paper has been specifically developed to address these issues.

The music and emotion literature has received increasing interest from researchers, clinicians, from the general public (people are curious about how their favorite music affects their brain), and has matured over the last several decades to include neuroimaging techniques aimed at identifying brain regions and neural networks that mediate musical emotions. Despite this increasing technological sophistication, improvements in analyzing continuous emotions, and a movement towards identifying neural music-emotion networks, the underlying theories of emotion referenced in this literature has received less critical examination; theoretical development in this domain has not matched its rate of data output. In the Handbook of Music and Emotion, Juslin and Sloboda point out that, “the field is still mainly descriptive rather than hypothesis-driven, which may suggest that the field has not yet quite reached maturity”. This point will become more relevant later, and although this line of research may not appear to offer any real world impact beyond quenching experimental curiosity, findings from music and emotion research have a strong ability to inform clinicians about the relationship between brain and emotion, and its relationship to psychological, neuropsychological, and neurological well-being and disorder. This line of research and its potential clinical relevance for Music Therapy (MT) may benefit from a more theoretically, rather than data driven research approach. A clear example of this is music therapy; despite numerous encouraging results of MT with populations diverse as depression and stroke (Altenmuller et al., 2009), visual neglect (Soto, 2009), and Parkinson’s disease (Hoemberg, 2005), the lower quality of experimental methodology in MT research has made MT’s therapeutic value speculative (Koelsch, 2010), if not still intriguing. The development of MT research and application will depend on methodological improvements,
which in turn will hinge upon theoretical advances. In sum, current theories of emotion may not be able to fully explain the relationship between music, emotion, and brain. A better understanding of this can improve MT research methodology, and beyond this, can inform clinicians where intense pleasant and unpleasant emotions (positive and negative emotions associated with addiction, and negative with anxiety, depression, PTSD, respectively), are the cornerstones of their pathology.

The Dynamic Functional Capacity Theory (DFCT; see Carmona, Holland, & Harrison, 2009; see also Harrison, 2015) approaches the limitations of the current theories of emotion by proposing a neuropsychological model of emotion that: 1) proposes that the prefrontal cortex (PFC) has a physiological capacity for normal functioning that when exceeded, impairs the cognitive and regulatory functions subserved by it, 2) emphasizes temporal cerebral dynamic interactions as emotions develop over time and in intensity, 3) provides a cerebral model of emotional activation that includes four phases characterized by distinct, regional patterns of neural interaction and activation/deactivation, 4) proposes a nonlinear relationship between emotional intensity and frontal lobe activity that may further our understanding of the PFC’s role in mediating emotions and cognitive abilities, 5) and proposes an adaptive role for exceeding capacity while also providing evidence of several mechanisms and mediators that limit the PFC’s capacity to mediate emotions and cognitive abilities. This theory is especially suited to music and emotion research because of its temporal focus and because temporal and emotional dynamics are core features, if not necessary and inherent conditions, of music. The purpose of this dissertation is to test assumptions of the DFCT by regionally comparing the temporal dynamics of brain activity (EEG) during periods of varying levels of self-reported emotional intensity elicited by music. The music-evoked emotion literature will be briefly reviewed with
special emphasis on experimental investigations of the “chills and thrills” phenomenon in music, findings from experiments measuring cortical (EEG and MEG) and emotional responses to music and highlights of how these findings do not always fit the current theories of emotion. Following that, the DFCT will be introduced to the reader and the main assumptions of the theory will provide a rationale for this experiments methodology.

Music and Emotion

One of the seminal experiments investigating cerebral activation during intense emotional reactions to music was conducted by Blood and Zatorre in 2001. They found increased regional cerebral blood flow (rCBF) in the amygdala, anterior hippocampal formation, ventral striatum, midbrain, anterior insula, anterior cingulate cortex, and the orbital frontal cortex (OFC) during emotional responses to participants’ self-selected music that elicited intense emotional arousal. Participants described “chills” during intensely pleasurable emotional arousal. Decreases in blood-oxygen-level dependent (BOLD) at the right ventromedial PFC occurred when participants experienced these intense emotions, providing provisional evidence for a nonlinear relationship between emotional intensity and frontal lobe activity. Of note, rather than interpreting brain region activation/deactivation by using contrast analyses, a more detailed picture of brain dynamics may be obtained by comparing brain regions during distinct periods marked by varying levels of self-reported emotional intensity. Simply using “before and after” contrasts can wash out important temporal trends in the data as they relate to changes in emotional intensity, an issue which the DFCT directly addresses.

Other investigations found that the cortical structures involved in similar music-evoked processes include the orbital frontal cortex (OFC) (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Khalfa, Schon, Anton, & Liegeois-Chauvel, 2005; Menon & Levitin,
2005), the superior temporal cortex, posterior parietal lobe, and the anterior cingulate cortex (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez, & Evans, 1999; Mitterschiffthaler, Fu, Dalton, Andrew, & Williams, 2007; Green et al, 2008). In a shift from observing regions of activation towards identifying the connections between them that mediate music-evoked emotions, Flores-Gutierrez (2007) investigated functional connectivity with fMRI and EEG coherence simultaneously while participants listened to three musical masterpieces (2 pleasant, 1 unpleasant). A left cortical network was seen involved with pleasant feelings that included the left primary auditory area, posterior temporal, inferior parietal and prefrontal regions while a network involved in unpleasant emotions included activation of right frontopolar and paralimbic areas. All three music stimuli activated the superior temporal gyrus in both hemispheres but only pleasant musical emotions involved the left temporal gyrus and only unpleasant ones activated the right temporal gyrus. Areas of activation involving right cortical regions were found only for unpleasant emotions both with fMRI and EEG (OFC, cingulum, insula).

At first inspection, the cerebral lateralization of valence seen above generally supports the Valence Theory (Tomarken, Davidson, Henriques, 1990; see Demaree, Everhart, Youngstrom, & Harrison, 2005), which states that the left hemisphere is specialized for processing and expressing positive emotions and the right hemisphere specializes in expressing and processing negative emotions. Consistent with this, subjects exhibited greater left frontal EEG activity to joy and happy musical excerpts and greater relative right frontal EEG activity to fear and sad musical excerpts (Schmidt & Trainor, 1994). Further support for the valence hypothesis comes from ear-asymmetry experiments. Gagnon & Peretz (2000) found ear asymmetries in normal listeners when judging the pleasantness of tonal and atonal melodies; a left-ear superiority effect reflecting right hemisphere predominance was found when judging
atonal melodies as unpleasant, while a right ear advantage was found when judging tonal melodies as pleasant. However, ear-asymmetry research also supports the Right Hemisphere hypothesis, that is, right hemisphere involvement in the judgment of both positive and negatively valenced music was been demonstrated. Bryden and colleagues (1982) found a left-ear advantage in normal subjects when judging both major and minor melodies as expressing positive or negative emotions. Additionally, Blood, Zatorre, Bermudez, and Evans (1999) found that the neural structures activated by pleasant, consonant music were found primarily in the right hemisphere.

The evidence for cerebral lateralization of music-evoked emotion predicted by the Valence theory is mixed; sometimes left and right cerebral activation is seen with positive and negative music-evoked emotions respectively, and sometimes predominantly right cerebral activation is seen to both valences, particularly when intense emotions are induced. This highlights the significance of emotional intensity in music-evoked emotions, and perhaps emotions in general, in that the current theories appear unable to correctly predict cerebral lateralization when emotional intensity varies. Again, supportive evidence for these theories tends to come from experiments using mild to moderate emotional provocation (e.g., passive listening, judging the valence of music through dichotic listening, use of unfamiliar classical pieces) while the inconsistent cerebral lateralization of musical affect appears when emotional intensity is highest (during “chills”). This may indicate that the relationship between affective cerebral lateralization and frontal lobe activation is mediated by emotional intensity, such that moderately intense emotions will present with cerebral lateralization and activation consistent with the current theories, while intense pleasant and unpleasant emotions may not show the lateralization patterns predicted by the Valence Theory and Right Hemisphere Model. This may
also imply that frontal lobe activation emotional intensity are not linearly related; the DFCT proposes that the most intense emotional arousal are preceded by increased frontal lobe, brainstem, and sensory region activation, but are caused by abrupt PFC deactivation and disconnection from other brain regions. In contrast, the Valence theory relies mainly on the activation of frontal systems while providing less evidence for the role of posterior cerebral systems (e.g., temporal, parietal, occipital regions). Thus, the DFCT incorporates the mediating role of emotional intensity and extends to the full range of emotional arousal. It is not that the Valence Theory is wrong; instead it is argued here that the current theories of emotion do not account for the full range of emotional intensity.

A rival hypothesis to the Valence Theory is the ‘right hemisphere hypothesis’ for the processing of all emotions regardless of valence (Bowers, Bauer, Heilman, 1993), which can be attributed to Jackson (1878) who noticed that emotional language is often preserved in aphasic symptoms. In a review of the literature, Silberman and Weingartner (1986) concluded that the largest amount of consistency supported the right hemisphere as being dominant for processing and expressing emotion. In the music-evoked emotion research, evidence supporting the right hemisphere hypothesis has been found by Blood, Zatorre, Bermudez, and Evans (1999). They found that the neural structures activated by pleasant, consonant music were found primarily in the right hemisphere and that reciprocal activations in the right cerebrum were found ipsilaterally, within the same hemisphere. Blood and colleagues (1999) found that unpleasant music increases blood flow in the right parahippocampal gyrus, while stirring and thrilling feelings produced by favorite musical stimuli also increase blood flow in OFC, medial subcallosal cingulate, and right frontopolar regions, as well as decreases in the right OFC (Blood and Zatorre, 2001).
When subjectively describing emotions, one can often describe the kind of emotion (e.g., happy), and the intensity of the emotional arousal. Where the Valence Theory places less emphasis on emotional intensity or arousal, the right hemisphere model suggests that right parietal lobe mediates emotional arousal and increases autonomic activity. In order to attempt to double-dissociate autonomic and emotional reactions to music, Johnsen et al. (2008) compared autonomic and self-reported emotional responses of groups that had ventromedial PFC (VMPFC) lesions, right somatosensory cortex (RSS) lesions in the parietal lobes, and a healthy control group. They found that lesions to the VMPFC disproportionately impaired autonomic responses (skin conductance) while leaving emotional experiences relatively unaffected. The RSS group had significantly lower ratings of experienced emotion intensity for the emotional music across the combined emotion categories compared to the NC/VMPFC group but autonomic responses were relatively unaffected. More specifically, skin conductance responses were lower in the VMPFC group compared to the RSS and NC group. This finding, that the group with RSS lesions had higher skin conductance and emotional intensity in response to music, would be falsely predicted by the right hemisphere model. On the other hand, VMPFC lesions impairing autonomic responses while leaving emotional intensity intact suggest a complex relationship.

In regards to both of these predominant theories of emotions, laterality findings have not distinguished between the intensity of music but bilateral frontal EEG activity increases have been shown to correlate with increased emotional intensity (Schmidt & Trainor, 1994). A number of investigators have argued that the pattern of absolute activation in the frontal region may reflect the intensity of affective experience (Dawson, 1994; Henriques & Davidson, 1991; Schmidt, 1999; Schmidt & Fox, 1999). Thus, emotional intensity may mediate the relationship
between cerebral lateralization of affect and frontal lobe activation. To understand the intense emotions that can make our lives incredible and miserable, perhaps we should begin adapting a temporally focused view on how neural networks mediating emotion interact, over time, as emotions develop and intensify. Next, we will examine several experiments using EEG coherence to identify functional connections among cortical regions.

EEG coherence has been used to identify functional connections among cortical sites involved in cognitive and emotional processes (Petsche, & Etlinger, 1998). EEG coherence results from the estimation of the relationship of two time-series by computing their correlation coefficients and is useful for determining the spatial relations of different EEG components, or roughly, the extent of their similarity. When EEG data from pairs or groups of electrodes are compared, the normalized cross-power-spectrum (or correlation coefficient) per frequency band is computed which provides a measure of the functional relations and cooperation between those sites. This value (cross-power-spectrum correlation coefficient) is coherence, and high coherence between electrode sites suggests functional cooperation between those cortical regions.

Petsch and Etlinger (1998) played a musical piece by Mozart to participants for one minute and observed bilateral amplitude decreases in a high percentage of locations in the theta, up to beta two bandwidths, while only increases in delta were found in the right frontotemporal area. They found increased coherence within the delta bandwidth bilaterally in parieto-occipital regions. They identified several electrode sites that had high coherence with many other sites and termed those “hubs” of coherence “nodes”. These nodes appeared at 01, T3 and T7 for theta, one node in the left hemisphere at T3 for beta, and a node in the right hemisphere at T4 from theta through beta two frequency bands. Moreover, they found differences between coherence
patterns in men and women, as well as between musicians and non-musicians. Other researchers have generally found increased coherence, and in manner supporting the Valence hypothesis. For example, (Flores-Gutierrez, 2008) found that pleasant emotions induced by classical musical pieces (e.g., Mahler, Bach) increased upper alpha couplings linking left anterior and posterior regions while unpleasant emotions were sustained by posterior midline coherence exclusively in the right hemisphere in men and bilaterally in women. Combined music induced bilateral oscillations among posterior sensory and predominantly left association areas in women. The author suggested musical emotion entails specific coupling among cortical regions involving coherent upper alpha activity between posterior association areas and frontal regions probably mediating emotional and perceptual integration (Flores-Guttierez, 2009).

**Dynamic Functional Capacity Theory**

The Dynamic Functional (DFCT: see Carmona, Holland, & Harrison, 2009; see also Harrison, 2015) proposes a model in which regions in the frontal lobes have a limited emotional, cognitive, and autonomic regulatory capacity, termed ‘functional capacity’. The cognitive functions (e.g., working memory, language, and emotional mediation processes rely on the neural substrates that subserve them (e.g., prefrontal cortex) and these neural substrates (e.g., neurons, glia, synapses) have limited capacity because they rely on cellular sources that are finite, and because they rely on a certain level of functional connections. The functional capacity of frontal regions becomes exceeded when interconnections between them and distal sites are insufficient or overwhelmed, and when cellular resources are depleted. When functional capacity is exceeded, it is hypothesized that frontal lobes abruptly deactivate and/or disconnect from interconnected brain regions; this would appear as increases in delta and decreases in beta EEG power and coherence measures. In a state of exceeded capacity, inhibitory release of posterior
sensory cortical and subcortical regions of the brain contribute to intense positive and negative emotional experiences such as rage-anger, or euphoria. Intense emotionally provocative stimuli and acute stressors (e.g., cognitive demands) can exceed capacity; chronic stress and brain insults can diminish the PFC’s ability or “capacity” for cognitive functions and emotional mediation. It should also be noted that the effects of frequent capacity breachure could be predicted to further diminish capacity due to cortisol release that has damaging effects on the brain. The DFCT is aimed specifically at describing the development of extreme emotions, but this subject should not have only negative connotations attached to it; extremely intense pleasant emotions are just as important to understanding psychological well being as extremely intense unpleasant emotions are important to understanding psychological disorder. Using music to challenge capacity, and to study the intense emotions that result, may uncover several cerebral mechanisms that are common to both pleasant and unpleasant emotions.

Specifically, functional capacity refers to the frontal lobes’ capability to function properly, for them to carry out their role mediating the experience and intensity of emotional arousal and performing complex cognitive functions. The PFC has a set limit, or exhaustion point for these cognitive functions termed ‘functional capacity’. The PFC can functionally operate while working within, but not beyond, its own capacity; when this functional capacity is exceeded, the PFC does not function properly and the regulatory roles that the PFC mediates fail resulting in intense emotional arousal and cognitive disorder. This capacity can be conceptualized as having a level, or “threshold” that can be reached and exceeded in an “either-or” fashion where it is either functional, or non-functional. This is reflected in the neuron’s refractory period; just as neurons have a refractory period immediately after firing during which time they cannot have an action potential, so too do the functions of the PFC when they reach a
functional “refractory period” after capacity is exceeded. Those with low, or diminished
capacity, are hypothesized to have a narrower range than normals, which within their PFC can
effectively function. This leads to capacity being exceeded easier and more frequently, leading
to heightened emotional sensitivity and reactivity.

According to the DFCT model, the development and intensification of an emotion from zero to peak emotion can be describes as occurring in four phases. During the first phase, subcortical and sensory cortices activate in response to a stimulus. In the second phase, the PFC activates in order to comprehend and regulate the resulting emotion and arousal, resulting in a global increase in brain activation, a state marked by large energy demands and expenditure. The functional capacity of the PFC is exceeded in the third phase if resources are exhausted and/or if interconnections between the PFC and other brain regions are insufficient (referred to here as neuroanatomical integrity). This third phase is characterized by an abrupt and temporary deactivation, and disconnection of the PFC from interconnected brain regions, allowing the latter to fire uninhibited. In the fourth phase, after resources have been replenished or the stimulus is no longer present, PFC functioning begins to return to baseline levels, or at least within in its capacity. Initial evidence that led to the development of this theory came from a case study by Everhart and Harrison (1995). Everhart and Harrison (1995) found relative right orbital frontal lobe deactivation concurrent with relative right temporal lobe activation during increased hostility in a patient following right cerebrovascular accident (CVA). In Everhart and Harrison’s (1995) investigation, stress induction occurred during the lateral arm oscillation procedure, suggesting right anterior deactivation and posterior activation concurrent with the patient's reported experience of hostility. Thus, sensory stimulation from lateral arm oscillation was capable of exceeding functional capacity of this patient whose capacity was diminish by a CVA.
The orbital-frontal cortex (OFC) has extensive interconnections with the amygdaloid bodies of the anterior temporal region. Heilman et al. (1993) hypothesized that these two extensively interconnected regions interact with each other to yield a relatively conservative and stable aggression levels. Extending on this notion, the DFCT propose that particularly strong activation in the anterior temporal region could “tip” the balance of the PFC, exceeding the capacity of the OFC which would lead to the decreases in PFC activity, ultimately allowing the temporal lobe to activate uninhibited.

In most everyday emotional experiences the intensity of the emotion won’t pass beyond the 2nd phase of the DFCT. In the 3rd phase of the DFCT capacity is exceeded, preceded by increasing emotional intensity, and followed by even further intensification; this is the phase that is key to understanding extreme emotions in normalcy and disorder. Rieser’s (2012) findings suggest that more loose prefrontal–posterior coupling (EEG coherence) may be related to loosening of control of the prefrontal cortex over incoming social–emotional information and consequently, to deeper emotional involvement and absorption, whereas increased prefrontal–posterior coupling may be related to strong control, dampening of emotional experience, and not letting oneself become emotionally affected. The Prefrontal-Subcortical Balance Model of Self-Regulation (Ocshner, 2002; Urry, 2006; Wager et al, 2008), and the Strength Model of Self-Control (Baumeister, 1999) also assumes that the emotional salience of an object can overpower frontal lobe inhibitory systems.

If the frontal lobes are there to do these jobs, then why do they appear to be so susceptible? The answer is in the functional neuroanatomy of the PFC which makes it extraordinarily powerful, yet leaves it vulnerable to interference effects and cellular exhaustion due to its high metabolic demands. The rostro-caudal model (Christoff & Gabrielli, 2000)
suggests that the rostro-caudal axis of PFC supports a control hierarchy whereby posterior-to-anterior PFC mediates progressively abstract, higher-order control, implying that relatively complex, flexible, integrative, and overlapping computing is subserved by the most anterior regions of the PFC. Significant overlap, or crowding of neural tissues mediating similar abstract cognitive (e.g., working memory) and emotional functions in the PFC can lead to dual-task interference or facilitation effects. Dual-task interference and facilitation results when the facilitation or impairment of concurrent performances of multiple tasks depends on the degree of task relatedness and the degree to which the multiple networks involved in the task are “close” in physical space in the brain. Dual-task demands bring with them increased demand which can lead to exhaustion. Using fMRI, Herath et al. (2001) found that the performance of dual reaction time tasks activated cortical regions in excess of those activated by the performance of component single tasks. Moreover, Herath et al (2001) reported, that dual task interference is specifically associated and correlated with increased activity in a cortical field located within the right inferior frontal gyrus. This area has been previously implicated in emotion regulation and hostility, lending to the notion that areas of the brain that regulate emotion in particular, may face the burden of dual-task interference. The PFC is also particularly vulnerable to stress; oligodendrocytes in the forebrain are highly vulnerable to excitotoxicity (McDonald, Althomsons, Krzystof, Dennis, Goldberg, 1998). Arnsten (2010) has proposed a theory of ‘rapid neuroplasticity’ that claims the cortical tissue in the PFC is able to rapidly deactivate or disconnect from other brain regions by way of recursive inhibitory connections in the PFC. More specifically, Arnsten (2010) believes that there is a mechanism inherent to the PFC that weakens network connections in the PFC that could prevent overexcitability. Arnsten (2010) claims that
there seems to be negative feedback mechanisms that might prevent seizures in PFC microcircuits.

The PFC’s regulatory capacity relies on neuroanatomical integrity such that traumatic brain injuries, cerebrovascular accidents, hypoxic events, etc., can diminish frontal capacity by interrupting neuronal signals and communication. Because of the mechanics and structure of the skull and the brain, traumatic brain injuries frequently lead to injuries of the frontal lobes, particularly the OFC (Eslinger, Grattan, & Geder, 1996) and the white matter tracts that connect the frontal lobes with subcortical structures (Bigler, 2004; Wilde et al., 2006). Individuals with these injuries are more likely to experience executive function deficits and emotional dysregulation, reflecting a diminished ability to mediate emotional experience. Further support for this notion comes from neuroimaging experiments in clinical populations. Patients with primary generalized anxiety disorder show a comparatively less myelinated uncinate fasciculus (Phan et al., 2009), the tract connecting the PFC to the amygdalae and temporal lobes. Patients with panic disorder show lesser activation in the orbital frontal cortex (OFC) in response to anxiety-inducing stimuli (Kent et al., 2005), and abnormalities in the OFC in the right hemisphere in particular are shared by several different anxiety disorders (Rauch, Savage, Alpert, Fischman, & Jenike, 1997). This is consistent with the notion that keeping anxiety in check relies at least in part on effective down-regulation of the amygdala by the OFC (Milad, 2007). Thus, damage to either a brain region (e.g., OFC) or the connections from it (white matter connecting OFC to the amygdala) can diminish one’s capacity for emotional mediation.

The DFCT proposes that exceeding capacity serves an adaptive, self-protective function that may be unique to the PFC. Specifically, the PFC attempts to prevent excitotoxicity associated with high firing by deactivating or disconnecting itself through recurrent inhibitory systems and
remaining temporarily dormant. As all biological systems require rest and replenishment after times of stress (Caccioppo & Bernston, 2007), exceeding capacity may allow time for the replenishment of neural resources and cellular repair. Exceeding capacity may allow older, more primitive brain regions to take control (Arnsten, Constantinos, Paspalas, Gamo, Yang, & Wang, 2010) and it may allow for the uninhibited intake and synthesis of sensory information allowing for creative responses (e.g., Foster et al. 2011). The consequences of exceeding capacity may be advantageous and/or disadvantageous depending on the individual’s capacity level.

The Dynamic Functional Capacity Theory (Carmona, Holland, Harrison, 2009; Mitchell & Harrison, 2010; Harrison, 2012; 2015) has evolved from emotional and autonomic regulation experiments and dual-concurrent task research on individuals evidenced to have diminished right frontal lobe capacity, including highly hostile and anxious individuals. This has also been apparent in emotionally labile individuals, including anger liability and gelastic lability. Hostility has been previously associated with increased reactive activation for auditory (Demaree & Harrison, 1997), visual (Harrison & Gorelczenko, 1990; Herridge, Harrison, Mollet, & Shenal, 2003), and somatosensory modalities (Herridge, Harrison, & Demaree, 1997; Rhodes, Harrison, & Demaree, 2002). Diminished regulatory capacity of the right frontal regions has also received support for motor (Demaree, Higgins, Williamson, & Harrison, 2002) and premotor systems (Williamson & Harrison, 2003). Individuals with diminished frontal lobe capacity have been found to have an exaggerated brainstem acoustic startle responses (Klineburger & Harrison, 2012, in preparation), heightened sympathetic reactivity (BP & HR) to nonverbal stressors, increased glucose mobility (Walters, Klineburger, Harrison, 2012; in preparation), increased GSR, and altered emotional processing (Carmona, Holland, Straton, Harrison, 2008). Results from these experiments have led to the conclusion that high-hostile individuals have diminished
right frontal lobe capacity and this has provided a basis for developing the Right Hemisphere Model of Hostility and the DFCT.

The DFCT provides several unique theoretical contributions to the current understanding of the relationship between music, emotion, and brain. The DFCT attempts to explain extreme emotions by placing a strong temporal focus on a stepwise sequence of cerebral interactions that produce extreme emotions. In contrast to other theories of emotion such as the Right Hemisphere Theory (Bowers, 1993) and Valence Theory (Davidson et al., 1995), the Dynamic Functional Capacity does not assume that the relationship between PFC activity and emotional intensity is linear, and this nonlinear relationship is hypothesized to be key to understanding PFC function/dysfunction as it relates to emotions.

The purpose of this dissertation is to test several hypotheses of the DFCT by using music to elicit strong emotions in participants. Changes in EEG power during the four phases (defined by participants self-reported emotional intensity) of the DFCT model will be compared in order to examine regional cerebral dynamics.

Variables

SEX (male and female) was the between-subjects factor. Within-subjects factors include TIME (baseline, music-onset, peak emotion), and LOCATION (left frontal, right frontal, left posterior, right posterior). TIME was defined as a function of participants’ emotional intensity ratings reported via continuous dial control while they listened to music; the beginning of the music was the start of the ‘music-onset’ phase, and an indication of peak-emotion (rating of a 7 or above on a scale of 1 to 9) demarcated between the ‘music-onset’ and ‘peak emotion’ phases.

Three classes of dependent variables were used: 1) Physiological measures, 2) EEG, and 3) self report data. Physiological measures included Skin Conductance Levels (SCL). EEG
included EEG bandwidths of beta magnitude (13-25 Hz), alpha (8-12 Hz), and delta magnitude (4-8 Hz). Self-report measures of emotional experience were taken continuously during music-listening via control dial, and after each musical piece via self-report on the PEF. Other self-report measures included the BDI, BAI, and the ATQ.

**Hypotheses**

Hypothesis 1: There will be an increase of EEG beta magnitude in the left frontal lobe from baseline to music-listening phases.

Hypothesis 2: From music-listening phase to peak-emotion phase, there will be a decrease of beta magnitude in the frontal lobes. There will also be a concurrent increase of beta magnitude in posterior regions.

Hypothesis 3: There will be increased sympathetic activation from baseline to peak-emotion (increased SCL, PR, and O2 saturation).

Hypothesis 4: Participants in the “low score” group on neuropsychological tests of executive functioning will evidence greater decreases in frontal lobe beta EEG from the music-listening phase to the peak-emotion phase than participants in the “high score” group.
Methods

Participants

Forty-eight participants were recruited (24 right-handed college-age men and 24 right-handed college-age women) from the undergraduate psychology department for inclusion in this music-listening experiment. A power analysis indicated that a sample size of 48 participants was necessary for a medium effect size. Potential participants were screened online via the SONA system at Virginia Tech. Online screening measures included the Coren, Porac, and Duncan Laterality Questionnaire (CPD), the Medical Health Questionnaire (MHQ), the Orienting Sensitivity scale of the Adult Temperament Scale (Evans & Rothbart, M.K., 2007), and a short questionnaire assessing participants emotional responses to music. Participants needed to obtain a score of $\geq +7$ on the CPD to be considered right-handed. On the MHQ, participants had to report an unremarkable medical history as pertaining to head injury, learning disability, neurological dysfunction or cardiovascular abnormalities. For inclusion, participants had to report having the ability to experience intense emotional responses to music commonly reported as experiencing ‘chills’ (Blood & Zatorre, 2001), goosebumps, becoming tearful, etc. as assessed with the music screener. Participants meeting these inclusion criteria were invited to participate in the laboratory portion of this experiment via e-mail. In the laboratory, participants were administered the Beck Depression Inventory (BDI, 2nd ed.) and the Beck Anxiety Inventory (BAI) for additional screening. Participants were not be excluded for participation in the laboratory portion of this experiment based on their BAI and BDI scores. All participants received course credit for their participation in the online screener and another course credit for participating in the laboratory session. All identifying information obtained from participants was coded to insure that all sensitive information remains confidential. This experiment was approved by the IRB and department HSC.
Materials

Self-report measures

Coren, Porac, and Duncan Laterality Questionnaire (CPD).

Participants completed the Coren, Porac, and Duncan Laterality Questionnaire as part of the on-line screener survey to determine sufficient right hemibody preference (CPD; Coren, Porac, & Duncan, 1979) (See Appendix B). The questionnaire is a 13 item self-report inventory. Scores range from +13, for complete right lateral preference, to -13, for complete left lateral preference. Only participants scoring +7 or above were included in this experiment, as used in previous experiments in our lab (Herridge, et al., 2004; Williamson & Harrison, 2004).

The Adult Temperament Questionnaire (ATQ).

The Adult Temperament Questionnaire (ATQ) was adapted from the Physiological Reactions Questionnaire developed by Derryberry and Rothbart (1988). Based upon the results from recent studies (Rothbart, Ahadi, & Evans, 2000), Rothbart and colleagues have formulated a self-report model of temperament that includes general constructs of effortful control, negative affect, extraversion/surgency, and orienting sensitivity. The Orienting Sensitivity subscale assesses the following constructs: Neutral Perceptual Sensitivity (detection of slight, low intensity stimuli from both within the body and the external environment), Affective Perceptual Sensitivity (spontaneous emotionally valenced, conscious cognition associated with low intensity stimuli), and Associative Sensitivity (spontaneous cognitive content that is not related to standard associations with the environment).

Medical History Questionnaire.

Participants completed the Medical History Questionnaire used previously in experiments in our lab (Williamson & Harrison, 2004) as part of the on-line screener survey (See Appendix
C). The Medical History Questionnaire assesses neurological trauma and major medical disorders. It asks questions regarding head injuries, strokes, seizures, paralysis, medical illness, psychiatric problems, sensory impairments, prescription medication use, and problems or pain related to movement (Foster et al, 2004). For inclusion in the laboratory portion of this experiment, participants had to report an unremarkable medical history as pertaining to head injury, learning disability, neurological dysfunction or cardiovascular abnormalities.

*Cook-Medley Hostility Scale (CMHS).*

Participants completed the Cook-Medley Hostility Scale (CMHS) (Cook & Medley, 1954) using the online screener. The Cook-Medley Hostility Scale is the most frequently used measure of hostility and shows construct validity as a predictor of interpersonal, medical, and psychological outcomes (Contrada & Jussim, 1992). The CMHS is a 50-item true/false questionnaire that measures aspects of hostility and has been shown to be a valid indicator of hostility in previous research (Herridge, Harrison, Mollet & Shenal, 2004) (See Appendix A). The CMHS shows a high degree of reliability ($r = .84$) (Smith & Frohm, 1985), convergent, and discriminant validity (Raikkonen, Matthews, Flory, & Owens, 1999) with respect to physiological measures such as blood pressure regulation. Participants who obtained a score of 19 or lower on the CMHS will be classified as low-hostiles. Participants who obtain a score of 29 or higher will be classified as high-hostiles. These classifications are consistent with previous research examining physiological and neuropsychological correlates of trait hostility 19 (Williamson & Harrison, 2003; Shenal & Harrison, 2003; Herridge, et al., 2004; Rhodes et al., 2002). Participants will be grouped as low and high hostiles for subsequent analyses.

*Participant Experience Form (PEF).*
The Participant Experience Form (PEF) was administered in the laboratory immediately after each listening task and then again at the end of the experiment. It assesses the intensity and valence of participants’ emotional responses to each musical piece. It also assesses perceived sensory changes (e.g., chills, goosebumps, teary eyes, changes in respiration, etc.) during emotional reactions to music. The final portion of the PEF assesses participants’ musical history such as music-listening frequency, favorite genres of music, pleasure obtained from listening to music, frequency of “euphoric musical reactions”, instruments played (if any), and years of musical education (including music theory education and instrument lessons). The latter part of this questionnaire may be used for additional analyses as well as an effort to begin collecting data on musical characteristics of participants in future experiments.

**Apparatus**

*Musical Stimuli and Apparatus*

Self-selected music is most likely to elicit the intensity of emotional arousal that is the primary focus of this experiment. Participants were instructed to bring to the laboratory, and have prepared ready for listening, at least four musical pieces that have the ability to evoke intense pleasurable emotions. Participants brought their music with them to the laboratory on either a compact disc or a portable music player. Despite the potential differences between these formats, the salience of the music is a more important factor than format and this should not be an issue. Participants were asked to select four songs that can evoke intense positive emotions (euphoria, chills, etc.). Over the ear headphones were provided. During pilot testing, foam-tip earphones were found to not fit comfortably underneath the EEG cap. Participants brought in music on a CD and they listened to it on a CD player provided by the experimenter. Participants were told to adjust volume levels as necessary in order to achieve a comfortable listening experience.
volume. Although volume is one factor of music, the emotional salience of the musical piece is the most important. Self-selected musical pieces were reviewed after the experiment to assess their appropriateness for the experiment.

*Emotional Intensity Ratings*

Participants rated their emotional intensity and the occurrence of peak emotions (e.g., chills, thrills, etc.) while listening to music with a control rating dial built specifically for use with the James Long QEEG system. The James Long Rating Dial Control system consists of a single knob which participants will turn clockwise from “1” to “9” to indicate increasing emotional intensity. A full turn of the dial to “9” will indicate that a peak emotion has been experienced. The signal sent from the control dial is recorded along with EEG data and was viewed before data analysis in order to determine the onset of a peak-emotion. Participants used their right hand to control the dial because skin conductance leads were attached to the left hand. Additionally, it was assumed that it would be easier for participants to use their right hand rather than their left hand to finely control the dial because all participants were right handed. The control dial was mounted to a desk in front of participants and remained stable throughout the experiment.

*EEG and Physiological Measurements*

Quantitative electroencephalography (qEEG) data were recorded and analyzed using the James Long Company’s 32-Channel EEG Analysis System. The data were quantified online to digital values using HEM Snap-Master on a Dell Desktop PC for display, storage, and analysis. Electroencephalographic data were amplified and sampled at a rate of 256 samples per second. Each epoch was carefully inspected for artifact and removed if found to contain artifacts. Electrooculography recorded along with the EEG provided additional help in the artifacting
process. Each epoch will be Fourier transformed to compute averaged power with a frequency resolution of 0.5 Hz. Delta (1.5-3.5 Hz), Theta (4.0-7.5 Hz), Alpha (8.0-12.5 Hz), Beta-1 (13.0-18.0 Hz). FFT of theta, alpha, and beta bandwidths used a one-second epoch and FFT used a two-second epoch. The final step was the computation of EEG power. The Electro-cap model ECI E1-M-Custom: version 090922A, Sensor, Electrode, Electro-Cap, was used. These caps have additional electrodes for recording electrooculogram (EOG). EOG was recorded for the sole purpose of off-line artifacting. NuPrep and Electro-Gel brand conductive gel were used for the EEG caps and Biogel Biopotential Contact gel was used for Skin Conductance.

Skin Conductance Levels were recorded concurrently with EEG using the James Long system. The JLC electrodermal activity (EDA) pair was be used, which is a pair of silver/silver-chloride electrodes that will be attached to the left index finger.

**Procedure**

Participants were contacted via e-mail for invitation for participation in the laboratory session of the experiment. This invitation e-mail read:

“When you come to the laboratory, you will listen to some of your own favorite music that you will bring with you on a CD or a portable music player. Please choose any four of your most favorite songs/musical pieces that you know can evoke intense pleasant emotions (happiness, joy, euphoria, bliss, etc.) in you. For example, on a scale of 1 to 10 with 10 being maximum emotional intensity, choose songs that can evoke an emotional intensity of at least 7 or higher. In other words, choose songs that make you feel very extremely pleasant. The extremely pleasant emotions evoked by music are often accompanied by feeling “chills”, “thrills”, “chills up and down your spine”, “goosebumps”, feelings of joy, ecstasy, and/or euphoria and are sometimes described as being a ‘spiritual’ or ‘transcendental’ experience that can be
accompanied by crying, by becoming teary-eyed, and by sudden changes in breathing. Choose four songs that have these effects on you, make a copy of them onto a compact disc (CD) (burn a CD), and bring that CD with you to the lab on the day of your experiment. If you do not bring the CD we cannot do the experiment. It is also requested that you leave your CD with the experimenter when you leave - CDs will be returned upon request. Blank CDs can be provided to you for free by request. You could also use a portable music player like an iPod, your phone, etc – just remember to have your device charged. However, a CD is strongly preferred over portable music devices. If you have any questions about any of these instructions, e-mail me directly at pklineb@vt.edu and I will respond promptly. Thank you for your time. “Participants signed up using the SONA system for a time slot for the laboratory session.

Upon arriving to the laboratory, participants completed the informed consent form, the BDI, and the BAI. BDI forms were checked for any indication of suicidality. Participants provided the experimenter with their CD so that it could be cued in the CD player. After measuring the circumference of the participant’s cranium and choosing the appropriate cap size following 10/20 EEG system standards, EEG caps were placed on their head. Next, Neuroprep gel was inserted into the electrodes and following this, electrode gel was inserted into the electrodes of the EEG cap. EEG Impedances were kept below 5 Kohm. EOG leads were attached to participants’ face after the cap was fitted and gelled. Next, JLC EDA electrodes were attached to their left hand. After all physiological recording apparati were set up, the participants were given general instructions about the experiment, and they were then familiarized with the control dial used to rate emotional intensity. Participants were told:

“Now I will give you a general idea of how this experiment will unfold. In this experiment you will be listening to music that you brought in and you will be listening to music
that the experimenter has provided. You will be continuously rating the strength/Intensity of your emotions while listening to music using this control dial [experimenter points to control dial]. I will tell you more about the control dial in just a moment. The songs that the experimenter has provided and the songs that you brought in will be played for you in a mixed up and random order so that for most of the experiment you will not know what song is about to be played for you. It may be one of the songs you brought in or one of the songs the experimenter has provided. While you listen to the song being played for you, you should focus on the music and naturally feel whatever emotion comes to you. Do not try to force any emotions and do not try to inhibit or decrease any emotions either. Act naturally as if you would any other time listening to music. When you are listening to the music, remember to remain seated comfortably upright with your body weight supported by the chair, with your arms supported by the armrests of the chair, and with your feet flat on the ground. Try to avoid excessive movement while listening to the music. Specifically, do not tap your feet or hands, do not ‘mouth’ the lyrics, do not hum along, avoid moving your tongue or jaw, and try to keep your face calm and still because these movements can introduce noise into the recordings. Just try your best. During this experiment, while you listen to the songs, you are not being asked to judge whether the song is happy or sad, fast or slow, etc. Rather, you are being specifically asked to rate the strength/intensity of the emotion you feel during the song. I will repeat these instructions before each song plays so do not feel as though you need to memorize them. Do you have any questions so far? Before each song is played for you, we will take a baseline recording of you and I will tell you more about this in a moment. In this experiment you will be listening to music and rating the strength/intensity of the emotions you feel using this rating dial [experimenter points to dial]. I will give you further instructions later before you begin listening to the music, but for
now I want you to become familiar with the rating dial. In order for you to rate the intensity or strength of the emotion you feel while you listen to music, you will turn this dial here with your right hand. Basically, turning the dial clockwise indicates increasing levels of emotional intensity. In other words, when you begin to feel increasing emotional intensity, begin turning the dial clockwise to an appropriate place. This increasing emotional intensity may be you starting to feel an emotion stronger, you may feel changes in breathing or heart rate, you may become teary eyed, you may experience chills, etc. See these numbers [experimenter points to numbers 1 through 9 labeled on the control dial]? You will be rating your emotional intensity level on a scale of 1 to 9 with 1 being no emotional intensity, with 5 being about a medium emotional intensity, and with 9 being extremely high emotional intensity that we will call a peak-emotion from now on. Here is an example of how you should use the control dial. Consider a song that makes you feel happy. If this song makes you feel a little bit happy then you might turn the dial to maybe a 2 or 3. If the song makes you feel very happy then you might turn the dial towards 7 or 8. If the song makes extremely intensely happy, maybe even euphoric, you would turn the dial to 9. Again, throughout each song you will continuously rate your emotional intensity with this control dial. You do not need to be constantly turning the dial throughout each song - just turn the control dial when you feel your emotional intensity changing. In other words, if your emotional intensity does not change, then you will not need to turn the dial – just leave the dial where it is. If you begin feeling increasingly emotional, happier, pleasant, euphoric, etc. turn the knob clockwise towards the appropriate number between 1 and 9 that corresponds with your emotional intensity/strength. When you feel your emotional intensity decreasing, turn the knob counter-clockwise back to a number that appropriately corresponds to your emotional intensity. Imagine that the knob on the control dial is like a volume knob for
your emotions – the stronger, more intense, and louder your emotions become, the more you will turn this knob up towards the higher numbers. Remember that you are rating the strength or intensity of whatever emotion you feel, whether it is happiness, calmness, bliss, euphoria etc. Do you understand? Do you have any questions so far?

This next part is important so if you have any questions please ask me. In this experiment, you brought with you songs that are supposed to be capable of creating intense pleasure, happiness, euphoria, bliss, a high, chills, etc. These experiences in which you feel intense, great pleasure while listening to music will be referred to as “peak-emotions”. I want to know exactly when you experience a peak-emotion and you will indicate this by turning up the volume on the control dial all the way to 9. In other words, a full turn of the dial to 9 is reserved only for when you think you have a peak-emotional experience. When you believe that you are experiencing a peak-emotion, turn the control dial all the way to 9 and when that peak-emotion begins to decrease, turn the knob back accordingly. Before each song starts the knob will be set at 1. Do you have any questions about how to use the knob? Do you have any questions about what a peak-emotion is? Now, please turn the knob from 1 to 9 and back again slowly several times so that you become comfortable and familiar with it.” [spoken instructions last about 5 minutes]

In the next phase of the experiment, baseline recordings were taken and the song was played. For each song, baseline physiological recordings lasting no less than 60 seconds were recorded immediately before each musical pieces began. Before each songs began, participants were reminded about what to do while the music plays. For baseline recordings, participants were instructed:
“Next we will take a baseline recording. Please sit upright in your chair comfortably, with your arms fully supported by the armrests, with your bodyweight comfortably supported by the chair, and with your feet flat on the floor. See the dot on the wall in front of you? When I say, “start”, I want you to look forward at that dot on the wall and remain as still as possible. Focus comfortably on the dot. In other words, stare at the dot but you do not need to intensely focus on the dot. Also, try to avoid excessive thinking. Keep your right hand comfortably on the control dial throughout the baseline recording. In order to get a good baseline recording, please keep your jaw and mouth comfortably relaxed and still, avoid moving your tongue, avoid moving your face, avoid excessive blinking, and remain comfortably still. We will do a baseline recording for about one minute before you listen to each song. After each baseline recording, I will briefly remind you of what you need to while listening to the music. When I say “start” you go ahead and focus on the dot and stay still. OK? Do you have any questions? OK, start.”

[baseline recording commences and ceases after at least 60 seconds]

Following the baseline-recording phase, the song was played immediately so that no stimuli (visual, instructions from experimenter, etc.) were introduced in between the baseline recording and the start of the music (music-onset stage). It was predicted that without any interruption between baseline and the beginning of the music, participants would begin to anticipate the start of the music as they sensed the end of the baseline-recording approaching. In order to remedy this, participants were told that they would be briefly reminded that they will receive verbal instructions immediately before the music listening phase begins, after each baseline recording. Thus after each baseline-recording, participants were told:

“Now you will hear a piece of music. Listen and naturally feel whatever emotion comes – do not force any emotions and try not to discourage any emotions either. Just try to listen
naturally as you would any other time. Throughout the song, remember to indicate the strength/intensity of your emotions using the control dial remembering that lower numbers indicate low levels of emotional intensity, higher numbers indicate higher levels of emotional intensity, and turn the knob all the way to 9 if and only when you believe you are experiencing a peak-emotion such as euphoria, bliss, become teary-eyed, get goosebumps, etc. Be sure to adjust the knob accordingly as your emotional intensity/strength changes throughout the song. Stay seated and still in your chair and look forward – you do not need to focus on the dot while listening to music but please do not close your eyes. Keep your arms supported by the armrests with your right hand on the control dial. [experimenter visually inspects for compliance]. Avoid humming, singing, tapping your hands or feet, excessive tongue and jaw movements, etc. [If the participant brought in a CD]: The experimenter will stop the song at his discretion. [If the participant brings in music on a laptop, iPod, phone, etc.]: You will be given a sign when you are to stop the song. When the music stops just remain seated until further instructions are given. Do you have any questions before the song starts? OK.” [spoken instructions lasted about 1 minute].

Each song was played in its entirety and the participants indicated that the song had ended by raising their hand. If a peak emotion was not reached, the song was played in its full entirety again with the exception of songs lasting more than five minutes. At the end of the song, the participant was instructed, “please remain still for several seconds”. Next, the participant was given the PEF to assess their emotional experience during the song. After each song, participants were instructed:

“Now you will fill out a brief questionnaire about the song you just listened to and the emotions and feelings you experienced while listening to it”. [experimenter hands participant
the form – experimenter takes form from participant when he/she completes it and checks for the occurrence of a peak-emotion).

All procedures and instructions were repeated (from baseline to PEF completion) for each song and this series of events constituted a block with each block consisting of the following phases: baseline, music-listening, and post song assessment via PEF. If for some reason participants were not reporting intense emotions (7 out of 9 or more on intensity on the PEM or the control dial), they were asked to select another piece of music to listen to or they were asked to re-listen to one of their songs again. In order for a song to be included in the analysis, each phase of each block (e.g., baseline, music-listening) needed to have at least 30 artifact-free, 1-second epochs of EEG data.

Following the music-listening portion of the experiment, physiological recording equipment was removed from the participants, and participants were debriefed and thanked as they were permitted to leave.
Analyses

Self-Report Data

Descriptive statistics for the BDI, BAI, CMHS, and the ATQ were generated in order to identify any potential outliers. Outliers may be excluded from final analyses. Participants’ PEFs were scored and reviewed after the laboratory session in order to examine participants’ emotional experiences, while listening to music in the laboratory.

Manipulation Checks

Emotional intensity ratings per ‘control dial’ were inspected as a manipulation check and in order to demarcate the peak-emotion phase of each song. A rating of 7 or higher was used to indicate that a peak emotion had occurred. Additionally, inspection of participants’ responses on the PEF ensured that each musical piece elicited a positively valenced peak emotion.

EEG and Physiological Data Analysis

For each level of the LOCATION variable, electrode sites were averaged. The left frontal site included FP1, F7, and F3; the right frontal site included FP2, F4, F8; the left posterior site included T3, T5, P3, and O1; and the right posterior site included T4, T6, P4, and O2. For statistical analyses, the multivariate procedure was used because it does not require the sphericity assumption of the univariate repeated measures methodology and its use is recommended for psychophysiological data (Vasey & Thayer, 1987). An omnibus 5-factor mixed between-within subjects MANOVA was performed using EEG (alpha, beta, delta bandwidths) and SCL as dependent variables. The between subjects factor was SEX (male and female). TIME (baseline, music-onset, and peak-emotion), and LOCATION (left frontal, right frontal, left posterior, and right posterior) were the within-subjects factors. In order to reduce the size of the data sets and to simplify their analysis, a predicted main effect for SEX provided rationale for analyzing males and females separately.
To test hypothesis 1, a 3 factor, between-within measures ANOVA was performed with LOCATION and TIME as the repeated measures, SEX as the between-subjects factor, and EEG beta magnitude as the dependent measure. More refined repeated measures ANOVAs were performed to analyze the predicted interactions and main effects, and planned comparison t-tests were performed using the Greenhouse-Geisser correction.

To test hypothesis 2, a two-factor repeated measures ANOVA with LOCATION and TIME as the within-subject factor and EEG beta magnitude as the dependent measure was performed. More refined repeated measure ANOVAs were performed and planned comparison t-tests were performed using the Greenhouse-Geisser correction.
Results

In order to only include EEG data with at least 30 artifact-free, one-second epochs, several songs were excluded from analyses due to excessive artifact resulting in recordings with less than 30 seconds of usable data. Several subjects’ EEG data were excluded due to unforeseen circumstances. For example, in several cases, participants reported a peak-emotion within the first 30 seconds of the music starting resulting in a music-onset period with less than 30 seconds. In several cases, the self-reported peak-emotion period was less than 30 seconds in length and thus, unusable for analysis. Some participants reported not experiencing a peak-emotion during any of the songs and were not usable for analyses. For several reasons, oxygen saturation/pulse rate data were not collected. After pilot data were collected, it was discovered that the oxygen saturation/pulse rate machine introduced electrical artifact into the EEG signal. In addition, the beeping sound from the unit was loud enough for several participants to hear. Because the skin conductance lead was applied to the left and middle index finger, and because the right hand was only to be used to control the emotional intensity rating dial, the oxygen saturation/pulse rate lead needed to be applied to the left ring finger. Several participants reported that having three leads on the left hand was uncomfortable and distracting. Due to time constraints, participants only listened to the self-selected music and neuropsychological test data were not collected. The natural log transformation (ln) used on the EEG data was prior to analyses and EEG data were subsequently reported as beta power in microvolts squared.

An omnibus MANOVA with SEX as the between-subjects factor, LOCATION and TIME as the within-subjects factor, and alpha, beta, and delta as dependent variables was performed. A significant LOCATION by TIME interaction was found $F(18, 299) = 5.28, p < .0001$. There were significant main effects for SEX, $F(3, 299) = 6.09, p < .001$, LOCATION,
F(9, 299) = 20.15, \( p < .0001 \), and TIME, F(6, 299) = 3.82, \( p < .01 \). Since these MANOVA results were significant, follow-up ANOVAs were performed.

In order to explore the main effects and interactions, a repeated-measure ANOVA was performed with SEX as the between-group variable, LOCATION and TIME as the within-subjects factor, and beta power as the dependent variable. A significant three-way SEX by LOCATION by TIME interaction, F(6, 138) = 2.60, \( p < .05 \) (see Figure 1), and a significant two-way LOCATION by TIME interaction, F(6, 138) = 6.72, \( p < .0001 \), was found. A significant main effect for SEX, F(1, 23) = 8.30, \( p < .01 \) was found, with females exhibiting significantly higher beta power (\( M = 2.715 \)) than males (\( M = 2.165 \)). A significant main effect for LOCATION F(3, 69) = \( p < .0001 \) was found, indicating that beta power at the left frontal site (\( M = 2.318 \)) and at the right frontal site (\( M = 2.277 \)) were significantly lower than the left posterior site (\( M = 2.695 \)) and the right posterior site (\( M = 2.602 \)).

To explore the significant LOCATION by TIME interaction, planned t-tests were conducted using both sexes and comparing levels of LOCATION and TIME (see Figure 2). Baseline beta power at the left frontal site (\( M = 2.584, SD = 0.86 \)) was significantly higher than that recorded at the left frontal site at peak emotion (\( M = 2.204, SD = 0.55 \)), \( t = 1.97, p < .05 \), indicating a decrease in beta power at the left frontal region from baseline to peak emotion. During the music-onset phase, beta power at the left frontal site (\( M = 2.165, SD = 0.465 \)) was significantly lower than the left posterior site (\( M = 2.654, SD = 0.718 \)), \( t = 2.537, p < .05 \), indicating relatively lower beta power in the left frontal compared to the left posterior sites. During the peak-emotion phase, beta power at the left frontal site (\( M = 2.204, SD = 0.55 \)) was significantly lower than the left posterior site (\( M = 2.724, SD = 0.793 \)), \( t = 2.69, p < .01 \). During the music-listening phase, beta power at the right frontal site (\( M = 2.135, SD = 0.535 \)) was
significantly lower than the right posterior site \( (M = 2.592, SD = 0.609), t = 2.369, p < .05. \)

During the peak-emotion phase, beta power at the right frontal site \( (M = 2.193, SD = 0.581) \) was significantly lower than the right posterior site \( (M = 2.669, SD = 0.669), t = 2.69, p < .01. \)

In order to better understand sex differences in cerebral activation, separate ANOVAs for each sex were conducted with LOCATION and TIME as the within-subjects variables, and beta as the dependent variable. There were no main effects or interactions for males. For females, there was a significant main effect of LOCATION, \( F (3, 39) = 11.61, p < .0001, \) with significantly higher beta in the left posterior site \( (M = 2.964, SD = 0.596) \) and right posterior site \( (M = 2.911, SD = 0.578) \) than in the left frontal site \( (M = 2.524, SD = 0.62) \) and the right frontal site \( (M = 2.461, SD = 0.527) \).
Discussion

Support for the Dynamic Functional Capacity Theory was found in this experiment within the beta bandwidth. Hypothesis two predicted a significant decrease in beta power in the left frontal lobe from baseline to peak-emotion reflecting capacity demands. This hypothesis was supported with a significant decrease in beta power at the left frontal site from baseline to peak-emotion when participants reported experiencing an intensely positive emotion referred to as peak-emotion. A number of investigators have argued that the pattern of absolute activation in the frontal region, rather than frontal asymmetry, may reflect the intensity of affective experience (Dawson, 1994; Henriques & Davidson, 1991; Schmidt, 1999; Schmidt & Fox, 1999). The results from this experiment were partially consistent with this, in that frontal asymmetry was not seen during music-listening or peak-emotion. In contrast, the results here indicate a significant decrease in frontal lobe activity and support the DFCT’s prediction that emotional intensity and frontal activation are not linearly related. Rather, the DFCT predicts that frontal lobe activity and emotional intensity will increase concurrently followed by a decrease in frontal lobe activity as emotional intensity continues to increase during a peak-emotion.

Evidence for decreased cerebral activity during peak-emotion, while listening to music, has also been found previously. Using fMRI, Blood and Zatorre (2001) found decreases in BOLD in the right ventromedial PFC when participants experienced intense music-evoked emotions reported as “chills”. Thus, the current experiment contributes to the music-evoked emotion literature by providing further evidence that the frontal lobes may deactivate during intensely pleasurable emotions.

According to the DFCT, these intensely pleasurable emotions not only result from frontal lobe deactivation, but from concurrent posterior brain activation as well. The DFCT predicts that
intense and provocative stimuli such as music can exceed the functional capacity of the frontal lobes to regulate emotion resulting in the release of inhibition of the temporal, parietal, and occipital lobes. When frontal lobe capacity is exceeded, a release of inhibition should result in a concurrent increase in beta power in the temporal, parietal, and occipital lobes. Consistent with this, during peak-emotion, beta power at the left frontal site was significantly lower than the left temporal, parietal, and occipital lobe. This finding has several implications. One, it is consistent with recent research that suggests highly pleasurable music may elicit greater connectivity between regions. Salimpoor et al. (2013) found positive correlations between valuations of unfamiliar musical stimuli and connectivity between auditory and reward-processing areas. In other words, Salimpoor et al. (2013) and these results both show a relationship between emotional intensity and a predicted frontal lobe release of inhibition of posterior regions in the brain. Additionally, Flores-Gutierrez (2007) investigated functional connectivity with fMRI and EEG coherence simultaneously while participants listened to three musical masterpieces (2 pleasant, 1 unpleasant). A left cortical network was evident, involved with pleasant feelings that included the left primary auditory cortex, posterior temporal, inferior parietal and prefrontal regions. The relative changes in frontal versus posterior activity in this experiment, as well as the cerebral networks identified in the previous experiments may contribute to a larger understanding of how the frontal lobes and posterior sensory regions interact with each other during intense emotions and may inform current theories of emotional-regulation. For example, according the DFCT, multiple concurrent demands on the frontal lobes may make individuals with low capacity more susceptible to emotional deregulation. This may apply to individuals with addiction who, according to this theory, would be less able to inhibit impulses to use drugs.
when there are multiple demands on the frontal lobes. Although this idea may not be new, the DFCT may provide additional neuropsychological evidence for this notion.

Another contribution to the music-evoked emotions literature from this experiment is a possible explanation for several well documented music related phenomena including “chills”, “thrills”, “goosebumps”, and “shivers down the spine” described in detail by Blood and Zatorre, (2001). These sensations are commonly reported by individuals experiencing intensely pleasurable emotions and currently, an explanation for this phenomenon has not been provided. Greater posterior compared to frontal beta activation during peak-emotion may explain these sensory alterations; increased parietal lobe activity may contribute to the production and perception of these altered sensory experiences. Since the frontal lobe, hypothalamus, and medial forebrain bundle play an important role in body temperature regulation, (Nishimura and Nishimura, 1991) it might also be that in this experiment, “chills”, “goosebumps”, and “shivers down the spine” associated with peak-emotions may result from decreased beta power in the frontal lobes.

The results from this experiment appear to be consistent with the Valence Theory (Tomarken, Davidson, & Henriques, 1990), since changes in beta power at the left hemisphere, particularly in the left temporal-parietal region, occurred during intensely positive emotion, while participants listened to positively valenced music. In contrast to the Valence Theory however, the DFCT predicts patterns of cerebral activation/deactivation through the full range of emotional intensity. Specifically, this experiment provides evidence that an intense positive emotion is actually associated with a decrease in left frontal lobe activity while the Valence Theory would predict an increase in left frontal activation as emotional intensity increases. It is
not the case that the Valence Theory is incorrect. Instead, these results indicate that the relationship between frontal lobe activity and emotional intensity may not be linear.

The opposing theory to the Valence Theory, the Right Hemisphere Model (Bowers, Heilman, 1989), contests that the right hemisphere is solely responsible for mediating emotions regardless of valence. This theory states that the right frontal lobe modulates emotional experience, while the right parietal lobe contributes to the level of emotional intensity and autonomic arousal. This appears consistent with the current findings. Specifically, beta power at the right posterior sites, including the right parietal lobe during music-listening and during peak-emotion, was significantly higher than at the right frontal lobe. Right frontal lobe beta power did not decrease significantly from baseline to peak-emotion, as predicted. However, this pattern does support the DFCT and the Right Hemisphere Model, in that music-listening and peak-emotion are associated with a concurrent decrease in beta power at the frontal region and increased beta power at the posterior cerebral region. Because the emotions experienced by participants were positively valenced, the changes in the left and right hemisphere appear to agree with both theories. However, as previously discussed in this paper, the DFCT predicts that emotional intensity may mediate the relationship between the frontal and posterior regions of the brain, without regard to lateralization, and this was partially supported in the current experiment. Furthermore, in regards to the two predominant theories of emotions, laterality findings have not distinguished between the intensity of music-evoked emotions, but bilateral frontal EEG activity increases have been shown to correlate with increased emotional intensity (Schmidt & Trainor, 1994).

As predicted, there was a main effect for SEX. However, when the data from each sex were analyzed separately, no main effects or interaction effects were found for males. In females,
there was a significant main effect for LOCATION, indicating relatively larger beta power at the posterior regions than that found at the frontal regions of the brain. This finding may provide further support of less functional cerebral lateralization in females than in males. For example, (Flores-Gutierrez, 2008) found that pleasant emotions, while listening to classical musical pieces (e.g. Mahler, Bach), increased upper alpha couplings linking left anterior and posterior brain regions, while unpleasant emotions (Prodromidès) were sustained by posterior midline coherence exclusively in the right hemisphere in men and bilaterally in women.

Beta power decreased from the baseline to music-listening and peak-emotion phase and this pattern may differ from Schmidt and Trainor’s (2001) finding of a significant positive correlation between adults’ ratings of intensity of music and overall frontal EEG power (decreased alpha power). However, on a scale of 1 to 9, the highest rated positively valenced song used in their experiment ($M = 6.18, SD = 2.26$) may not induce sufficient emotional arousal necessary to produce a peak-emotion. Pavlygina, Sakharov, Davydov, (2004) found that listening to rock music (of moderate and high intensity) produced increases in theta and low alpha power while Tatsuya, Mitsuo, & Tadao (1997) found alpha power reductions during both stimulating and calm music. Researchers agree that these differences in cerebral activation may result from differing methodology and stimuli used in the experiments.

A few studies investigated the association between beta power and emotional processing (e.g., Aftanas, Reva, Savotina, & Hakhnev, 2006; Sebastiani, Simoni, Gemigani, Gherladucci, & Santarcangelo, 2003). They mainly reported an increase in beta power following an unspecific increase of emotional arousal (mainly independent of valence). Nakamura et al. (1999) also reported an increase in beta from rest to music-listening. Widely distributed EEG beta activity is thought to be related to increased alertness and activation with cognitive processes (Steriade,
Beta rhythm is used as a measure of cortical integrity, because it is diminished in the presence of cortical injury. Additionally, reduced beta activity, whether diffuse or focal, indicates compromised cortical function (Kozelka, Pedley, 1990). In this experiment, the significant decrease in beta activity may reflect diminished cortical integrity in the form of capacity limitations, directly resulting from excess functional processing demands underlying emotional release and occurring with a reduction in frontal lobe regulatory control. Once frontal lobe capacity is exceeded, the DFCT predicts a functional disconnect between this region and the posterior brain region as indicated by beta activation reduction. This uncoupling or release of regulatory control over the posterior brain regions would underlie a sensory and perceptual increment in intensity and an unbridled emotional experience secondary to exposure to high intensity events (see Harrison, 2015).

Thomson, Reece, and Di Benedetto (2014) found a relationship between music-related mood regulation behaviors and levels of psychopathology. Thomson et. al (2014) investigated several mood regulation strategies that employed the use of music, including Discharge (venting of negative emotion through music), Diversion (distraction from worries and stress), and Entertainment (happy mood maintenance and enhancement) providing a basis for the prediction of depression, anxiety, and stress. Discharge predicted high levels of depression, anxiety, and stress; Diversion predicted high levels of anxiety and stress; and Entertainment predicted low levels of depression. The authors suggest that music-related mood regulation may perform a maladaptive function in certain individuals that promotes psychopathology. However, the authors acknowledge that it is equally plausible that young people experiencing psychopathology are more likely to employ music in an attempt to reduce their symptoms. The current experiment provides evidence that individuals are capable of producing significant
music-induced neurophysiological changes and mood changes from listening to self-selected music. This may be an example of the Entertainment process described by Thomson et al. (2014). This evidence may support Thomson et al. (2014) proposition that there are practical implications for the use of music as a self-therapeutic resource for young people with psychopathology in music therapy settings. A factor to be considered here is the role of frontal lobe capacity. As previously hypothesized, the low capacity associated with anxiety and depression, and psychopathology in general, may allow these individuals to intensify both positive and negative emotions by exceeding their frontal lobes’ emotional regulation capacity.

Specifically, this may be occurring in the case of Discharge, where participants vent negative emotion by exceeding frontal lobe capacity with music. Since these individuals are more prone to experiencing negative intense emotions, these individuals may be unwittingly exacerbating their depression and anxiety.

On the other hand, Fachner, Gold, and Erkkila (2013) have shown that music therapy has beneficial effects on cortical activity in depressed individuals. They have shown that music listening shifted frontal alpha asymmetries in depression. Specifically, relative right frontal alpha attenuation occurred during and after music-listening, along with increases in frontal midline theta. Moreover, they found that music therapy significantly reduced depression and anxiety symptoms with lasting changes in resting EEG after three months of music therapy with significant absolute alpha power increases at the left fronto-temporal region. Fachner et al. (2013) conclude that music therapy may induce neural reorganization in this area. Although the music-listening procedure used in this experiment is not music therapy per se, such neural reorganization could likely result from numerous and repetitive changes in frontal lobe activity, like those seen in the present experiment.
Schafer, Smukalla, & Oelker (2014) have also shown that intense musical experiences (IMEs) prove to be of high significance for the people who have them. They investigated the long-term effects of such experiences on people’s way of life and developed a process model where: (1) IMEs lead to altered states of consciousness, which leads to the experience of harmony and self-realization; (2) IMEs leave people with a strong motivation to attain the same harmony in their daily lives; and (3) IMEs cause long-term changes to occur in people’s personal values, their perception of the meaning of life, social relationships, engagement, activities, and personal development. They conclude that music can change lives by making it more fulfilling, spiritual, and harmonious. It could be reasoned that such changes in motivation and engagement are associated with the activation of the limbic system and reward-center of the brain during intensely positive music-evoked emotions seen in previous research (Blood & Zatorre, 2001), and with the large neurophysiological changes induced during the peak-emotions experienced in this experiment. For example, some participants described their peak-emotions as “harmonious”, and “spiritual”. It is plausible that the effect of IMEs and music-induced peak-emotions can have wide ranging psychological benefits resulting from neural reorganization associated with significant changes in brain electrical activity as seen in the present experiment. In several ways, these experiences may be similar to what Robert Maslow described as “peak experiences” in which individuals can achieve self-actualization.

Several limitations in this experiment should be noted. First, the nature of dividing the EEG data, by using self-reported emotional intensity ratings, may have introduced variability and altered the results in several unforeseen ways. For example, several participants did not experience a peak-emotion, while others experienced a peak-emotion within the first thirty seconds of the song, which resulted in a music-onset period with less than thirty seconds of
usable data. On occasion, the recorded peak-emotion period was less than thirty-seconds. Collectively, this had the effect of considerably reducing the amount of usable data for the analyses. Another potential issue is when participants experienced a peak-emotion within the first minute of the song, which resulted in the music-onset and peak-emotion phases being temporally adjacent and nearly continuous. This could mean that emotional intensity was rapidly increasing during the music-onset phase and that the unexpected decrease in beta from baseline to music-onset was the result of how the self-reported emotional intensity ratings were used to demarcate the levels of time. Specifically, it is possible that emotional intensity ratings during this period could occasionally reflect a ramping up of emotion, when the music-onset period was designed to serve as somewhat of a control. Overall, Schubert (2013) found the reliability of continuous emotional response to be quite good, but suggest that caution must be taken as to how to deal with the opening and the ending of continuous emotional response data.

It appeared that a fair amount of artifact was present in both the EEG and EOG data during the peak-emotion phase. This could be because many participants reported experiencing noticeable changes in respiration and muscle tension/relaxation, as well as becoming teary-eyed or close to it, and other physiological changes associated with intense emotions that can introduce artifact. Unfortunately, these cannot be avoided. Artifact elimination from the EEG record remains a best effort process rather than a process of absolute integrity in signal and noise discrimination techniques. The experimenter also observed a small but visible front to back movement of the head and upper trunk in many participants, while they listened to music. When asked about this, none of the participants were aware that this was happening. This movement may have also contributed artifact to the EEG signal. Although the control rating dial which was controlled with the right hand was very simple and straightforward, participants occasionally
needed to look down to ensure accuracy in reporting their emotional intensity and this also produced artifact. This was apparent in the VEOG and HEOG signals, which indicated a rightward and downward eye movement pattern that occurred more frequently at the beginning of the song, and during peak-emotion. Although this was considered during the design of the present experiment, control rating dial feedback from a monitor placed in front of the participants might reduce eye-movement related artifact. However, it could also introduce confounding variables such as changes in visual stimulation and an attentional shift from audition to vision.

Although necessary for this experiment, the exclusive use of participants who are able to experience intense music-evoked emotions may have introduced selection bias. Previous research has used participant-selected music for experimental stimuli (Blood & Zatorre, 2001). However, such songs capable of evoking intense emotions might also activate song related memories, which may help contribute to the emotional intensity. Thus, unlike stimuli in many experiments that are standardized and unfamiliar to participants, songs used in this experiment may be activating cerebral networks that go beyond the music-related networks.

Future investigations of music-evoked emotions and the frontal lobe regulatory control or capacity should consider these limitations. To improve upon these limitations, researchers might analyze emotional intensity data and EEG data continuously, rather than comparing distinct time periods (e.g., baseline, music-onset, etc.). Researchers will continue to face song variables (e.g., tempo, modality, vocal, lyric content, etc.) that are difficult to control for in experiments utilizing self-selected music. One suggestion is that researchers ask participants to select many more songs and submit them to the researchers prior to the experiment so that the researchers can identify variables in common with all participants’ songs. This would be one step towards
controlling for the great variability in the songs different participants might choose. In order to further test the DFCT, participants could listen to songs capable of evoking intense emotions and researchers might ask them to suppress any emotions they might experience while listening to the songs. Music was chosen as the stimulus domain of interest in this experiment partially based upon its ability to evoke pleasant emotions and intense pleasant emotions, potentially in excess of the functional limitations of frontal regions charged with regulatory control, down regulation, and inhibition of brain regions more directly involved in sensory reception, analysis, comprehension, and the experience of emotional depth. To further test the DFCT and specifically the hypothesis that intense emotions, regardless of valence, are associated with bi-frontal lobe deactivation of oppositional systems, stimuli capable of evoking intensely unpleasant emotions should be used. However, IRB approval of such stimuli may be difficult.

The present experiment has provided evidence of frontal lobe deactivation with concurrent temporal, parietal, and occipital lobe activation during intensely pleasurable emotions induced by music. This finding is partially consistent with several current predominant neuropsychological theories of emotion. However, it is inconsistent with these theories’ assumption that the relationship between emotional intensely and frontal lobe activity is linear and that mechanisms exist for situations in which processing capacity limitations exist capable of yielding an unbridled emotional experience. Moreover, it is derived from this capacity theory that these mechanisms are fundamental, within an evolutionary context for survival, and for protection of the underlying neuroanatomical and neurophysiological architecture under extreme stress conditions (see Harrison, 2015). The research findings from the present experiment may have implications for the understanding of emotional regulation and deregulation in various forms of psychopathology (e.g., mood disturbances) by providing a neuropsychological theory
based ultimately upon functional neural systems theory. It may well have implications also for PTSD related disorders, where extremely intense emotional experiences have been directly related to focal neuroanatomical damage and/or neurodegenerative disturbances. Finally, the DFCT may prove complimentary to current neuropsychological theories of emotion, whereas the predictions and findings from the DFCT argue for modification of each of these theoretical positions (see Harrison, 2015).
References


Running Head: DFCT AND MUSIC-EVOKED EMOTIONS


Reasoning and Attention Studied with Positron Emission Tomography. *Intelligence* 12, 199-217.


Running Head: DFCT AND MUSIC-EVOKED EMOTIONS


Appendices

Appendix A: Participant Experience Form

Participant Experience Form

1. While listening to that piece of music, did you experience any intense emotions?
   a. Yes
   b. No

2. If you did experience an intense emotion, was it generally positive or negative? Circle one:
   a. Positive
   b. Negative

3. When you experienced an extremely intense emotion, did you indicate it by turning the dial all the way to the right?
   a. Yes
   b. No

4. On the line below, mark an X on the line to indicate the intensity of your emotional experience when you turned the dial all the way to the right, with a mark all the way to left indicating very little or no emotional intensity and a mark at the end of the line indicating extreme emotional intensity.

   ________________________________________________________
   ________________________________________________________

5. Which of the following describe how you felt as you experienced an intense emotion? You can choose as many as you need.
   a. Joy
   b. Happiness
   c. Enjoyment
   d. Delight
   e. Sweetness
   f. Beauty
   g. Calm
   h. Relaxing
   i. Peaceful
   j. Harmony
   k. Stillness
   l. Elation
   m. Excitement
   n. Tension
   o. Intoxication
p. Rapture
q. Blissful
r. Euphoric
s. Ecstasy
t. Transcendental
u. Spiritual
v. Words cannot sufficiently explain
w. Complete loss of control
x. Amazed
y. Spellbound
z. Totally overwhelmed
aa. Out-of-body experience
bb. Sadness
cc. Empty
dd. Longing
ee. Melancholy
ff. Nervous
gg. Shame
hh. Anxiety
ii. Fear
jj. Dread
kk. Despair

6. If you experienced any bodily sensations during your peak emotion, what were they?
   Choose as many as you need.
   a. I cried
   b. I became teary-eyed
   c. I experienced chills
   d. I felt shivers
   e. I had goose bumps
   f. I felt my muscles get tense
   g. I felt muscle relaxation
   h. I felt warm
   i. I felt changes in my heart rate or rhythm
   j. I trembled/quivered
   k. I felt changes in my chest or stomach
   l. It felt like there was a lump in my throat
   m. I experienced dizziness
   n. I felt pain
   o. I felt weightless or like I was floating
Participant Experience Form

7. While listening to that piece of music, did you experience any intense emotions?
   a. Yes
   b. No

8. If you did experience an intense emotion, was it generally positive or negative? Circle one:
   a. Positive
   b. Negative

9. When you experienced an extremely intense emotion, did you indicate it by turning the dial all the way to 9?
   a. Yes
   b. No

10. On the line below, mark an X on the line to indicate the intensity of your emotional experience when you turned the dial all the way to the right, with a mark all the way to left indicating very little or no emotional intensity and a mark at the end of the line indicating extreme emotional intensity.

____________________________________________________________________

11. Which of the following describe how you felt as you experienced an intense emotion? You can choose as many as you need.
   a. Joy
   b. Happiness
   c. Enjoyment
   d. Delight
   e. Sweetness
   f. Beauty
   g. Calm
   h. Relaxing
   i. Peaceful
   j. Harmony
   k. Stillness
   l. Elation
   m. Excitement
   n. Tension
   o. Intoxication
   p. Rapture
   q. Blissful
   r. Euphoric
   s. Ecstasy
   t. Transcendental
u. Spiritual  
v. Words cannot sufficiently explain  
w. Complete loss of control  
x. Amazed  
y. Spellbound  
z. Totally overwhelmed  
aa. Out-of-body experience  

12. What bodily sensations did you experience when you had your ‘peak-emotion’? Choose as many as you need.
   a. I cried  
   b. I became teary-eyed  
   c. I experienced chills  
   d. I felt shivers  
   e. I had goose bumps  
   f. I felt my muscles get tense  
   g. I felt muscle relaxation  
   h. I felt warm  
   i. I felt changes in my heart rate or rhythm  
   j. I trembled/quivered  
   k. I felt changes in my chest or stomach  
   l. It felt like there was a lump in my throat  
   m. I experienced dizziness  
   n. I felt pain  
   o. I felt weightless or like I was floating
### Appendix B: Medical Health Questionnaire

**Participant #________________**

**Medical History Questionnaire**

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Y</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Do you have any history of congenital or developmental problems?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Do you have any history of learning disabilities or special education?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Have you ever suffered a head injury resulting in a hospital stay longer than 24 hours</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Have you ever been knocked out or rendered unconscious (more than 5 minutes)?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>Have you ever suffered &quot;black-out&quot; or fainting spells?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>Do you have a history of other neurological disorders (e.g. stroke or brain tumor)?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>Have you ever received psychiatric/psychological care or counseling?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>Have you ever been hospitalized in a psychiatric facility/hospital?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Have you ever been diagnosed with a psychiatric/psychological disorder?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>10</td>
<td>Have you ever been administered any (neuro)psychological tests or measures?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>11</td>
<td>Do you have a history of substance abuse or alcohol abuse?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>12</td>
<td>Do you have a history of high blood pressure?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>13</td>
<td>Do you have any uncorrected visual or hearing impairments?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>14</td>
<td>Are you able to read, write, and speak English effectively?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>15</td>
<td>Do you consume three or more alcoholic drinks more than two nights a week?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>16</td>
<td>Have you ever experienced a medical or psychiatric condition that could potentially affect cognitive functioning, such as stroke, electroconvulsive treatment, epilepsy, brain surgery, encephalitis, meningitis, multiple sclerosis, Parkinson's Disease, Huntington's Chorea, Alzheimer's dementia, Schizophrenia, Bipolar Disorder?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>17</td>
<td>Have you ever used smoked or used tobacco products?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>18</td>
<td>Do you use any unprescribed or &quot;illegal/street&quot; drugs?</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Question</td>
<td>Y</td>
<td>N</td>
<td></td>
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<tr>
<td>-------------------------------------------------------------------------</td>
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<tr>
<td>Are you taking any of the following medications: antidepressant,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>antianxiety, antipsychotic?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you taking any allergy or cold medication?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If you answered “yes” to any of the above please explain fully:

_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________

MORE ON NEXT PAGE

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Appendix C: Screener Survey

Online Screening Survey

Screener Survey

Please answer the following questions as accurately and honestly as possible. Some of these questions will ask you about your emotional experiences with music, particularly about intensely pleasant emotional reactions that you might have when you listen to music. These pleasant intense emotional reactions to music are often described as feeling “chills”, “thrills”, or “goosebumps”, happiness, joy, ecstasy, euphoria, excitement, or “shivers up and down your spine”. These intense emotions can be accompanied by crying, becoming teary-eyed, and by sudden changes in breathing, heart rate, or changes in your stomach and chest. On a scale of 1 to 10, with 10 being the highest level of emotional intensity, these intense emotions should be around a 7 or higher.

1. Have you ever experienced a very strong or intense emotion when you listened to music? In other words, the intensity of the emotion you experienced was about a 7 out of 10.
   a. Yes
   b. No
   c. I don’t know

2. How often do you experience intense emotional reactions to music?
   a. I never have
   b. Once in my life
   c. A few times in my life
   d. About once a year
   e. About once a month
   f. About once a week
   g. Almost every day
   h. Almost every time I listen to music
   i. I don’t know

3. Do you intentionally listen to music in order to feel intense emotions?
   a. Yes
   b. No
   c. I don’t know

4. How easily are you able to experience an intense emotion when listening to a song or piece of music?
   a. It is impossible or it has never happened
   b. It is very difficult
   c. It is not very difficult
   d. It is very easy
e. I can experience an intense emotion to music almost anytime I desire
f. I don’t know

5. Do art (visual art such as paintings, sculptures, drawings) or media (TV shows, movies, etc.) give you intense emotional feelings?
   a. Yes
   b. No
   c. I don’t know

6. Do you play any musical instruments?
   a. Yes
   b. No

7. Have you ever had any music lessons?
   a. Yes
   b. No

8. Would you consider yourself a musician?
   a. Yes
   b. No
   c. I don’t know

9. How many years of formal musical education have you received?
   a. I have no formal musical education
   b. Less than 1 year
   c. 1 – 4 years
   d. 4 – 8 years
   e. 8 – 12 years
   f. 12 or more years

10. How much do you enjoy music?
    a. Not at all
    b. A little bit
    c. Somewhat
    d. Very much
Appendix D: Figure 1

Figure 1. SEX by LOCATION by TIME interaction with beta power as the dependent variable. Overall, women exhibited greater overall beta power. Compared to men, women displayed greater bi-frontal lobe beta deactivation from baseline to music-onset and peak emotion.
Appendix E: Figure 2

Figure 2. Each level of LOCATION and TIME for beta power including both sexes is displayed. At the left frontal site, beta power decreased significantly from time 1 to time 3, providing evidence for exceeded capacity at time 3 when participants reported experiencing a peak-emotion. At the left posterior sites, beta power was significantly lower in the frontal sites than posterior sites at time 3 when participants reported experiencing a peak-emotion.