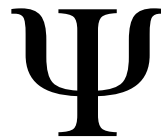




**DET PSYKOLOGISKE FAKULTET**



*Multisensory Integration of Emotional Stimuli: an fMRI Study of the  
Immediate and Enduring Effects of Emotional Film and Music*

**HOVEDOPPGAVE**

*profesjonsstudiet i psykologi*

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### Abstract

Responding appropriately in social contexts depends on the integration of emotional information from multiple sensory organs into a coherent construct of a situation. Research has identified a multisensory integration network of anterior superior temporal gyrus (aSTG), fusiform gyrus (FG), and amygdala (AMY; Pehrs et al., 2014; Pehrs et al. 2015). In the present study, largely based on Pehrs et al. (2014), two groups saw sad or happy film clips during fMRI scanning, coupled with alternating sad, happy or no music. The imaging results demonstrated increased STG activity during happy music and increased activity in default mode network (DMN) related areas during sad music. Incongruent audiovisual presentations were associated with increased activity in inferior temporal gyrus/temporal pole (ITG/TP) and medial prefrontal cortex (mPFC). The involvement of the aSTG-FG-AMY network in multisensory integration of emotional information was demonstrated with emotion-specific changes in connectivity. Congruent presentations of happy music and film were associated with increased coupling strength from FG to AMY, in contrast to previous findings of decreased coupling strength in the congruent condition (Pehrs et al., 2014). Sad visual stimuli produced increased network connectivity independent of the music, suggesting an increased information flow from AMY to FG, with aSTG as a mediator. Resting state data revealed attenuated connectivity between dorsal anterior cingulate cortex (dACC) and the posterior default mode network (DMN) in the group that had watched the sad film clips, showing enduring effects of emotional audiovisual stimuli on resting state activity.

*Keywords:* multisensory integration, emotional processing, fMRI, resting state fMRI, network analysis

### Sammendrag

Passende responser i sosiale kontekster er avhengig av å kunne integrere emosjonell informasjon fra flere sanseorganer til en sammenhengende representasjon. Tidligere

forskning har identifisert et nettverk for multisensorisk integrasjon, bestående av anterior superior temporal gyrus (aSTG), fusiform gyrus (FG) og amygdala (AMY; Pehrs et al. 2014; Pehrs et al. 2015). I denne studien, som i stor grad er basert på arbeidet til Pehrs og kollegaer (2014), så to grupper triste eller glade filmklipp under scanning i en funksjonell MRI-maskin, mens de lyttet til enten glad, trist eller ingen musikk. fMRI-resultatene demonstrerte økt STG-aktivitet ved glad musikk og økt aktivitet i områder relatert til default mode network (DMN) ved trist musikk. Presentasjoner av inkongruent audiovisuell stimuli var assosiert med økt aktivitet i inferior temporal gyrus/temporal pol (ITG/TP) og medial prefrontal cortex (mPFC). Rollen til aSTG-FG-AMY-nettverket i multisensorisk integrasjon av emosjonell informasjon ble demonstrert, med emosjonsspesifikke endringer i konnektivitet. Kongruente presentasjoner av glad musikk og film var assosiert med forsterket kobling fra FG til AMY, dette i kontrast til tidligere funn av redusert kobling i den kongruente betingelsen (Pehrs et al., 2014). Trist visuell stimuli produserte forsterket konnektivitet i nettverket, uavhengig av musikken. Dette antyder en økt informasjonsflyt fra AMY til FG med aSTG som en mediator. Resting state-resultatene viste dempet konnektivitet mellom dorsal anterior cingulate cortex (dACC) og posterior DMN i den gruppen som hadde sett på triste filmklipp. Dette viser vedvarende effekter av emosjonell audiovisuell stimuli på resting state-aktivitet.

*Nøkkelord:* multisensorisk integrasjon, emosjonsprosessering, fMRI, resting state fMRI, nettverksanalyse

## Introduction

In social interaction, emotional information is largely multimodal and comes from different sources such as facial expressions, vocal prosody, body language, and gestures, all of which express the emotional state of the individual. These signals may be congruent, such as a happy face and the sound of laughter, or incongruent, such as in the display of irony. Responding appropriately in social situations requires attention to all sources of emotional input. Thus, successful social interaction depends on the integration of emotional information from multiple sensory organs into a coherent construct of the situation. How the brain accomplishes this multisensory integration is not fully understood (Jeong et al., 2011). Studies of the neural correlates of emotional multisensory integration have used a variety of multimodal stimuli, such as pictures of emotional facial expressions coupled with emotional human sounds (Müller et al., 2011), videos of emotional facial mimicry coupled with vocal prosody (e.g. Klasen, Kenworthy, Mathiak, Kircher, & Mathiak, 2011; Kreifelts, Ethofer, Huberle, Grodd, & Wildgruber, 2010; Robins, Hunyadi, & Schultz, 2009), and emotional music and dynamic films of social interaction (Pehrs et al., 2014; Pehrs et al., 2015).

Functional neuroimaging provides a method to investigate the neural mechanisms of multisensory integration in the human brain. Functional brain imaging, such as functional magnetic resonance imaging (fMRI), enables the observation of brain function in vivo (Calvert & Thesen, 2004). fMRI detects signals originating from the different magnetic properties of deoxygenated blood compared to oxygenated blood (Pauling & Coryell, 1936). When a brain area is active, blood flow and glucose utilization in this area is up-regulated, and oxygen availability increases (Gusnard & Raichle, 2001). This increase in oxygen availability, and hence the local changes in magnetic properties, accounts for the blood oxygenation level-dependent (BOLD) signal which is measured in fMRI (Kwong et al., 1992; Ogawa et al., 1993). Therefore, the BOLD signal indirectly reflects the neural responses to a

stimulus (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001). fMRI has become a popular method of studying the neural correlates of diverse tasks and processes, as well as structural and functional connections between brain regions, both during task performance and during rest. Numerous studies have applied fMRI in the study of neural correlates of emotion and integration of multisensory emotional information.

Music has been shown to evoke emotions and therefore provide a good method for investigating the neural correlates of emotions using fMRI (Blood, Zatorre, Bermudez, & Evans, 1999; Koelsch, 2010; Zatorre, 2015). Music is associated with activity in emotional core regions such as the amygdala (AMY), parahippocampal gyrus, hippocampus, temporal poles (TP), cingulate cortex, hypothalamus, striatum, orbitofrontal cortex (OFC), insula, and the midbrain (see Koelsch, 2010 and 2014 for reviews). Some of these areas are illustrated in Figure 1.

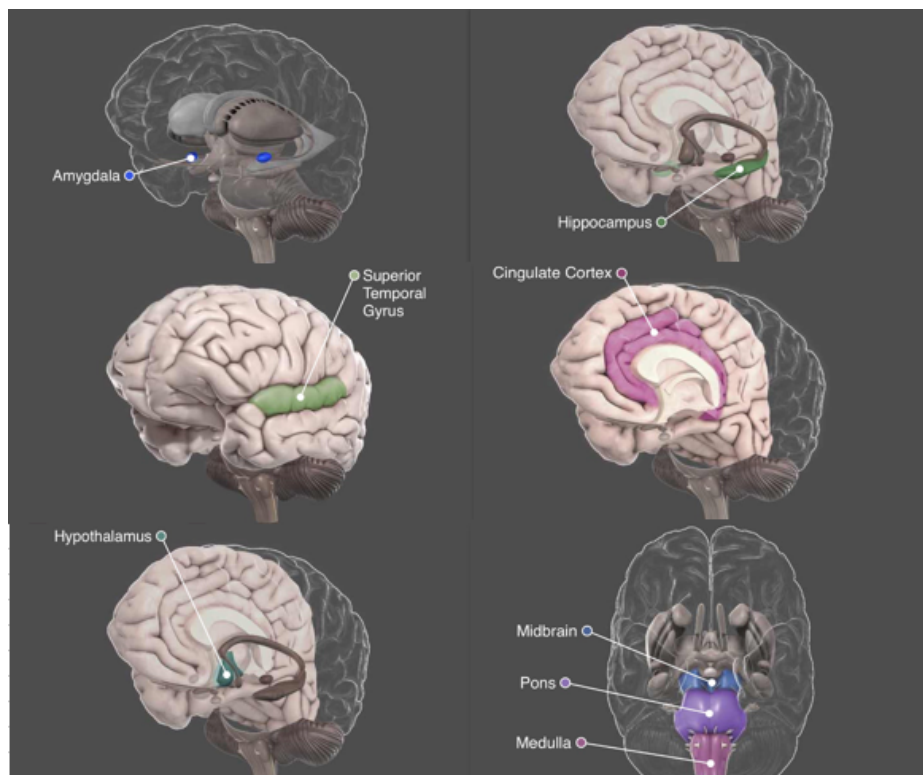


Figure 1: Illustrations of some of the anatomical sites seen to be activated in previous studies on music and emotion. 3D brain application by Connolly & Nisselle (2009).

These areas are associated with emotions and behaviours such as arousal, motivation and reward-seeking, and withdrawal or approach (Baumgartner, Esslen, & Jäncke, 2006). Listening to music can even lead to neural activation resembling that observed in the context of strong reward stimuli like food, drugs, and sex (Blood & Zatorre, 2001). Emotion-evoking films are also associated with activity in emotion-related brain areas. Britton and colleagues (2006) showed that films that evoke social emotions of joy and sadness activated AMY, superior temporal gyrus (STG), hippocampus and posterior cingulate cortex (PCC). Joyful films also activated OFC and nucleus accumbens, while sad films additionally activated the anterior cingulate cortex (ACC; Britton et al., 2006).

Pictures and films also have the ability to evoke emotions (Britton et al., 2006; Lang, Greenwald, Bradley, & Hamm, 1993), and has been combined with music to provide a multisensory emotional context during functional imaging (Baumgartner, Esslen, et al., 2006; Jeong et al., 2011; Pehrs et al., 2014; Pehrs et al., 2015). Music function as a source of emotional information when watching a movie (Baumgartner, et al., 2006a; Cohen, 2001; Pehrs et al., 2014). For example, a film clip is perceived differently depending on the emotional quality of the music accompanying it (Baumgartner et al., 2006a; Jeong et al., 2011; Pehrs et al., 2014; Pehrs et al., 2015). Vitousch (2001) presented film clips together with either happy or sad music, and demonstrated that the emotional quality of the music affected the participants' expectations about the continuation of the scene in accordance to the emotionality of the music. Further, music can affect people's impression about the characters' emotions, personality traits and intentions (Tan, Spackman, & Bezdek, 2007; Vitouch, 2001). Happy music can make viewers infer that the character in the film is happy, and the presence of scary music can make subjects assume that the character has malicious plans (Tan et al., 2007). Adding music to emotional pictures and film intensify the evoked emotional experience, in terms of rating emotional stimuli as more intense if accompanied by

corresponding emotional music (Baumgartner et al., 2006a; Baumgartner, Lutz, Schmidt, & Jäncke, 2006b; Pehrs et al., 2015). Also, the audiovisual combination of emotional music and film has been shown to evoke stronger activity in emotional brain areas than music alone (Baumgartner et al., 2006b; Eldar, Ganor, Admon, Bleich, & Hendler, 2007; Pehrs et al., 2014). The combination of music and film can be used to simulate the multimodal social world where emotional stimuli come from many different sources, from facial expressions and vocal prosody, to body language (Regenbogen et al., 2012). Also, combining visual and auditory emotional stimuli provides a context of studying conflicting or incongruent emotional perception.

The following section will provide an overview of the current research findings on the neural mechanisms of multisensory integration of emotional stimuli, both emotional stimuli in general and related to film and music specifically. Studies of how the brain process incongruent multimodal emotional stimuli will also be highlighted. The issue of spontaneous brain activity during rest and how this activity is affected by emotional input will be discussed to provide a background for the present investigation of resting state activity after perception of emotional stimuli.

### **Neural Correlates of Multisensory Integration of Emotional Stimuli**

In studying the neural correlates of multisensory integration of emotional information, many studies have used human voices and facial expressions as bimodal stimuli (Dolan, Morris, & de Gelder, 2001; Ethofer et al., 2006; Klasen et al., 2011; Kreifelts, Ethofer, Grodd, Erb, & Wildgruber, 2007; Kreifelts et al., 2010; Park et al., 2010; Pourtois, de Gelder, Bol, & Crommelinck, 2005; Robins et al., 2009). Often, the voices pronounce a word or a sentence in an emotional tone, presented with a picture or a film of an emotionally congruent or incongruent facial expression, and the participants must report the emotion they perceive. These types of studies have investigated a range of different emotions and implicated several



brain areas in multimodal emotion processing, such as the STG and superior temporal sulcus (STS; Klasen et al., 2011; Kreifelts et al., 2007; Pourtois et al., 2005; Robins et al., 2009), AMY, fusiform gyrus (FG; Dolan et al., 2001; Ethofer et al., 2006; Kreifelts et al., 2010), thalamus (Klasen et al., 2011; Kreifelts et al., 2007), medial temporal gyrus (MTG; Park et al., 2010; Pourtois et al., 2005), and TP (Baumgartner et al., 2006b; Robins et al., 2009). These areas show increased activity during multimodal emotion perception compared to unimodal perception.

Some studies have used music as auditory input instead of vocal prosody, combined with pictures or films (Baumgartner et al., 2006a; Baumgartner et al., 2006b; Eldar et al., 2007; Pehrs et al., 2014; Pehrs et al., 2015). Baumgartner and colleagues (2006b) showed that adding emotional music to affective pictures produced activity in emotional brain areas such as AMY, insula, hippocampus, parahippocampus, striatum, ventromedial prefrontal cortex (vmPFC), cerebellum, TP, FG, and PCC/precuneus. Perceiving affective pictures alone elicited activity mainly in the right dorsolateral prefrontal cortex (dlPFC). Eldar and colleagues (2007) demonstrated that adding emotional fear-evoking music to neutral film clips produced additional activity in AMY, hippocampus and lateral PFC (lPFC). Presentation of the music alone did not elicit activity in these areas. The film clips in Eldar and colleagues' (2007) study were selected in order to be emotionally neutral and ambiguous, and had no social aspect to them (opposed to studies using facial expressions). Nonetheless, the study demonstrated the increased neural activity in response to multisensory input compared to unisensory input.

### **Networks and connectivity in multisensory integration.**

In everyday life, social interactions happen in a dynamic interplay between two or more individuals. The use of film showing emotional facial expressions and body language provides a more naturalistic multisensory condition than static pictures or films of faces

alone. Pehrs et al. (2014) studied how emotional music altered the experience of film clips and the underlying neural mechanism of this process. They used dynamic film clips of emotionally positive romantic scenes where couples are kissing accompanied by alternating happy, sad or no music. A whole-brain analysis demonstrated the involvement of AMY, hippocampus, FG, and medial PFC (mPFC) in processing the emotional audiovisual stimuli with increased activity in anterior STG (aSTG) bilaterally during happy music. Based on previous findings, the authors conducted a connectivity analysis with three regions of interest (ROIs) to explore the activity of a network involved in multisensory integration. These ROIs were the aSTG, FG and AMY, and time courses were extracted while participants performed this multisensory emotional integration paradigm (Pehrs et al., 2014). ROIs are pre-defined brain regions chosen to test an a-priori hypothesis about the function of specific brain regions, and the use of ROIs increase the statistical sensitivity to subtle activations in these areas (Maldjian, Laurienti, Kraft, & Burdette, 2003). A connectivity analysis of fMRI data identifies anatomically separated brain regions that show a high level of temporal correlation in their BOLD-signal and are therefore assumed to make up a tightly coupled neural network (Friston, Frith, Liddle, & Frackowiak, 1993; Greicius, Krasnow, Reiss, & Menon, 2003). A more advanced variant of connectivity analysis is dynamic causal modeling (DCM), that is sensitive to changes in the temporal correlation between brain areas, caused by an external stimulus or cognitive processes (Friston, Harrison, & Penny, 2003). Using DCM, Pehrs et al. (2014) demonstrated that together with FG and AMY, the aSTG form a multisensory integration network where aSTG integrates emotional input from AMY and FG. Specifically, they found that aSTG gated the connectivity from FG to AMY, so that activity in the aSTG attenuated connectivity between FG and AMY, whereas activity in FG and AMY had a suppressing effect the BOLD-signal from aSTG. The suppressing effect of aSTG on FG-AMY connectivity was weakest during sad music, resulting in increased information transfer from

FG to AMY during sad music conditions. This showed that the soundtrack had an emotion-specific modulatory effect on this network and the authors suggested that this process may underlie the impact of emotional music on perception of visual stimuli (Pehrs et al., 2014). In a later article, Pehrs and colleagues (2015) examined the possible inclusion of the TP in the network of aSTG, AMY and FG, based on its proposed role as an area of multisensory integration (Olson, Plotzker, & Ezzyat, 2007; Skipper, Ross, & Olson, 2011). Pehrs and colleagues (2015) used negatively valenced film clips and written contextual information to induce empathic concern in participants. Half of the visual stimuli were presented together with sad music, half with no music. The results placed the TP in the integration network of aSTG, FG and AMY (Pehrs et al., 2014), where TP and aSTG gated the fusiform-amygdalar coupling. When film and music were presented together, the backward projection from TP to FG increased. Thus, TP integrates sensory information from different modalities and modulates activity in lower-level perceptual areas, such as the FG (Pehrs et al., 2015).

Different studies have implicated diverse areas in the integration of emotional information in the brain, and there is no clear consensus to date. However, candidate regions have been identified, among others the STG, AMY, FG, TP, and mPFC. The present study will further elucidate the underlying neural mechanisms of multisensory integration of emotional information.

### **Emotionally Congruent and Incongruent Audiovisual Stimuli**

Another question in multisensory integration is how the brain processes incongruent emotional information, when the valence of the inputs does not match. A common finding is that congruent stimuli can enhance the recognition of an emotion, while incongruent stimuli can change emotional perception (De Gelder & Bertelson, 2003; Jeong et al., 2011). It has been shown that pairing a neutral face (digitally morphed in a continuum between a happy and sad expression) with a sentence expressed in a happy or sad tone, can change the

perception of the emotion in the face accordingly (De Gelder & Bertelson, 2003). De Gelder & Bertelson (2003) named this tendency “the emotional McGurk effect”. Similarly, Jeong and colleagues (2011) presented happy and sad music together with images of happy and sad faces. Their behavioural results showed that people rated both happy and sad face as happier when paired with happy music. Happy faces paired with sad music were rated as less happy, and sad faces paired with sad music were rated as sadder. Logeswaran & Bhattacharya (2009) found this effect even when the music was presented before (separately from) seeing the picture. Collignon and colleagues (2008) showed that performance in discriminating between emotions was impaired during incongruent presentations compared to congruent presentations, even when the participants were asked to attend to only one sensory modality. Findings such as these highlight the automatic nature of the integration of stimuli from different sources when making assumptions about a situation.

The neural correlates of the processing of incongruent emotional stimuli has rarely been investigated (Müller et al., 2011), but some findings have emerged. Jeong et al. (2011) found activity in FG and STG to differ depending on the congruence of the emotional content in the music and images. When the music and faces in the images displayed the same emotions, there was a greater BOLD response in STG. There was also a difference between the happy and sad conditions, with stronger activation in STG during presentation of happy music and faces compared to sad music and faces. Incongruent stimuli reduced the BOLD response in the STG and increased the signal in bilateral FG. Similarly, Pehrs and colleagues’ (2014) found a weaker BOLD signal in the STG during the incongruent presentation of sad music and a romantic (happy) kissing scene compared to the congruent condition. Less activation in the aSTG further led to enhanced transfer of information from FG to AMY.

Studies using images of faces and voices as emotional audiovisual stimuli have also identified several brain areas involved in processing incongruent emotional information.

Klasen and colleagues (2011) demonstrated increased activity in dlPFC, operculum, anterior insula, mPFC, ACC, inferior parietal lobe (IPL), precuneus, intraparietal sulcus (IPS), cerebellum and caudate nucleus during presentation of incongruent emotional voices and faces compared to congruent presentations. Congruent trials produced stronger activity in ventral PCC (vPCC), AMY, the right inferior temporal gyrus (ITG), left STG and left insula (Klasen et al., 2011). A study by Müller (2011) used images of happy and fearful faces combined with laughter (happy) and screams (fearful) and found significant incongruence effects in right superior frontal gyrus (SFG), middle cingulate cortex, the right supplementary motor area (SMA) and the right temporo-parietal junction (TPJ; Müller et al., 2011). Etkin, Egner, Peraza, Kandel, & Hirsch (2006) created emotional conflict by showing incongruent emotion words and images of emotional facial expressions, and saw that reaction times in labelling the emotion of the face increased substantially during conflict. The authors argued that the amount of conflict was higher when an incongruent task was preceded by a congruent task, compared to an incongruent task preceded by an incongruent task, which created an expectancy effect. Their fMRI results indicated that activity in dmPFC and dlPFC, as well as AMY, reflected the amount of emotional conflict, with increased activity during high conflict (incongruent trials preceded by congruent trials). Activity in the rostral ACC was associated with resolution of the conflict (incongruent trials preceded by incongruent trials), where there was less behavioural interference of the incongruent word because of the expectancy effect (Etkin et al., 2006). Others have suggested that the ventral portions of mPFC and ACC are involved in emotional conflict processing (Etkin, Egner, & Kalisch, 2011).

Studies of the perception of incongruent emotional information have used a variety of stimuli and tasks to create and evaluate emotional conflict and have implicated many different brain regions. The diversity of methods and areas of focus makes it difficult to make conclusions about the neural correlates of the processing of incongruent emotional stimuli.

### **Audiovisually Evoked Emotions and Resting State Activity**

Beyond the ability of audiovisual stimuli to evoke transient emotions, these emotions may have continuing effects on mental activity, sustaining after the period of exposure (Harrison et al., 2008). Functional imaging provides a context of exploring lasting effects of multimodal emotional information in terms of changes in subsequent brain activity during rest. Resting state fMRI measures the co-occurring, synchronized activity in spatially outspread brain regions that happen in the absence of tasks (Lee, Smyser, & Shimony, 2013). During wakeful rest, brain areas related to monitoring the internal and external environment and to self-referential and introspective mental activity are active (Gusnard & Raichle, 2001; Raichle et al., 2001). Many different resting state networks (RSNs) have been discovered, which are networks of areas that show synchronized increase and decrease in activation and that are assumed to be linked in some functional or structural way (Raichle et al., 2001). The default mode network (DMN) is one important RSN. The brain regions considered part of the DMN are functionally correlated and anatomically connected (see e.g. Andrews-Hanna, 2012; Raichle, 2015) and are more metabolically active during wakeful rest than during cognitive effort (Eryilmaz, Van De Ville, Schwartz, & Vuilleumier, 2011; Spreng & Grady, 2010). The DMN areas have been observed to be consistently deactivated during demanding cognitive tasks such as working memory, language, and attention. Increased activity in DMN related areas has been demonstrated when people are engaged in self-generated thoughts, when asked to think about personal plans and memories, during moral reasoning, in imagining or comprehending novel scenes and narratives, and in making assumptions about others' mental states (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010; Andrews-Hanna, Smallwood, & Spreng, 2014; Buckner, Andrews-Hanna, & Schacter, 2008; Greene, Sommerville, Nystrom, Darley, & Cohen, 2001). These types of mental activities, mentalizing and drawing inference about others internal states, are often referred to as theory

of mind-tasks (Spreng & Grady, 2010). The precise anatomical and functional organization of the DMN is not fully understood (Andrews-Hanna, 2012), however, Andrews-Hanna and colleagues (2010) demonstrated that the DMN can be divided into two subsystems of correlated regions. The medial temporal lobe (MTL) subsystem comprises MTL, the hippocampal formation, parahippocampal cortex, vmPFC, and posterior inferior parietal lobe (pIPL). The dorsomedial PFC (dmPFC) subsystem consists of dmPFC, TPJ, lateral temporal cortex, and the TP. Both systems correlate with the mPFC and PCC, which are considered hubs in the DMN due to their extensive connections with other nodes of the DMN (Andrews-Hanna, 2012; Andrews-Hanna et al., 2010). The DMN is thought to be functionally and anatomically distinct from networks involved in tasks that require external attention (Andrews-Hanna, 2012). Hugdahl, Raichle, Mitra, & Specht (2015) suggested the existence of a network of extrinsic activity, called the Extrinsic Mode Network (EMN). This is a network of areas that are active during all forms of cognitive demands and that is anti-correlated with the DMN. They also suggested the possibility that EMN and DMN are parts of a larger network, and that their activation work in a continuum (Hugdahl et al., 2015). The authors suggested that failure in this dynamic up- and down-regulation may point to neural underpinnings of different mental disorders, such as bipolar disorder and schizophrenia. Further investigations of the DMN and EMN might give us more insight to the function, activations and clinical applications of brain networks.

#### **Enduring effects on resting state activity.**

Studies have demonstrated that the nature of a cognitive and/or emotional task performed during fMRI-scanning affect subsequent resting state activity after the task is completed (Harrison et al., 2008; Pyka et al., 2009; Waites, Stanislavsky, Abbott, & Jackson, 2005). However, the impact of emotional states on subsequent mental activity is still poorly understood (Eryilmaz et al., 2011). Eryilmaz and colleagues (2011) demonstrated that the

emotional valence of film clips (positive, negative or neutral) had different effects on following spontaneous thought content and resting state brain activity in the DMN. They demonstrated that DMN areas were more strongly deactivated during emotional films than neutral films, and that the activity of insula and ACC was suppressed in resting state after exposure to emotional films, but not after neutral films. Pitroda, Angstadt, McCluskey, Coccaro, & Phan (2008) showed that after engaging in an emotional processing tasks (involving happiness and sadness), subjects displayed attenuated activity in DMN areas. Studies of the impact of emotional stimuli on resting state activity may contribute to the understanding of the functional role of the DMN. Also, these findings highlight the importance of controlling the emotional context in studies of resting state activity (Eryilmaz et al., 2011).

Both connectivity and activity in the DMN have been linked to important core aspects of healthy human cognition, hereunder the integration of emotional and cognitive processing (Greicius et al., 2003). Interestingly, several studies have shown disrupted activity of the DMN in individuals with cognitive impairments and in different diseases. For example, Greicius, Srivastava, Reiss, & Menon (2004) found abnormalities in DMN activity in subjects with Alzheimer's Disease compared to healthy controls, and several studies have identified abnormalities in individuals diagnosed with schizophrenia (Buckner et al., 2008; Nygård et al., 2012; Williamson, 2007; Woodward, Rogers, & Heckers, 2011). Calhoun et al. (2011) found that patients diagnosed with bipolar disorder had differing resting state activity from normal controls. In a review, Buckner et al. (2008) suggested that diagnoses like depression, attention deficit/hyperactivity disorders, obsessional disorders, autism-spectre and post-traumatic stress disorders can be linked to the function of the DMN. Findings such as these show that resting state fMRI has the potential to increase the clinical application of fMRI (Greicius, 2008). Investigating how emotional audiovisual stimuli affect resting state



connectivity may contribute to the understanding of the neural basis of different diseases and the development of therapeutic tools.

### **This Study**

The aim of the present study was to investigate the neural correlates of multisensory integration of emotional information using music and film and how the brain processes congruent and incongruent emotional information, as well as the lasting effect of emotional multimodal stimuli on resting state brain activity. Behavioural measures were obtained to investigate the effect of emotional music on the perception of emotional visual stimuli. The auditory and the happy visual stimuli used in the present study was provided by Pehrs and colleagues (2014). In addition to the happy romantic kissing scenes, the present study added a group of subjects presented with sad visual stimuli (farewell scenes). The sad film clips were selected to be as similar to the happy romantic scenes from Pehrs et al. (2014) as possible, only changing the emotional valence. This provided the opportunity to investigate congruent and incongruent combinations of the emotional music and film clips.

Behavioural data was collected to examine how music affected the perception of the film clips. We hypothesized that the emotional valence of music would have an impact on perception of the film clips on the emotion variables of happiness and sadness. There were three variations of the musical condition (happy, sad and no music), and two types of film (happy and sad). Specifically, we hypothesized that happy music would be associated with higher scores of happiness, and lower scores of sadness, and that the sad music would produce the opposite effect on the scores. Based on the findings of Pehrs et al. (2014), we did not expect significant effects of music on the behavioural variables of valence and arousal. In terms of the effect of visual stimuli, we hypothesized that the group watching scenes ending in a farewell (sad condition - Group 1) would report less happiness and more sadness than the group watching romantic kissing scenes (happy condition - Group 2). We expected similar

ratings of valence and arousal in both groups, as the farewell film clips were selected to be as similar to the romantic film clips as possible.

We wanted to look at the effect of film and music on a whole-brain level to investigate any differences in brain activity due to film valence and musical valence. We predicted to find differences in brain activity associated with different musical valence (positive or negative). Further, we hypothesised that there would be a difference in brain activity due to film type, based on findings of emotion specific neural activity associated with films of different emotional valence (Britton et al., 2006).

We aimed to investigate the neural correlates of processing congruent and incongruent emotional information and predicted to see different brain activity during congruent audiovisual stimuli (e.g. Group 1 with sad music/Group 2 with happy music) than during incongruent stimuli (e.g. Group 1 with happy music/Group 2 with sad music).

Also, we wanted to explore the multisensory integration network of aSTG, FG, and AMY demonstrated by Pehrs et al. (2014) and Pehrs et al. (2015). Due to time limitations, the TP was not included in the network analysis. We hypothesized that the connectivity within this network would be influenced by the emotional quality of music and film.

Last, resting-state connectivity was measured before and after the experimental procedure to investigate a possible carry-over effect of the evoked emotions. We hypothesized that emotions evoked by film valence would produce changes in resting-state connectivity that varied between the groups (romantic vs farewell scenes).

## **Method**

### **Participants**

Thirty-two healthy subjects were recruited using social media and student contact e-mail. Twenty-six females (23 right-handed, 3 left-handed) and six men (6 right-handed, 0 left-handed) participated. Mean age for the females was 23.0, and males was 24.2. The

subjects reported no psychiatric or neurological disorders. All data from one subject was collected in a single session and the time spent in the scanner was on average 55 minutes. The subjects were each given NOK 200,- in total for their participation.

All participants signed a written informed consent. The study was approved by the Regional Committee for Medical Research Ethics (REK-Vest).

### **Stimuli and Rating**

The participants were divided into two groups that each saw 21 film clips. Group 1 saw sad kissing scenes that ended in a separation/farewell (15 subjects). Group 2 saw happy romantic kissing scenes where the actors did not leave each other in the end (17 subjects). The average length of the clips for Group 1 was 57,4 seconds, and 64,8 seconds for Group 2. Seven clips were accompanied by sad music, seven by happy music and seven by no music. The order of the music was determined randomly in three variations to ensure that specific clips were not associated with only one musical valence across subjects. The romantic kissing scenes and the auditory stimuli were provided by Pehrs et al. (2014). The separation scenes were selected in order to match the original clips as closely as possible, only changing the emotional valence. This gave the opportunity to compare brain activity associated with congruent and incongruent emotional audiovisual stimuli. The film clips were selected from Hollywood movies in the romantic and drama genre based on two criteria: 1) They had to contain two characters kissing each other; 2) they had to end with a separation of the same characters. All clips showed heterosexual couples. See Appendix A for an overview of the sad visual stimuli and Pehrs et al. (2014) for happy visual stimuli and auditory stimuli. The film clips were cut and edited using iMovie for iOS version 10.1 from Apple. All film clips were faded in and out with a black shade of 0.5 s and saved with a resolution of 800 × 1200 pixels.

After watching each clip, the subjects had 16 seconds to indicate their experienced level of each variable (valence, arousal, happiness and sadness. See Figure 2). This was followed by a varying delay without any stimulation of 4.4 – 58.8 seconds, with a mean of 21 seconds. The length of the delay was determined from the length of the film clip and the next trigger signal from the MR machine. Subjects used a response grip to move the cursor with their thumb and index finger on a black screen with white text. For the valence variable, the scale ranged from -3 to 3. Sadness-, happiness- and arousal used a scale from 1-7. Half the subjects held the response grip in their right hand, half in the left. Measures of arousal and valence was collected to explore if participants felt more or less activated or reported more or less pleasurable due to film type or music. This was done to control the similarity of the film clips and musical pieces, in other aspects than the emotional quality of happiness and sadness.

The specific questions in terms of emotional experience were collected from Pehrs et al. (2014) and translated into Norwegian. The instruction for the valence variable was: Indicate your experience: very unpleasant - very pleasant. For the arousal variable: indicate your experience: not very uplifting - very uplifting (1-7). For the happiness variable: how happy are you?: not happy - very happy (1-7), and for the sadness variable: how sad are you?: not sad - very sad (1-7).

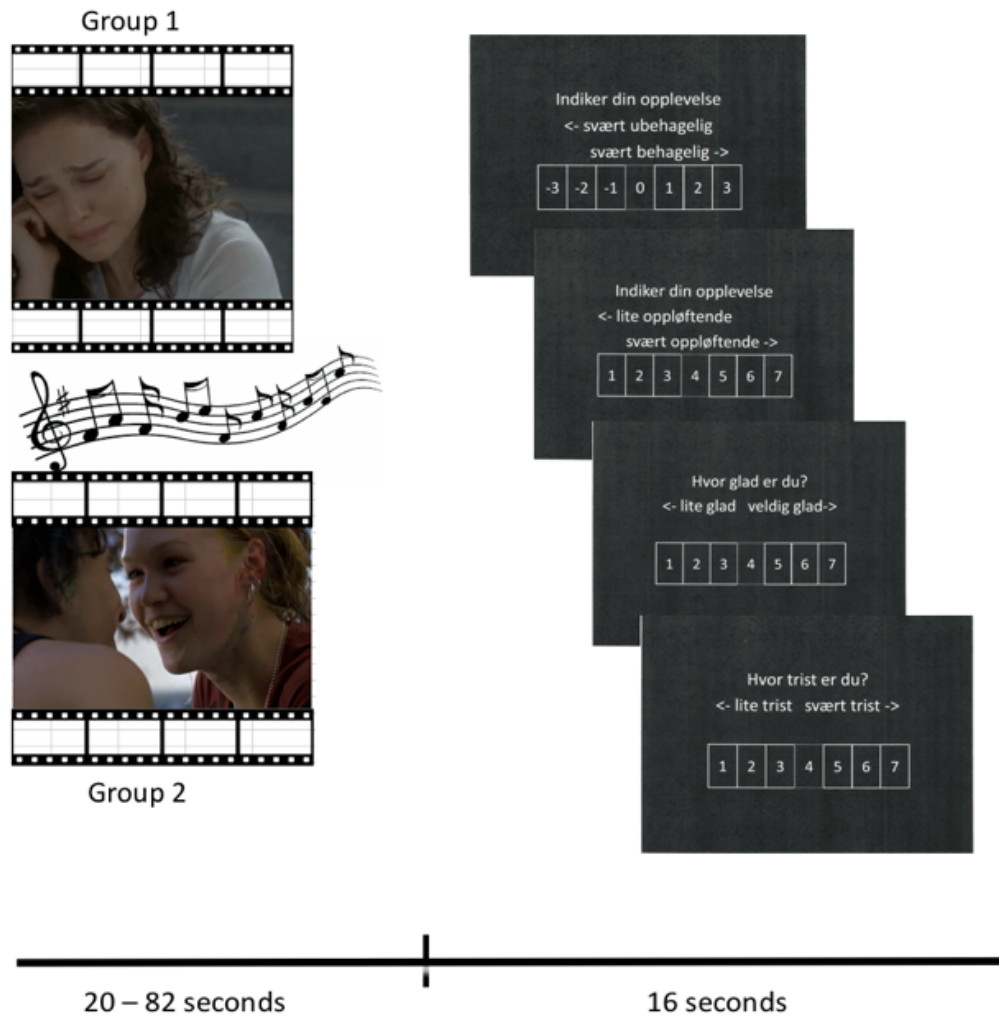


Figure 2. Experimental design. Participants saw sad or happy film clips paired randomly with happy, sad and no music and then indicated degree of experienced emotions on valence, arousal, happiness and sadness.

### Resting State

Resting state activity was measured before and after the experimental condition, where the subjects were instructed to relax with their eyes closed for 6 minutes.

### fMRI Acquisition

The fMRI data was collected using a General Electric scanner (GE) 750 with a field strength of 3 Tesla. The stimuli were presented using video goggles (NordicNeuroLab, [www.nordineurolab.no](http://www.nordineurolab.no)) mounted on the head coil, and the corresponding sound was delivered through MR compatible headphones that also reduced the ambient scanner noise by about 25dB. Responses were collected through a response-grip (NordicNeuroLab).

Presentation of stimuli and collection of responses was controlled by E-Prime 2.0 (Psychology Software Tools, Inc., [www.pstnet.com](http://www.pstnet.com)). E-Prime was installed on a separate PC that was connected to the MR machine in order to receive trigger signals for precise timing of stimulus presentations.

During the condition, where participants were watching the movie clips and listened to the music, 675 170 fMRI images were acquired, with a repetition time (TR) of 3 seconds, 64x64 matrix, 3.44mm x 3.44mm x 4.5mm. During each of the two resting state measurements, 170 fMRI images were acquired (TR = 2 seconds).

### **Behavioural Data Analysis**

Behavioural data were analysed using IBM® SPSS23 (Inc., 2015, Chicago, IL, [www.spss.com](http://www.spss.com)). A mixed between-within subjects analysis of variance (ANOVA) was conducted to assess the impact of two different interventions (farewell scene, kissing scene) on participants' scores on the four different variables, across three musical conditions (positive music, negative music and no music).

### **fMRI Data Analysis**

The fMRI data was analysed with the SPM12 software package (Wellcome Trust Centre for Neuroimaging, Department of Cognitive Neurology, Institute of Neurology, London; <http://www.fil.ion.ucl.ac.uk/spm>). All fMRI data was pre-processed in SPM12. The task fMRI data was analysed through a general linear model (GLM; Friston et al., 1994) analysis within statistical parametric mapping (SPM). GLM is a statistical linear model that incorporates a number of different statistical models such as linear regression, ANOVA and multivariate methods (Poline & Brett, 2012). The GLM is “a simple multiple regression where a series of numbers are approximated by the weighted sum of other numbers” (Poline & Brett, 2012, p. 5). A paramount and much simplified hypothesis in this and other studies is that our independent variables (the type of music and film) will affect the fMRI data.

At the first level, an individual analysis was conducted. Contrasts were defined where the effects of watching movies without music were subtracted (happy-neutral & sad-neutral). On the second level, the data was analysed using a 2x2 repeated measure ANOVA with factors music (happy-neutral/sad-neutral) and group (farewell/romantic).

Resting state fMRI was analysed with an independent component analysis (ICA). Group analysis was conducted using group ICA of fMRI toolbox (GIFT). ICA is a method of determining and separating the spatial extent and time course of task-related activations from other sources contributing to the fMRI signal, such as physical and scanner related events (McKeown et al., 1998). ICA detects transient task-related (TTR) activations that occur during an experimental trial and places them in a component map of spatially distributed values, with one value for each voxel. Each component map is assumed to be spatially independent from other maps, in that the voxel values in one map says nothing about the voxel values in another map (McKeown et al., 1998). Thus, the fMRI signal is separated into several independent component maps with associated time courses of activation that are unique for each component. This method is used to uncover hidden features from a set of measurements and make them maximally independent (Calhoun, Liu, & Adali, 2009).

In total, 70 components were estimated with the ICA. To select the component of interest, 2x2 ANOVA models were estimated for each component with factors Repetition (before/after task fMRI) and Group. Only those components that showed a significant ( $p$  (FWE) $<0.05$ ) Repetition x Group interaction were explored further.

### **Dynamic Causal Modelling (DCM)**

DCM12 as implemented in SPM12 was used to analyse the effective connectivity in a three-region brain network of aSTG, AMY and FG demonstrated to be involved in multisensory emotional processing by Pehrs et al. (2014) and Pehrs et al. (2015). Dynamic causal modelling (DCM) is used to estimate the coupling strength between brain regions and

to make inferences about how the coupling is influenced by changes in experimental conditions, in terms of effective connectivity (Friston et al., 2003). DCM produces realistic neural models of interacting cortical regions and examine the influence of neural systems on each other. The aim of DCM is to estimate effective connectivity in a brain network system by interfering the system and measure the response (Friston et al., 2003). DCM was extended to include the modelling of activity-dependent gating of connections between nodes (Stephan et al., 2008). Using this approach, the neural dynamics associated with emotion processing in the context of multisensory perception can be investigated.

### **Regions and time series extraction.**

The selection of regions of interest was based on the studies by Pehrs et al. (2014). The same coordinates were used as starting point, and time courses were extracted from these coordinates. If no active voxel was at the respective coordinate, the time course was extracted from the closest voxel that was within a radius of 8mm. The areas for the here presented DCM analysis consisted of aSTG, AMY and FG of both hemispheres, but DCMs were estimated for each hemisphere separately, as done by Pehrs et al. (2014).

### **Model space.**

The same model space as Pehrs et al. (2014) was defined consisting of 16 models per music type, where the influence of the music on the different connections was modelled (see Figure 3). This resulted in 32 different models (16 sad and 16 happy) per participant. In contrast to the original work by Pehrs et al. (2014), only bilinear models were estimated for the present study. After estimating the models for each subject, a Bayesian Model Selection (BMS) was applied to discover the most probable model. The estimated parameter from the winning model were subjected to an 2x2 ANOVA model to analyse main effects of Group and Music, and interactions.



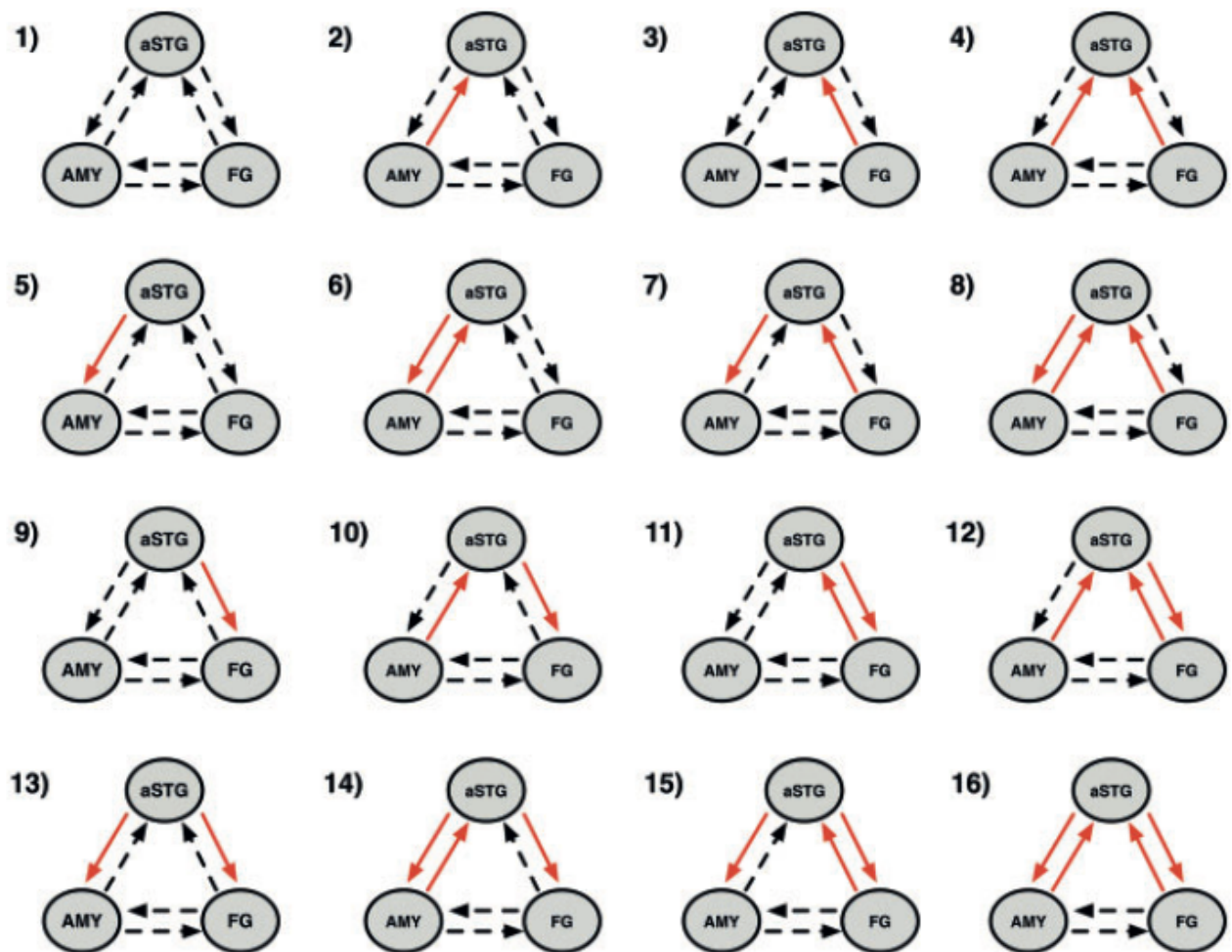


Figure 3. Model space. Models 1-16 illustrate all possible backward and forward connections, as well as bidirectional modulations between network nodes. The red arrows show the modulatory impact of music. Figure collected from Pehrs et al. (2014).

## Results

### Behavioural Data Analysis

The behavioural data showed no significant effect of the interaction between type of music and group (type of film) in any of the dependent variables. In terms of the variables of arousal and sadness, there was a main effect on the responses of both Group and Music. On the happiness scores, there was a main effect of music only, and the type of film did not have a significant effect on how happy the subjects indicated that they felt. See Table 1 for a summary of the mean scores and standard deviations on all four variables. See Figure 4 for

total scores of both groups displaying different effect of music, and Figure 5 for total means across all musical conditions showing differences between groups.

Table 1

*Descriptive statistics of all behaviour responses.*

|                  | Happy music | Sad music   | No music   | p(music)     | p(group)     | p(interaction) |
|------------------|-------------|-------------|------------|--------------|--------------|----------------|
|                  | Mean (SD)   | Mean (SD)   | Mean (SD)  |              |              |                |
| <b>Valence</b>   |             |             |            |              |              |                |
| Gr 1             | 4.19 (.96)  | 4.09 (.98)  | 4.24 (.83) |              |              |                |
| Gr 2             | 5.00 (.63)  | 4.62 (.60)  | 4.47 (.57) | 0.11         | 0.032*       | 0.103          |
| Total            | 4.62 (.88)  | 4.37 (.83)  | 4.36 (.70) |              |              |                |
| <b>Arousal</b>   |             |             |            |              |              |                |
| Gr 1             | 4.26 (.45)  | 3.56 (.72)  | 3.68 (.70) |              |              |                |
| Gr 2             | 4.99 (.86)  | 4.17 (.74)  | 4.25 (.86) | <b>0.000</b> | <b>0.004</b> | 0.865          |
| Total            | 4.65 (.78)  | 3.88 (.78)  | 3.98 (.82) |              |              |                |
| <b>Happiness</b> |             |             |            |              |              |                |
| Gr 1             | 4.59 (.83)  | 3.95 (.89)  | 3.96 (.93) |              |              |                |
| Gr 2             | 5.00 (.56)  | 4.30 (.62)  | 4.35 (.83) | <b>0.000</b> | 0.11         | 0.978          |
| Total            | 4.80 (.72)  | 4.14 (.77)  | 4.17 (.88) |              |              |                |
| <b>Sadness</b>   |             |             |            |              |              |                |
| Gr 1             | 3.03 (1.17) | 3,57 (.98)  | 3.60 (.98) |              |              |                |
| Gr 2             | 2.13 (.67)  | 2.91 (.99)  | 3.59 (.72) | <b>0.000</b> | <b>0.008</b> | 0.246          |
| Total            | 2.55 (1.03) | 3.22 (1.02) | 3.06 (.98) |              |              |                |

*Note.* Behavioural ratings of the visual stimuli for Group 1 (N=15) and Group 2 (N=17). Mean and standard deviation (SD) of all behaviour responses on all depended variables and groups. Bold text indicate significant results at  $p < 0.05$ . \* The significance threshold was lowered due to a violation of the assumption of homogeneity. This effect is not significant at the more stringent significance level of  $p < 0.01$ .

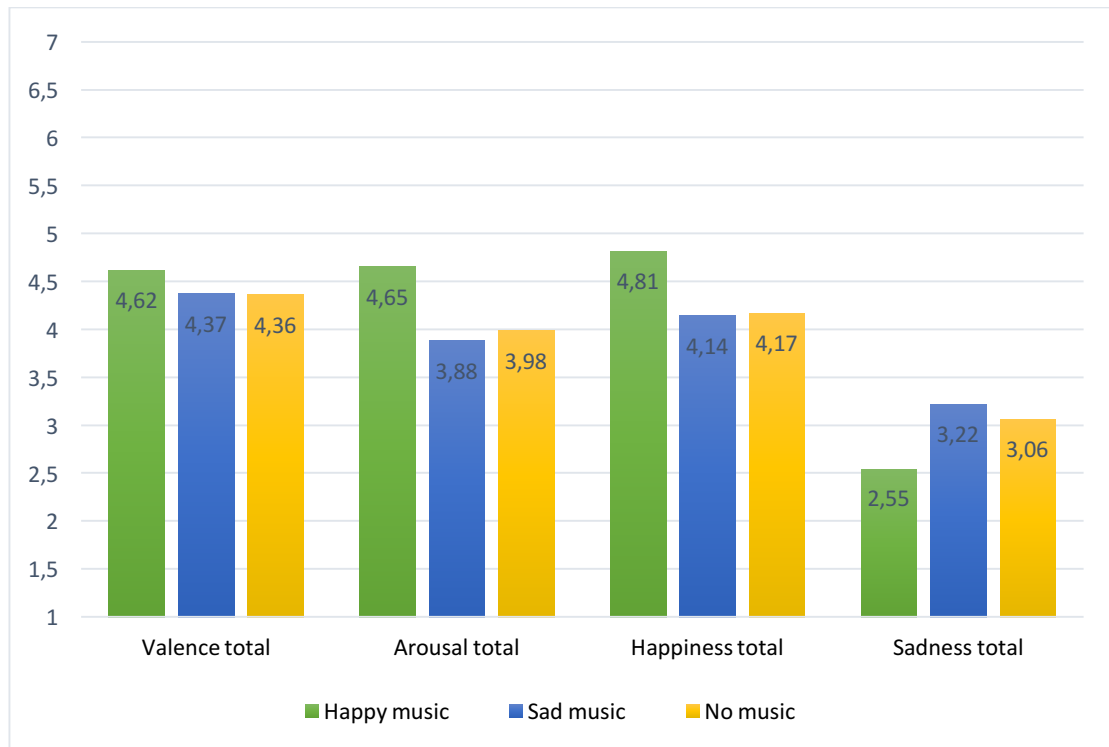


Figure 4. Subjective behavioural ratings across groups. The total means on all four dependent variables of valence, arousal, happiness and sadness.

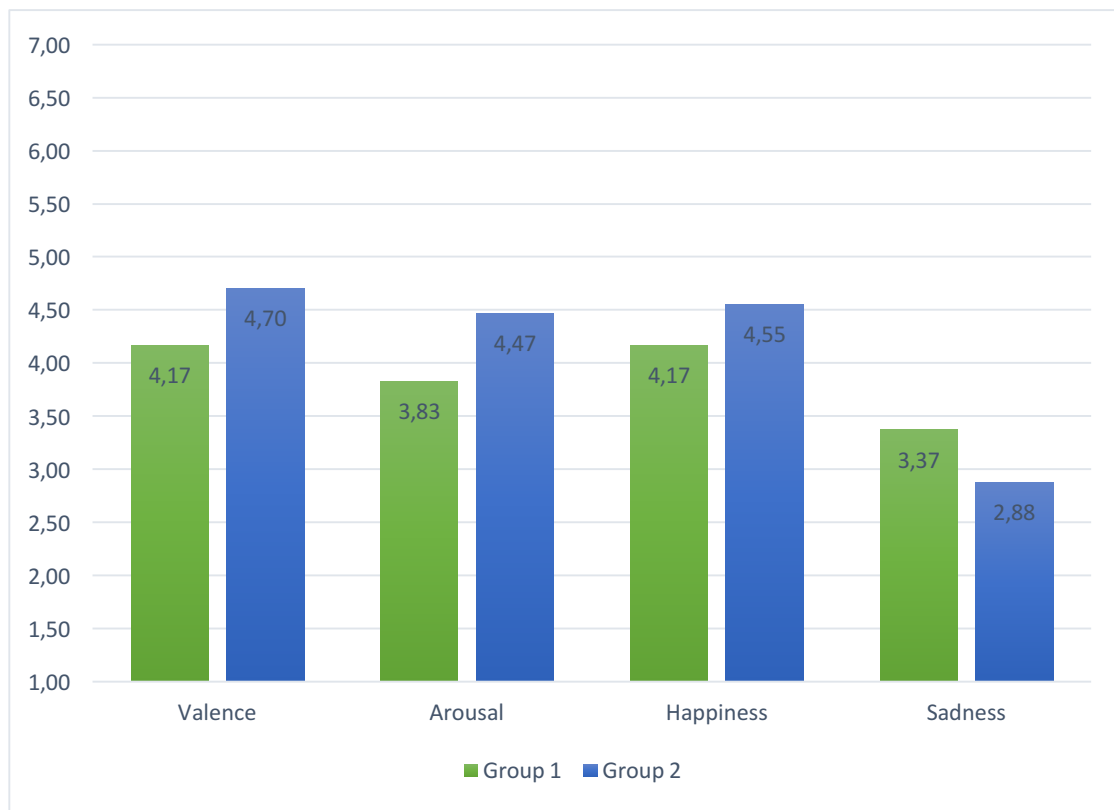


Figure 5. Total mean for both groups across musical conditions on all four variables.

### Valence.

On the valence scores, there was no significant interaction between group and music, Wilks' Lambda = .855,  $F(2, 29) = 2.459$ ,  $p = .103$ , partial eta squared = .145. There was no main effect of music, Wilks' Lambda = .859,  $F(2, 29) = 2.382$ ,  $p = .141$ , partial eta squared = .141.

A Levene's test of the valence results was significant. A significant result of the Levene's test suggests that homogeneity of variance cannot be presumed, and that the significance level must be set to a more conservative value (e.g. 0.01). Therefore, the main effect of Group on valence are seen as significant only if the significance value is greater than .01. The main effect of Group was  $>.01$  ( $p = .032$ ), meaning that the main effect of Group on valence scores is not significant (See Table 1 and Figure 6 for differences in scores).

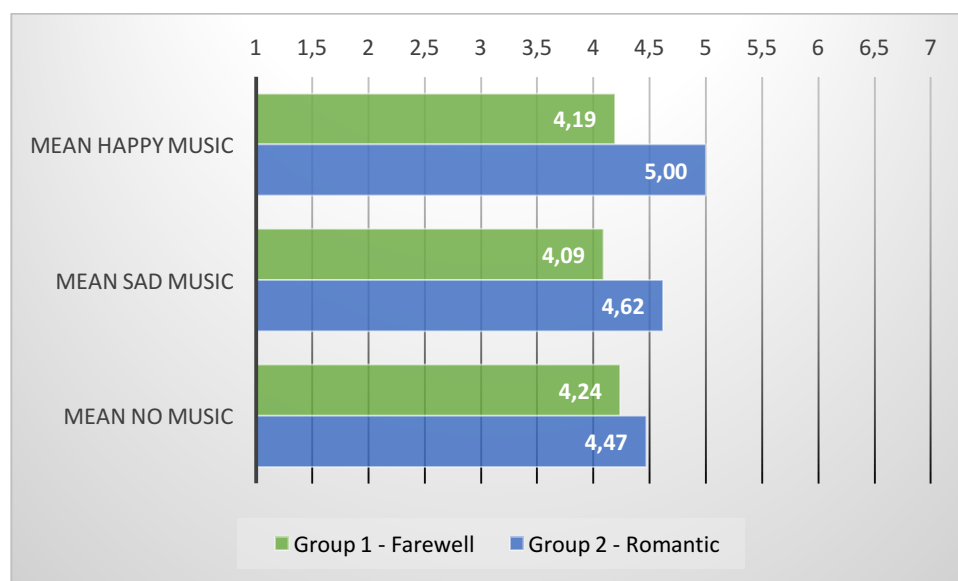


Figure 6. Means of experienced valence for both groups over all musical conditions.

### Arousal.

There was no significant interaction between group and music, Wilks' Lambda = .99,  $F(2, 29) = .146$ ,  $p = .865$ , partial eta squared = .01. There was a substantial main effect of music, suggesting a reduction in arousal scores from positive to negative (and no) music. Wilks' Lambda = .465,  $F(2, 29) = 16.687$ ,  $p < .0005$ , partial eta squared = .535. There was

also a main effect of Group,  $F(1, 30) = 9.735, p < .005$ , partial eta squared = .245, suggesting a significant effect of Group on arousal scores in terms of more arousal associated with Group 2 (see Table 1 and Figure 7).

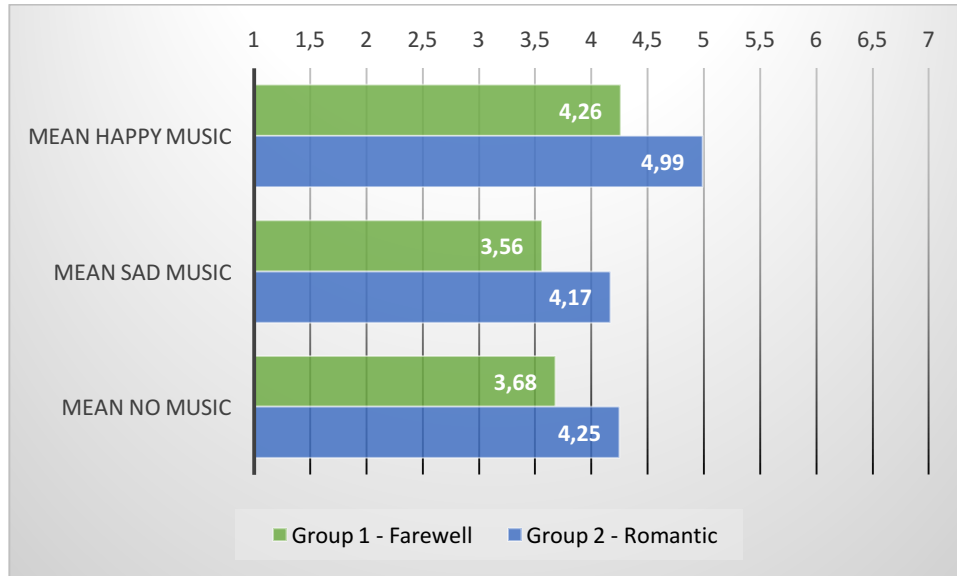


Figure 7. Means of experienced arousal for both groups over all musical conditions.

**Happiness.**

The interaction between group and music was not significant, Wilks’ Lambda = .998,  $F(2, 29) = .022, p = .978$ , partial eta squared = .002. There was a main effect of music on happiness ratings, Wilks’ Lambda = .445,  $F(2, 29) = 18.06, p < .0005$ , partial eta squared = .555, with both groups showing a reduction in happiness scores from happy to sad music. There was no main effect of Group,  $F(1, 30) = 2.717, p = .110$ , partial eta squared = .083 (see Table 1 and Figure 8).

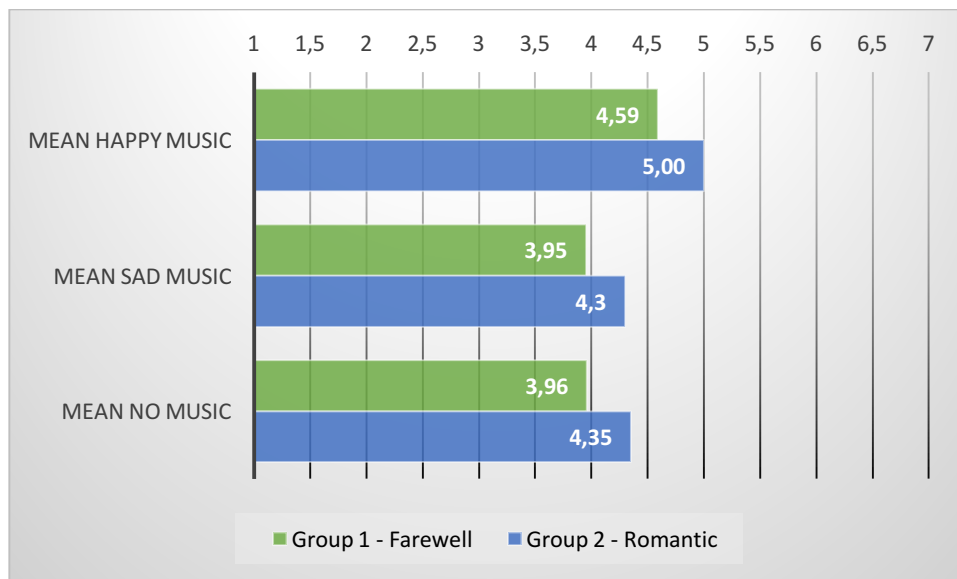


Figure 8. Means of experienced happiness for both groups over all musical conditions.

**Sadness.**

There was no significant interaction between group and music in ratings of sadness, Wilks’ Lambda = .908,  $F(2, 29) = 1.472, p = .246$ , partial eta squared = .092. There was a substantial main effect of music, Wilks’ Lambda = .482,  $F(2, 29) = 15.557, p < .0005$ , partial eta squared = .518, indicating that the sadness scores increased significantly from positive to negative music. There was a main effect of Group,  $F(1, 30) = 8.172, p < .01$ , partial eta squared = .214, where Group 1 had the highest sadness score (See Table 1 and Figure 9)

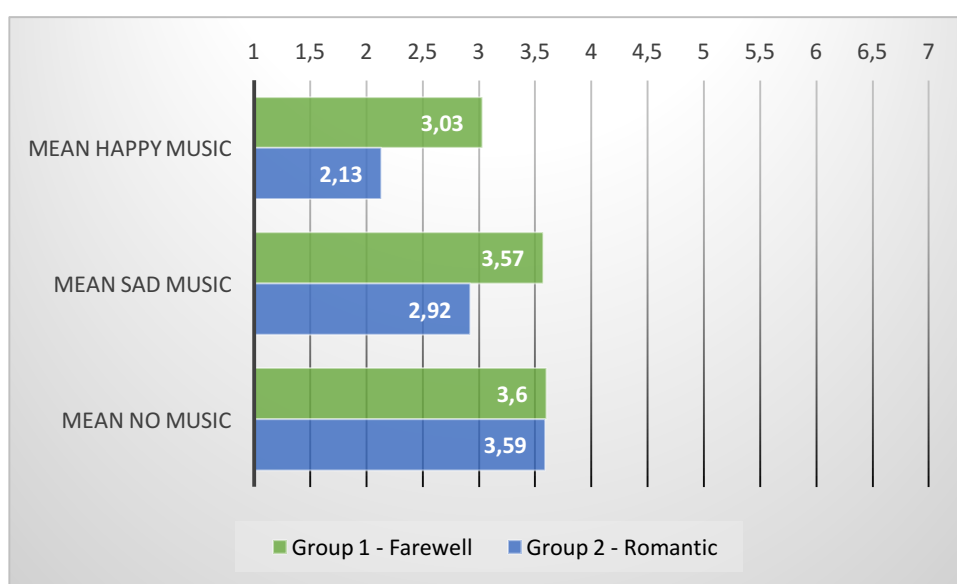


Figure 9. Means of experienced sadness for both groups over all musical conditions.

**fMRI Results****Whole-brain analysis.**

See Table 2 for an overview of the results of the whole-brain analysis.

Table 2

*Significant activations associated with happy and sad music (happy>sad, sad>happy).*

| <b>Effect of Music (Happy &gt; Sad)</b> |               |                     |              |                  |              |                            |
|---|---------------|---------------------|--------------|------------------|--------------|----------------------------|
| Region                                  | Brodmann area | Cluster p(FWE-corr) | Cluster size | Peak p(FWE-corr) | Peak T-value | MNI-coordinates x,y,z (mm) |
| R. STG                                  | 22            | 0                   | 299          | 0                | 8,19         | 52 -6 -2                   |
| R. Primary auditory cortex              | 41            |                     |              | 0                | 7,56         | 54 -16 2                   |
| R. Primary auditory cortex              | 41            |                     |              | 0,002            | 6,25         | 46 -16 4                   |
| L. Primary auditory cortex              | 41            | 0                   | 171          | 0                | 7,88         | -50 -18 2                  |
| R. STG                                  | 22            |                     |              | 0,001            | 6,44         | -50 -6 -2                  |
| L. STG                                  | 22            |                     |              | 0,005            | 5,98         | -44 -10 -10                |
| <b>Effect of Music (Sad &gt; Happy)</b> |               |                     |              |                  |              |                            |
| L. amPFC                                | 10            | 0,021               | 3            | 0,021            | 5,55         | -16 48 2                   |
| R. vPCC                                 | 23            | 0,016               | 2            | 0,031            | 5,44         | 18 -54 14                  |
| R. Secondary visual cortex              | 18            | 0,016               | 2            | 0,032            | 5,44         | 4 -70 6                    |

*Note:* Brain coordinates and corresponding brain regions and Brodmann areas. Table showing the post hoc test data for happy > sad music (p(FWE)<0.05, cluster size: at least 20 voxel), and for sad > happy music (p(FWE)<0.05, no cluster threshold). Superior temporal gyrus = STG; ventral posterior cingulate cortex = vPCC; anterior medial prefrontal cortex = amPFC.

The task fMRI results showed a significant main effect of music (p(FWE)<0.05, cluster 20), mainly in bilateral STG and primary auditory cortex (BA 22 and 41, see Figure 10).

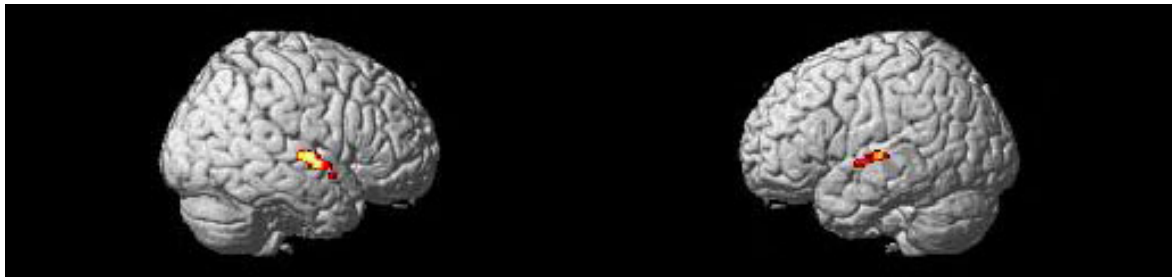


Figure 10: This image shows increased activity in STG and primary auditory cortex, during happy compared to sad music (happy > sad). Superior temporal gyrus = STG

Post hoc testing ( $p(\text{FWE}) < 0.05$ , cluster level > 20 voxel) showed increased activity bilaterally in primary auditory cortex and STG during happy music when compared to sad music. The opposite comparison, that is where sad music showed higher activation than happy music, showed increased activity in DMN-related areas of mPFC and vPCC (see Table 2). This effect was only evident when there was no lower limit for the cluster size ( $p(\text{FWE}) < 0.05$ , no cluster threshold).

There was no main effect of group in the task fMRI images. However, there was an interaction effect ( $p(\text{FWE}) < 0.05$ , cluster level > 20 voxel) in the junction between the ITG and the TP, as well as an area in the left mPFC (see Table 3 and Figure 11). A post hoc t-test used to explore the direction of the interaction effect, showed that these areas were more active during incongruent conditions for both groups.

Table 3

*Significant interaction effects of Group and Music*

| Region                        | Brodmann area | Cluster p(FWE-corr) | Cluster size | Peak p(FWE-corr) | Peak T-value | MNI - coordinates x,y,z (mm) |
|-------------------------------|---------------|---------------------|--------------|------------------|--------------|------------------------------|
| R. Inferior temporal gyrus/TP | 20/38         | 0,002               | 14           | 0,001            | 6,42         | 54 0 -32                     |
| R. inferior temporal gyrus/TP | 20            | 0,002               | 14           | 0,034            | 5,42         | 46 -2 -34                    |
| L. Anterior mPFC              | 10            | 0,002               | 14           | 0,008            | 5,85         | -6 58 14                     |

Note: Brain coordinates and corresponding brain regions and Brodmann areas for the interaction effects ( $p(\text{FWE}) < 0.05$ , cluster size at least 20 voxel).



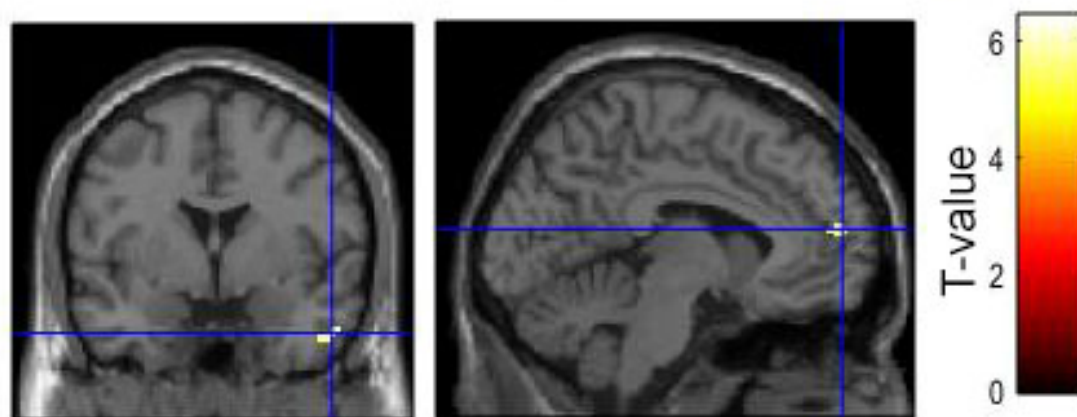


Figure 11. This image shows the significant interaction effect of music and group in ITG/TP and amPFC.

Inferior temporal gyrus = ITG; Temporal poles = TP; anterior medial prefrontal cortex = amPFC.

### Dynamic Causal Modelling (DCM)

The DCM for the network analysis aSTG-AMY-FG revealed that there were significant bidirectional connections between all three nodes. In addition, happy music had a stronger impact on the coupling of FG and AMY in Group 2 than in Group 1. On the other hand, Group 1 had generally stronger coupling from AMY to aSTG as well as from aSTG to FG, and also from AMY to FG than in Group 2, independent of the music. All other connections were equal in both groups (see Figure 12).

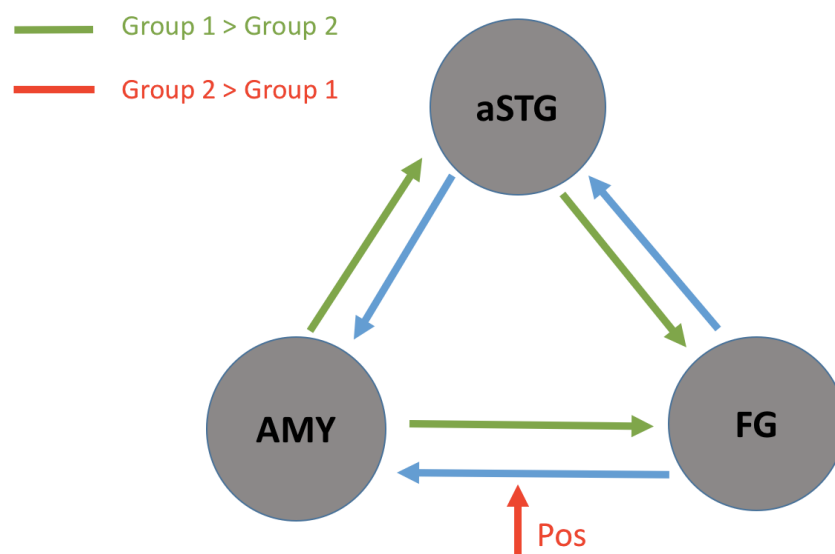
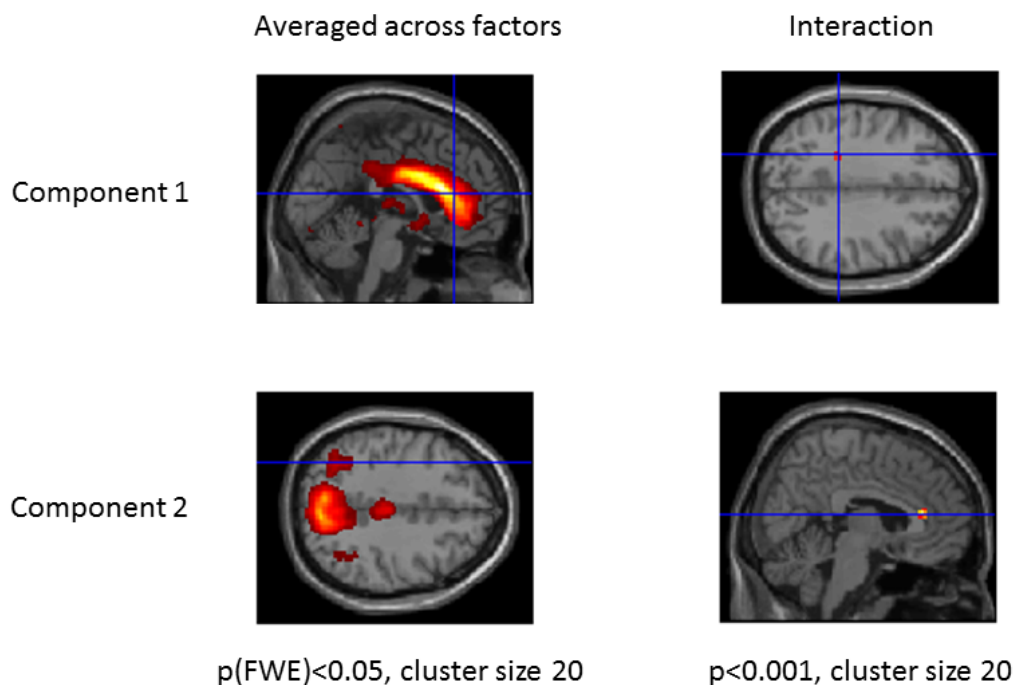


Figure 12: The connections between the amygdala (AMY), anterior superior temporal gyrus (aSTG) and fusiform gyrus (FG). The blue arrows indicate the direction of connection across both Groups. The red arrow

indicates that the happy music had a stronger impact on the coupling from FG to AMY in Group 2 (romantic film clips). The green arrows indicate where the connectivity is stronger for Group 1 (farewell film clips), across all musical conditions.

### Resting State fMRI

In the resting state fMRI data, two components revealed a significant Repetition x Group interaction and were explored further. The ANOVA revealed no main effect of Group or Repetition for either of the components, however, there were significant interaction effects (significant at  $p(\text{FWE}) < 0.05$ , displayed here at  $p < 0.001$ , cluster size 10, see Figure 13).



*Figure 13.* Resting state activity averaged across factors and significant interactions. Interaction effects in dorsal anterior cingulate cortex (dACC) and an area between the inferior parietal lobe (IPL) and the posterior cingulate cortex (PCC).

The first component, when averaged across all factors, represented an anterior cingulate cortex network, while the significant interaction appeared in the posterior mid-brain (MNI-coordinates: -22 -34 32), between the inferior parietal lobe (IPL) and PCC, which are both parts of the DMN. By contrast, the second component, when averaged across the factors repetition and group, reflected the posterior DMN network, while the significant interaction

appeared in the dorsal ACC (dACC - MNI coordinates: 6 34 12). See Figure 13 for an illustration of the components and interaction effects. Interestingly, both interactions concordantly indicate a reduced connectivity between the dACC and the posterior DMN for those subjects that observed the farewell movie clips.

### **Discussion**

This study was designed to investigate the effect of emotional music and films of different emotional quality on subjective experience, and the activity in neural brain networks, as well as possible carry-over effects of emotional audiovisual stimuli on resting state activity. A whole-brain approach was used to investigate the neural correlates of multisensory integration of congruent and incongruent stimuli and the underlying neural mechanism of the effect of emotional music on film perception. DCM was used to study the multisensory network identified by Pehrs et al. (2014). Resting state data was collected before and after the audiovisual conditions.

### **Behavioural Data**

The results confirm that the experimental condition in this study was successful in evoking subjective emotions, in terms of behavioural ratings, and is in line with previous research showing the emotion-evoking ability of film and music (Eldar et al., 2007; Pehrs et al., 2014; Pehrs et al., 2015).

There was a main effect of music on the scores of happiness and sadness. Happy music was associated with higher scores on happiness, and lower scores on sadness compared to sad music across groups, confirming the behavioural hypotheses on these variables. Contrary to the findings of Pehrs et al. (2014), the emotional quality of music had a significant effect on arousal. This finding have implications for the interpretation of the fMRI data. For example, the main effect of music seen in the imaging data may be attributed to this

increase in arousal. There was no main effect of music on valence ratings, in line with our hypothesis and Pehrs and colleagues' (2014) findings.

There was no main effect of Group on happiness, showing that the film clips did not differently affect subjective ratings of happiness. There was, however, a significant main effect of Group on sadness scores, where Group 1 (farewell) reported significantly higher sadness than Group 2, showing the emotion-evoking effect of the sad film clips. Further, there was a main effect of Group on arousal, with more arousal in Group 2 than in Group 1. This arousal effect of film needs to be taken into consideration when interpreting the fMRI data. There was no main effect of Group on valence, showing that the film types were rated as equally pleasurable. The farewell film clips in the present study were added as a new component to the romantic scenes provided by Pehrs and colleagues (2014) and the results indicate that the new film clips were successful in evoking sadness in the participants.

There was no interaction effect of Group and Music in the behavioural data, showing that the behavioural ratings caused by happy, sad and no music was not contingent on Group.

The smallest difference in mean values between groups was seen on the sadness variable during the no music condition. Here, the ratings of sadness in both groups are almost identical when no music is present, but there is a difference in both happy and sad music conditions (see Table 1 and Figure 9). This is in line with the suggestion that music intensifies the experienced emotion when watching a visual scene, as proposed by Eldar and colleagues (2007).

### **Task fMRI – General Linear Model**

#### **Main effects of music.**

To assess the emotion effect of music, we compared happy and sad music conditions and found a main effects of music. This confirms our hypothesis that there would be differences in brain activity associated with happy and sad music across groups.

***Superior temporal gyrus (STG).***

Post hoc analyses showed that the processing of happy music involved increased activity in bilateral STG, including primary auditory cortex, compared to sad music (happy > sad, see Table 2). Similarly, Pehrs and colleagues (2014), using the same auditory stimuli as in the present study, found greater activity in the aSTG during happy music compared to sad music, and attributed this finding to the difference in emotional valence of the music. The sad and happy music was processed by Pehrs et al. (2014) to be as similar as possible in terms of tempo, to exclude possible neural effects of arousal. Pehrs and colleagues (2014) found similar behavioural arousal levels for happy and sad music, underpinning the similarity of the music. In the present study, we found an arousal effect of music, in terms of higher arousal scores during happy music than during sad music. Alluri et al. (2012) showed that increased activity of the left and right STG is associated with high values of timbre-related characteristics of music, as well as a high clarity of the pulse of music. The increased activity of bilateral STG seen in the present study may indicate that the happy music has more of the musical characteristics found to be associated with increased activity of the STG, and the activity may not be attributable solely to the emotional valence of the music. Klasen, Kenworthy, Mathiak, Kircher, & Mathiak (2011) found that the STG was involved in both congruent and incongruent emotion processing and suggested that STG is involved in multisensory integration in general, and not necessarily the integration of emotional information. However, the STG has been implicated in emotion processing in several studies (Jeong et al., 2011; Kreifelts et al., 2007; Müller, Cieslik, Turetsky, & Eickhoff, 2012; Müller et al., 2011; Pourtois et al., 2005; Robins et al., 2009). Park and colleagues (2010) suggested that STG is part of a common network involved in multisensory integration of all emotions. They compared multisensory integration of emotionally neutral information to integration of emotional information and suggested that a shared common network of STG, inferior frontal

gyrus (IFG), parahippocampal gyrus, and AMY is involved in the formation of a unified concept of emotional information from multiple sensory organs. These areas showed stronger activity in emotional bimodal conditions compared to emotional unimodal conditions, regardless of the emotional content. Further, based on the observation of specific activations for different emotions, Park et al. (2010) suggested that different emotions are associated with a separate network of brain areas in the integration of bimodal information, in addition to the common network of multisensory integration. In the present study, aSTG, FG and AMY were showed to be involved in processing both happy and sad emotional stimuli, however, also showed emotion specific activity. The STG was more active during happy music and mPFC and PCC was more active during sad music, corresponding to specific activations associated with different emotions (Park et al., 2010).

***Medial prefrontal cortex (mPFC).***

Post hoc analyses of the imaging results showed that audiovisual presentations with sad music involved increased activity in the medial prefrontal cortex (mPFC), the PCC and in the visual association area in the occipital lobe (sad > happy, see Table 2). However, this effect was only evident when there was no lower limit for the cluster size. This means that the effects are significant on a corrected level, but the clusters are small and this should be taken into consideration in the interpretation of the data.

The mPFC and PCC are main hubs of the DMN (Andrews-Hanna, 2012; Andrews-Hanna et al., 2010). Harrison et al. (2008) used a sad mood induction paradigm during functional imaging where participants were instructed to recall a personally experienced sad real life event while listening to sad music. They compared functional connectivity during this task and a neutral recall task and found reduced connectivity between the PCC and mPFC of the DMN during the sad recall task. They explained this finding in terms of the sad mood task being more cognitively challenging than recalling neutral material, leading to

decreased activity in DMN. Following this line of reasoning, the increased activity in DMN areas during sad music in the present results may indicate that the sad music conditions were less cognitively challenging than the happy music conditions. In contrast to the present study, where the participants had no task during audiovisual processing, the participants in Harrison and colleagues' (2008) study had to recall and maintain personal sad and neutral events. It may have been more challenging recalling and maintaining a sad event in mind than a neutral event, leading to attenuated DMN activity during the sad condition. In the present study, it may be well as likely that the sad music triggered the introspective processes associated with DMN activity to a greater extent than the happy music. Emotion effects on DMN activity is largely unknown (Eryilmaz et al., 2011), complicating the interpretation of the present results. Also, the present activations were only evident with no lower limit for the cluster size, and these results must be interpreted with caution. The present findings nonetheless indicate that emotional music have an effect on DMN activity, in line with previous findings (Eryilmaz et al., 2011; Harrison et al., 2008).

There was also a main effect of music in the visual association area in the occipital lobe (BA 18), with more activity during sad music compared to happy music. Emotional music affects the perception of visual stimuli (Baumgartner et al., 2006a; Jeong et al., 2011), and one possible interpretation of the present effect in BA 18 may be that sad music increases visual attention. Areas of the visual cortex have been observed to be activated in perceptual processing of emotionally and socially relevant stimuli (Adolphs, 2002). Bradley (2003) presented stimuli of different emotional valence and found that pictures more related to primary motive states (especially those of danger), activated the occipital cortex more. It may be the case that sad auditory stimuli signals salience and the need to respond to the environment, leading to increased visual attention. The present finding of activity in BA 18 during sad music may indicate such an effect of enhanced visual attention.

**Main effect of group.**

There was no main effect of group in the task fMRI data (Group 1 > Group 2 and Group 2 > Group 1), and the hypothesis of activity change depending on Group was not confirmed. This is in contrast to Britton and colleagues' (2006) findings of emotion specific neural activations related to film-evoked happiness and sadness in OFC and nucleus accumbens during happy films, and ACC during sad films. The present DCM results did however find differences in Group- and Music-dependent activity. It is possible that the activity differences caused by films were too subtle to appear in the whole-brain analysis, and needed the statistical sensitivity associated with the use of ROIs in DCM to appear in the imaging results.

**Interaction effects task fMRI.**

There was an interaction effect of Music and Group in the right ITG/TP and left mPFC, with higher activity in these areas during incongruent than congruent conditions. For Group 1, happy music represented incongruent conditions and sad music represent incongruent conditions for Group 2. The incongruency effect was not evident in the behavioural data, where no interaction effect of music and group on behavioural measures was observed. This might suggest that the integrated emotional representation (and the reported subjective feeling) of the audiovisual information was affected similarly by music regardless of the film content, but that the brain areas involved in producing this integrated representation varied depending on emotional congruency and incongruency.

The mPFC has been implicated in processing of incongruent emotional information by Klasen et al. (2011). They demonstrated that incongruent presentations of emotional faces and vocal prosody evoked stronger activity in mPFC, among other frontal and prefrontal areas, compared to congruent presentations. Similarly, Etkin et al. (2006) demonstrated that dmPFC was involved in emotional conflict processing of happy and fearful faces and



emotion words, along with the dlPFC. Here, the participants were asked to ignore the written word and report the emotional expression of the face. Unlike many studies on emotional conflict, and emotion processing in general, the present study had no task that asked for a correct answer, and the participants were only asked to assess their own emotional state after emotion-evoking stimuli presentation. The dlPFC is an area largely involved in executive control (Robins et al., 2009) and perhaps the tasks of ignoring a written word was more cognitively challenging than the mere reporting of own emotional state, and therefore recruited the dlPFC.

The TP has been implicated in integrating sensory input with emotional responses (Olson et al., 2007) and in integrating multisensory emotional information (Pehrs et al., 2015). It is more sensitive to social stimuli compared to non-social stimuli (Skipper et al., 2011) and show increased activity during multimodal perception compared to unimodal perception (Klasen et al., 2011). Also, it has been proposed to be involved in the integration of semantic information represented in distributed brain areas into a coherent representation (Patterson, Nestor, & Rogers, 2007). The interaction effect in TP suggest that the activity of TP changes in response to the emotional quality of music depending on film type. The present results suggest that the activity of the TP is increased during conflicting emotional information. This may mean that the suppressive modulatory effect of TP on FG, shown by Pehrs et al. (2015), increases during incongruent presentations of emotional stimuli. The present DCM analysis did not include the TP and we can therefore not draw conclusion about the effect of TP on FG.

Yomogida et al. (2014) showed that both the mPFC and TP is involved in the process of integrating contextual information and previous experience to create a coherent representation of a situation, termed event simulation (ES) by the authors. Also the ACC, left parahippocampal cortex, left PCC/retrosplenial cortex and left TPJ was shown to be

associated with ES. These areas overlap with DMN areas and have also been associated with evaluation, reflection, and appraisal of social information, including the mental state of self and others (theory of mind; Andrews-Hanna, 2012; Andrews-Hanna et al., 2010). The mPFC has been observed to be consistently activated when participants reflect on their own current experience (Lieberman, 2007), which correspond to the present finding of mPFC activation.

ES involves integrating emotional stimuli from different sources (Yomogida et al., 2014) and the interaction effects in mPFC and ITG/TP, suggest that these areas are involved in multisensory emotional processing. The experimental design of the present study created a situation where the subjects received the stimuli in a relatively passive way, without any correct or incorrect responses to the social emotional information. However, ES processes happen spontaneous and automatically (Yomogida et al., 2014), and the experimental paradigm in the present study is likely to have triggered ES in the participants. The finding of stronger activity in ITG/TP and mPFC during incongruent trials may reflect greater involvement of these areas due to conflicting emotional input. It may be the case that incongruent emotional information recruits these regions more heavily because incongruent information makes it harder to decode the emotional state of a social agent, as reflected in lower accuracy and longer reaction times during emotion labelling of emotionally conflicting stimuli (Collignon et al., 2008; Etkin et al., 2006).

The underlying neural mechanism of ES and theory of mind can be explained in terms of predictive coding (de-Wit, Machilsen, & Putzeys, 2010; Rao & Ballard, 1999). Predictive coding is the idea that the brain learns the regularities of the natural world (Rao & Ballard, 1999) and constantly predicts upcoming stimuli, rather than registering information passively as it appears (de-Wit et al., 2010). Input that deviate from expectations are signalled to higher-level brain areas, so that activation in early sensory areas only represents the parts of the sensory input that was not predicted. Unexpected input is processed and updates the

prediction (de-Wit et al., 2010). Related to the present paradigm, music creates expectations about the development of a scene that corresponds to the emotional quality of the music (Vitouch, 2001). During incongruent presentations, the prediction is violated and must be updated. The present findings of incongruency effects in mPFC and ITG/TP implicate these regions in this process.

In contrast of the incongruency effect in ITG/TP found in the present study, Klasen et al. (2011) found increased activity in ITG during congruent trials of emotional faces and voices, compared to incongruent trials. Conflicting findings are common in studies of multisensory emotional integration, due to the use of different stimuli, experimental designs, and methods. Thus, the involvement of ITG/TP has been demonstrated in several studies, but its exact role is unclear.

### **Task fMRI – Dual Causal Modeling**

The present DCM-analysis did not include non-linear modelling and therefore it is not directly comparable to the results of Pehrs et al. (2014), and we can not draw conclusions about the effects of the separate nodes on each other. However, the present results showed emotion-specific activity in the network of aSTG, FG and AMY.

The results showed a strengthening of the coupling from FG to AMY driven by the experimental manipulation of happy music. This change in connectivity was stronger in Group 2 (happy) than Group 1 (sad), suggesting a stronger effect of congruent emotional stimuli on FG-AMY connectivity compared to incongruent stimuli. Pehrs and colleagues (2014) found a suppressive effect of aSTG on the coupling strength of FG and AMY. They showed that aSTG was more active during happy music, and therefore the suppressive effect of aSTG was stronger during congruent conditions (e.g. happy film and happy music), compared to incongruent conditions (e.g. happy film and sad music), leading to weaker connectivity between FG and AMY. This stands in contrast to the present findings of

increased coupling strength from FG to AMY during the congruent presentation of happy film and music. Dolan et al. (2001) also found a congruency-dependent increase in fusiform-amygdalar connectivity. In the whole-brain analysis, the STG was seen to be more active during happy music. A suppressive role of aSTG on the connectivity between FG and AMY should have produces weaker connectivity between these nodes during happy music, however, this was not the case. Thus, the present results do not correspond to a suppressive role of aSTG on FG-AMY connectivity.

Further, the farewell scenes had a strong effect on network connectivity across all musical conditions. Group 1 showed elevated connectivity from AMY to aSTG, from AMY to FG, and from aSTG to FG, which indicate an increased information flow from AMY to FG with aSTG as a mediator during sad film clips. This suggest that sad, compared to happy visual stimuli, change the strength of the coupling between the nodes of this three-region-network.

The DCM result was mainly constricted to the right hemisphere. This is in line with the right hemispheric lateralization of Pehrs and colleagues' (2014) findings.

### **Correspondence of the whole-brain analysis and regions of interest.**

In the whole-brain imaging results, we did not find activation in FG and AMY at the selected, corrected thresholds. This can be explained by to reasons: First, we explored only difference contrasts, where the effects of watching the film clips without music are subtracted. This may also have subtracted parts of the activations in AMY and FG. In addition, AMY is close to a strong artefact that all fMRI studies suffer from. This artefact covers parts of the orbitofrontal cortex and may extend towards AMY. This artefact causes a reduced sensitivity to the BOLD effect in these regions. However, when lowering the significance threshold to an uncorrected level of  $p > 0.01$ , both AMY and FG appear in the

results. Further, applying a small volume correction may improve the results for these areas. Therefore, these areas were included in the DCM analysis.

### **Resting State fMRI**

There was no main effect of Repetition (before/after experimental procedure) or Group in the resting state data. This indicates that the groups had similar resting state brain activity before the experimental procedure. There was an interaction effect of Group and Repetition, showing that resting state activity changed from before to after the experimental procedure depending on the type of film perceived. This confirms the hypothesis that the type of film would affect subsequent resting state activity in different ways.

Two components revealed significant interaction effects of repetition and group. The first component represented an ACC network with a significant interaction effect in an area located between the PCC and IPL, which are both parts of the DMN (Andrews-Hanna, 2012). The second component represented the posterior DMN, with a significant interaction effect in an area corresponding to the dACC, close to the vACC. Both interaction effects indicate reduced connectivity between dACC and the DMN in Group 1 compared to Group 2 after the experimental paradigm, suggesting that sad visual stimuli have an effect on this connection.

The ACC is a large and heterogeneous region, where many subregions of the ACC are connected to a wide range of brain areas (Margulies et al., 2007). This heterogeneity of the ACC complicates the interpretation of the findings. The dACC has been implicated in different brain networks and mental processes, for example in the EMN, and related functions such as cognitive flexibility, executive function and impulse control (Hugdahl et al., 2015). A consensus about a division of the ACC in a cognitive dorsal part and an emotional ventral part has been widely accepted (Bush, Luu, & Posner, 2000). However, the dACC has been shown to be involved in emotion processing and this distinction is not necessarily as clear cut as previously assumed (Etkin et al., 2011; Etkin & Wager, 2007; Mechias, Etkin, & Kalisch,

2010). In fact, Etkin et al. (2011) reviewed research on the role of mPFC and ACC in emotion and cognition and suggested a distinction of evaluative and regulatory functions rather than the distinction between cognition and emotion. Specifically, they suggested that the dACC and dmPFC have an evaluative role in emotion, and that the ventral ACC (vACC) and vmPFC have a regulatory role. Gallese, Keyers, and Rizzolatti (2004) also suggested that ACC plays an evaluative role in emotion, together with anterior insula. They proposed anterior insula and ACC are involved in evaluating emotional and behavioural input from others, representing a mirror mechanism in the human brain that allow humans to understand the meaning of the emotions and actions of others by simulating them internally in an automatic fashion. This mechanism is comparable to ES, shown to involve the ACC (Yomogida et al., 2014). The finding of dACC involvement in the present results corresponds to its role in emotion processing, and may reflect an evaluative role as suggested by Gallese et al. (2004) and Etkin et al. (2011).

Together with the fronto-insular cortex, the dACC has also been implicated as a central node of a network called the “Salience Network” (SN; Seeley et al., 2007). These nodes, and other subcortical areas included in the SN, co-activate in response to personal salience of internal and external stimuli, and dACC and fronto-insular cortex is thought to mediate subjective emotional states that arise from bodily responses (Seeley et al., 2007). The SN has been implicated in switching between the DMN and executive control networks, which is deactivated when the DMN is recruited (Menon & Uddin, 2010; Rilling, Dagenais, Goldsmith, Glenn, & Pagnoni, 2008; Sridharan, Levitin, & Menon, 2008). Chiong et al. (2013) demonstrated that the SN causally influences the DMN during moral reasoning. They found directed influences from SN to DMN, specifically from the right fronto-insular node to PCC and from the ACC node to the mPFC (Chiong et al., 2013). In the present resting state data, the two interaction effects indicated decreased connectivity between the dACC and

posterior DMN after watching sad film clips. Further, the task fMRI data showed increased activity in the DMN areas of mPFC and PCC during sad music perception. These findings may be explained by the modulating role of SN on DMN activity. It may be the case that the dACC, as part of the SN, up-regulates the DMN when sadness is evoked. When the sadness-evoking salient stimuli is no longer present, the dACC no longer influence the activity of the DMN and thus disconnects from it, in terms of reduced connectivity.

In the present study, however, differences in dACC activity due to film type was not evident in the task fMRI data, and this interpretation is made with caution. Several research findings point to the role of ACC in emotional audiovisual perception, and this should be looked into in future research. The ACC is involved in ES (Yomogida et al., 2014) and this points to the recruitment of ACC in emotional audiovisual perception. Evidence of the recruitment of dACC during sad emotion experience comes from Harrison and colleagues (2008), who found increased connectivity in a network corresponding to the SN (termed the “paralimbic” RSN in their study), with dACC and anterior insula as central nodes, during the subjective experience of sadness. The decreased connectivity between dACC and the DMN in the present resting-state results may be explained in terms of dACC being more involved in processing sad than happy visual stimuli, due to a stronger salience of the sad stimuli, and therefore disconnected from the DMN in subsequent resting state. Again, this interpretation is hypothetical in that an increased recruitment of the SN was not evident in the task fMRI data.

Few studies have investigated the emotion effect of audiovisual stimuli on resting state activity. Harrison et al. (2008) induced sad emotion in a resting-state like condition of recalling a sad personally experienced event and found attenuated DMN activity associated with sad recall compared to neutral recall. These results are not suitable for comparison to the present study, because the task of evoking experienced events may represent a cognitive challenge leading to DMN attenuation. A study by Eryilmaz and colleagues' (2011) used film

clips to evoke emotions in a similar way as the present study. They found decreased activity in ACC and mPFC in resting state after happy and fearful film clips, compared to neutral films. A study by Pitroda et al. (2008) found decreased activity in the PCC and precuneus of the posterior DMN after looking at emotional pictures compared to neutral pictures. The decrease in connectivity between dACC and the posterior DMN in the present resting state data may reflect such a decrease in ACC, mPFC, and PCC/precuneus activity as seen in Eryilmaz et al. (2011) and Pitroda et al. (2008).

Why the connectivity between dACC and the DMN was decreased more after watching sad film clips than after happy film clips in the present study is not clear. The differences in resting state activity in the two groups in the present study indicate an effect of emotional audiovisual stimuli on DMN activity. To date, the exact function of the DMN is largely unknown (Raichle, 2015), however, the ability of audiovisually evoked emotions to change spontaneous neural activity may prove valuable in future therapeutic tools.

### **General Discussion**

The field of multisensory emotion processing is pervaded by diverging results. This may be explained by the use of a wide variety of stimuli and tasks in studies of emotional multisensory integration. Many of the previously mentioned studies on multisensory integration involved experimental designs of observing and making judgements about the emotional content of the stimuli (Klasen et al., 2011; Kreifelts et al., 2010; Müller et al., 2012; Müller et al., 2011). According to Wager et al. (2008), these tasks does not necessarily involve the subjective experience of emotions in the participants, and categorized these as studies of “perception”. Investigations of “experience”, in the other hand, involve the generation of subjective feelings in response to experimental stimuli. The use of music and film, as in the present study, has been shown to evoke emotions in humans (Baumgartner et al., 2006a; Baumgartner et al., 2006b; Eldar et al., 2007; Pehrs et al., 2014; Pehrs et al., 2015)



and is therefore best categorized as studies of “experience”. However, the distinction between the two categorizations is not unambiguous, and both variations will include some degree of perception and experience of emotion (Wager et al., 2008). Wager and colleagues (2008) nevertheless showed that separating the two types of studies revealed different findings in terms of neural correlates. For example, mPFC and TP showed increased activity in “experience” studies compared to “perception” studies (Wager et al., 2008), in line with the present findings of mPFC and TP involvement in audiovisual emotion processing. The studies included in Wager and colleagues’ (2008) meta-analysis were studies of emotions in general and not multimodal emotions. However, the possibly different neural correlates of perception and experience of emotions highlights the difficulty in comparing results across studies. To make a justified comparison between studies, more studies using identical or systematically similar stimuli are needed.

The present findings are in concordance with findings in clinical populations. For example, autism spectre disorders are associated with decreased activity in mPFC and the right STG during judgments of verbal and facial expressions of irony compared to normal controls (Wang, Lee, Sigman, & Dapretto, 2007). Individuals with autism spectre disorders show impairments in social interactions and have difficulties reading emotions from a facial expression (Harms, Martin, & Wallace, 2010). Autistic individuals have been seen to have a preference for single-mode stimuli compared to multimodal stimuli (Inoue & Kobayashi, 1993 in Celani, Battacchi, & Arcidiacono, 1999). Understanding irony involves detecting conflicting emotional content in verbal utterances, vocal prosody and facial expression (Wang et al., 2007). The deficits associated with autism correspond largely with the involvement mPFC and STG in the processing of emotional audiovisual information, as seen in the results of the present study. Also frontotemporal dementia is associated with deficits in

socioemotional processing and this condition is associated with TP atrophy (Olson et al., 2007).

Learning more about the neural basis of emotions evoked by audiovisual stimuli may contribute to the understanding of psychopathology, and how to use emotional audiovisual stimuli in the treatment of brain-related disorders. One can imagine a vast application area including, but not limited to, symptom relief or social training aimed at different disorders, syndromes or conditions.

### **Conclusion**

The present study has confirmed the effectiveness of film and music in evoking emotions in participants, and provided a dynamic context of investigating emotion processing and multisensory integration. The present results point to the involvement of mPFC, PCC, TP, aSTG, FG, and AMY in multisensory integration of emotional information, supporting previous findings of the involvement of these areas (e.g. Klasen et al., 2011; Pehrs et al., 2014; Pehrs et al., 2015; Yomogida et al., 2014).

The work of Pehrs et al. (2014; 2015) was largely replicated. We too found the involvement aSTG, FG and AMY in the process of multisensory integration of emotional stimuli, with increased STG activity during happy music. We also demonstrated an emotion effect of visual stimuli on network connectivity, with stronger connectivity from AMY to aSTG, from AMY to FG, and from aSTG to FG associated with sad film clips. The emotion specific activity in this network is thought to mediate the different subjective experiences arising from the emotional valence of film and music.

We found that the sad visual stimuli were successful in evoking emotions in the participants. Using happy and sad visual stimuli enabled the research of incongruent audiovisual stimuli. The results indicated a difference in the neural correlates of processing congruent and incongruent information, with increased activity in mPFC and TP during

incongruent emotion perception. There were also differences between congruent and incongruent conditions in the DCM results, with a stronger effect of congruent happy stimuli on the connectivity from FG to AMY in the identified multisensory network. The increased activity in STG during happy music and the congruency effect of happy music and film on the coupling from FG to AMY does not correspond to the suppressive role of aSTG on FG-AMY coupling strength as shown by Pehrs et al. (2014).

The mechanisms and implications of resting state activity is an exciting area of currently expanding research, giving way for important clinical discoveries. The present study demonstrated that audiovisual information lead to measurable changes in subsequent resting state activity depending on the emotional quality of the preceding stimuli. After watching sad film clips, the connectivity between dACC and the posterior DMN was attenuated. The involvement of the DMN in processing sad stimuli was also indicated by increased activity in mPFC and PCC during sad music.

The present findings provide insight into basic mechanisms of emotion processing and multisensory integration and will hopefully contribute to a better understanding of how emotional stimuli in the everyday context is integrated and processed in the brain.

### **Limitations**

In the present study, no physical measures of emotions were included. Thus, subjective ratings and brain activity measures alone was used as a confirmation of the emotion-evoking ability of the audiovisual stimuli. It would further strengthen the study to include measures of emotion-related physical responses, such as heart rate monitoring and measures of skin conductance.

Due to time limitations, no pilot study was conducted to rate the new visual stimuli used in Group 1. However, the behavioural results demonstrated that the visual stimuli were

successful in evoking subjective emotions in participants corresponding to the emotional valence of the film clips.

There is a possibility that the movies used as visual stimuli was previously known by the participants, or that the actors were familiar. This may have had an impact on the emotional experience of the films.

The participants in the present study were selected from a student population and represented a relatively homogenous group in terms of age and educational level. The generalizability of the results would be increased by including more participants and a heterogeneous sample.

### **Future Directions**

Due to time restrictions, not all the DCM analyses done by Pehrs et al. (2014) were replicated. We did not perform the non-linear analyses. Future studies should include the TP in their DCM analysis to explore the possible involvement of the multisensory network of aSTG, TP, FG, and AMY in the processing of different emotions and of incongruent stimuli.

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## Appendix A

Visual stimuli for Group 1.

List of used film stimuli with the title (year), clip (length) and the name of the actor and actress.

| <b>Title (year)</b>               | <b>Clip (length in sec)</b> | <b>Actress and Actor</b>                  |
|-----------------------------------|-----------------------------|---|
| Garden State (2004)               | 1:32:21 – 1:33:14 (53)      | Natalie Portman & Zach Braff              |
| Lost in Translation (2003)        | 1:32:49 – 1:34:06 (77)      | Scarlett Johanson & Bill Murray           |
| Kickass 2 (2013)                  | 1:34:25 – 1:35:46 (81)      | Chloë Grace Moretz & Aaron Taylor-Johnson |
| The Perks of Being a Wallflower   | 1:27:40 – 1:28:35 (55)      | Emma Watson & Logan Lerman                |
| The Breakfast Club (1985)         | 1:32:43 – 1:33:50 (34)      | Ally Sheedy & Emilio Estevez              |
| The Breakfast Club (1985)         | 1:33:15-1:34:00 (45)        | Molly Ringwald & Judd Nelson              |
| 10 Things I Hate about You (1999) | 0:53:58 – 55:02 (64)        | Larisa Oleynik & Joseph Gordon-Levitt     |
| 10 Things I Hate about You (1999) | 1:11:05 – 1:12:22 (77)      | Julia Stiles & Heath Ledger               |
| How to Lose a Guy in 10 Days      | 0:27:04 – 0:28:13(69)       | Kate Hudson & Matthew McConaughey         |
| Love Actually (2003)              | 1:33:00 – 1:33:58 (58)      | Joanna Page & Martin Freeman              |
| Love Actually (2003)              | 1:01:26 – 1:02:21 (55)      | Sienna Guillory & Colin Firth             |
| Love Actually (2003)              | 1:38:07 – 1:38:53 (46)      | Keira Knightley & Andrew Lincoln          |
| Notting Hill (1999)               | 0:15:52 – 0:17:17 (85)      | Julia Roberts & Hugh Grant                |
| The Holiday (2006)                | 1:10:27 – 1:11:41 (74)      | Cameron Diaz & Jude Law                   |
| Troy (2004)                       | 1:18:53 – 1:19:37 (45)      | Eric Bana & Saffron Burrows               |
| Troy (2004)                       | (20)                        | Orlando Bloom & Diane Kruger              |
| Troy (2004)                       | 3:01:00 – 3:01:54 (54)      | Brad Pitt & Rose Byrne                    |
| Braveheart (1995)                 | 0:27:23 – 0:27:56 (33)      | Julie Austin & Tommy Flanagan             |
| Braveheart (1995)                 | 02:33:08 – 02:34:05 (57)    | Mel Gibson & Sophie Marceau               |

|                         |                          |                                     |
|-------------------------|--------------------------|-------------------------------------|
| Braveheart (1995)       | 02:22:53 – 02:24:37 (44) | Mel Gibson & Sophie Marceau         |
| Dirty Dancing (1987)    | 1:23:23 – 1:24:26 (63)   | Jennifer Grey & Patrick Swayze      |
| The Hunger Games (2012) | 1:54:12 – 1:55:28 (76)   | Jennifer Lawrence & Josh Hutcherson |

## Appendix B

List of abbreviations.

|      |                                     |
|------|-------------------------------------|
| ACC  | Anterior cingulate cortex           |
| AMY  | Amygdala                            |
| BOLD | Blood oxygenation level-dependent   |
| DCM  | Dual causal modelling               |
| DMN  | Default mode network                |
| EMN  | Extrinsic mode network              |
| ES   | Event simulation                    |
| FG   | Fusiform gyrus                      |
| fMRI | Functional magnetic resonance image |
| GLM  | General linear model                |
| ICA  | Independent component analysis      |
| IFG  | Inferior frontal gyrus              |
| IPL  | Inferior parietal lobe              |
| IPS  | Intraparietal sulcus                |
| ITG  | Inferior temporal gyrus             |
| OFC  | Orbitofrontal cortex                |
| PCC  | Posterior cingulate cortex          |
| PFC  | Prefrontal cortex                   |
| ROI  | Regions of interest                 |
| RSN  | Resting state network               |
| SFG  | Superior frontal gyrus              |
| SMA  | Supplementary motor area            |
| SN   | Salience network                    |
| SPM  | Statistical parametric mapping      |
| STG  | Superior temporal gyrus             |
| STS  | Superior temporal sulcus            |
| TP   | Temporal poles                      |
| TPJ  | Temporo-parietal junction           |
| TR   | Repetition time                     |
| TTR  | Transient task-related              |
| a    | anterior                            |
| d    | dorsal                              |
| l    | lateral                             |
| m    | medial                              |
| p    | posterior                           |
| v    | ventral                             |