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The Influence of Arousal on Musical Memory

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Declaration of Authorship

I, Madeline HUBERTH, declare that this dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
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"Great music is that which penetrates the ear with facility and leaves the memory with difficulty. Magical music never leaves the memory."

Sir Thomas Beecham

UNIVERSITY OF CAMBRIDGE

Abstract

Faculty of Music

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The Influence of Arousal on Musical Memory

by Madeline Huberth

The primary motivation for listening to music is the emotional response elicited in the listener (Sloboda, 2012) and indeed, the emotional response can be potent (Goldstein, 1990). It is reasonable to hypothesize that these strong emotions are connected to memory — music that elicits stronger emotions may be more readily recalled than music that is not felt as strongly. This has been demonstrated in other fields: for example, emotional pictures, words, and events are recalled better and more easily retrieved from long-term memory than less emotionally impactful ones (Heuer and Resiberg, 1990; Kensinger and Corkin, 2003; Hirst et al., 2009). However, for music, this relationship has only been recently examined (Eschrich, 2008). Multiple experiments were conducted using Likert-scale arousal and valence reports in conjunction with measures of the sympathetic nervous system (e.g. heart rate, electrodermal activity, and respiration). Results showed that while valence ratings strongly correlated with recall performance, arousal played no significant role in recall. This contradicts the literature showing arousal is very important in recognition memory (Kensinger and Corkin, 2003; LaBar and Phelps, 1998), and merits further examination of the relationship of arousal to musical memory. The goal of this study is to further explore the effect of arousal on memory by:

1. Using stimuli that elicit both strong positive and negative emotions. The missing arousal effect in previous studies might be due to the lack of negative emotions elicited in the listeners, as arousal is found to be strong for negative events (Lang et al., 1997).

2. Using alternative measures of arousal (e.g. self-assessment manikins, emotional face recognition), which would serve to reinforce or contradict previous studies.

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This thesis is dedicated to my parents,
who, with their undying love and support,
made all of this possible.

Chapter 1

Theoretical Background

1.1 Historical Context

Emotionally-charged memories tend to persist longer than neutral ones, and often with more enhanced details (e.g. Cahill and McGaugh, 1995; LaBar and Phelps, 1998). Since these memories are often meaningful to us, it is unsurprising that the interaction between emotion and memory is of interest to psychologists. Within the past 60 years, they have applied well-known and well-supported psychological models of emotion to understand the enhancement of emotional memories in more detail. One dimension of a two-dimensional emotional model has garnered wide support as being particularly influential to memory: arousal, a reflection of how exciting/agitating or calming/soothing an event is. The model applied is Russel's two-dimensional model of emotion, the other dimension of which is valence, or how positive or negative an event is (Russell, 1980). While memory experiments that use lists of words, images, or free recall of historic events show mounting support for heightened levels of arousal as the dominant factor in memory enhancement, the literature that uses music as a stimulus, albeit still relatively small, shows different results. There is currently a split, with some support for arousal as influencing musical memory (Aubé et al., 2013), but with greater support for valence as the dominant factor (Eschrich, 2008). Unless the nature of musical emotions is somehow different than emotions produced by other stimuli (and the arguments that it is not are growing stronger), why is there not strong evidence of an effect of arousal on memory when using music as a stimulus?

Though formal research on music, emotion, and memory is relatively recent, we have intuitively known for a long time that they are linked. The realization of music and memory's relationship stretches at least as far back as the ancient Greeks, where it is embedded in the story of the birth of the nine Muses. The Muses were goddesses of art, literature, and the sciences, but according to the earliest writers, were primarily goddesses of song. Their mother, Mnemosyne, was the goddess of memory, and thus music is literally conceived by memory in ancient Greek mythology. Evidence for the strong link between music and emotion also stretches back in time, evident in various facets of our languages. Consider the the Old English poem, "The Gifts of Man", written down sometime in the 10th century (although it might be older), in which lines 49-50 discuss a harpist:

> Sum mid hondum mg hearpan gretan,
> ah he gleobeames gearobrygda list.
>
> *One with his hands may play the harp,*
> *he possesses the skill of quick playing of the glee-beam.*
>
> – Translation by Alexandra Reider

Not only is the harp is directly compared to glee, but the Old English word, 'glig', which is another spelling of 'gleo-', as in 'gleobeam', can also mean mirth, joy, fun, *music*, sport, and social entertainment. Even in modern English, one can wonder if the category of song, the 'glee', similar to a madrigal, and the origins of title of larger a cappella groups known as 'glee clubs', is connected to how we use the word emotively.

We now understand some aspects of these relationships more fully. There is a huge literature from a wide range of disciplines that relates various phenomena of emotion and music, including how listeners tend to report positive emotions while listening to music (Schulkind et al., 1999), how reports of strong experiences with music often are of an autobiographical nature (Gabrielsson, 2001), and how violating our expectations of how the music should go can cause an emotional response (Steinbeis et al., 2006). Studies that focus on how melodic and harmonic structures in music evoke an emotional response typically focus on quite momentary emotions. In listeners accustomed to classical music, emotions can be the result of changes in harmonic and melodic structures as short as an appoggiatura or suspension (Sloboda, 1991). From the study of deviations in timing patterns in live performance and their influence on perceived expressivity, to inquires into how various modes are perceived as common emotions, the study of the emotional characterizations of music is a growing field of research.

Regarding memory, as the Greeks intuited, our data now show that music perception relies on memory at almost every stage of the listening process. Upon hearing a sound, early auditory processing allows us to attend to the finest details of the acoustics, converting sound into nerve impulses that represent the frequency and amplitude of the sound waves. Research has even suggested that our memory prolongs short sounds (in the range of 30-100 ms) to 130 ms to render them long enough for analysis (Efron, 1970a,b). These traces are bound together with other concurrent sounds, coded into single, coherent auditory events that are then grouped together over time based on similarity and proximity, creating a sense of continuity (or discontinuity, depending on the musical style) in a phrase. Finally, long-term memory helps to create coherence in a piece. As previously heard melodies, harmonies, and lyrics reoccur, we draw connections between them that help to create unity in our perception of the piece.

We know much less about how memory for music persists after the piece has ended. Feats of skilled musicians come to mind, such as the story of a 14-year-old Mozart who, after one listen of Gregorio Allegris "Miserere" in the Sistine Chapel, transcribed the 11 minute piece in its entirety, and after a second listen, fixed his mistakes (Anderson, 1966). Less impressive, but feats nonetheless, concertmasters can often recall vast sections of major orchestral works just by looking at the first page of the violin part (J. Thayer, personal communication, Nov 1, 2011). However, there is a large technical component and active practice involved in recalling music in these ways. In actuality, persistent memory for music is a common experience that does not require declarative knowledge of musical structure or notation. The current literature on musical memory has thus studied the long-term memory of both musicians and nonmusicians (e.g. Halpern et al., 1986; Gaab and Schlaug, 2003; Schulkind et al., 1999).

Regarding those without formal training, the persistence of memory for music seems especially strong for music played during one's youth (Schulkind et al., 1999). Indeed, memory for music can be so enduring that, even in the face of severe cognitive impairment from dementia and Alzheimer's disease, it is often spared. Cuddy and Duffin (2005) recorded instances of a patient expressing joy at a melody played in a familiar style, and expressing bewilderment or amusement at a selection that did not follow the rules of harmony that she was familiar with. Similarly, the documentary 'Alive Inside', which investigates the power music has to awaken deeply locked memories, features a video of a man in the late stages of dementia who recalls and proceeds to sing a song by Cab Calloway, one of his favorite artists when he was young (Rossato-Bennett, 2013). This persistence of musical memory and musical understanding occurs along with other complex skills like playing card games or assembling jigsaw puzzles. With neuroimaging techniques, researchers are in a better position to find out why. It may be that since complex skills rely on many neural networks, co-activation of these networks support and reinforce weakened components (Cuddy and Duffin, 2005). What makes music unique among these skills though, is that unlike the explicit knowledge required in playing card games, no explicit knowledge is needed to understand music. Regardless of formal training, we acquire an intuitive understanding of music - following a melody line, feeling release at a cadence - through mere exposure.

Although we are passively exposed to music through our daily activities, much of our exposure is active. We want to listen to music; we actively seek it out. While there are many reasons why we choose to listen, the most cited is because of the emotion it elicits in us (Panskepp, 1995; Gantz et al., 1978; Lonsdale and North, 2011). Several studies have examined emotional responses to music and how they affect memory outside of the lab setting, but have used music the participants have heard before. These studies offer no way to control the number of times a participant heard the music in question. This is problematic. It is a basic principle of memory that, if information is 'rehearsed', or actively repeated in the mind, the information will leave a deeper trace in the memory (Hebb, 1949; Anderson, 2000; Awh et al., 1999). Furthermore, emotions for familiar music tends to be stronger than for unfamiliar music (Rickard, 2004; Blood and Zatorre, 2001). As such, these studies cannot isolate the impact of emotional response on memory for music.

To my knowledge, only two experiments relating music-induced emotion to memory controlled for the number of times the participants heard the music (Aubé et al., 2013; Eschrich, 2008). Although Aubé used basic emotions (fear, happiness, peacefulness, and sadness) in their study, they generally found that the pieces meant to elicit typically higher-arousal emotions (fear and happiness) were more often recognized during a later session than the low-arousal pieces were. Eschrich's series of experiments, however, found an effect of valence on memory, but not of arousal. The missing arousal effect in Eschrich (2008) was not met without surprise by the researchers. Overall, the memory literature shows the importance of arousal during stimulus encoding on memory, and so the recent findings that arousal does not affect subsequent recognition of unfamiliar music merits further investigation.

1.2 Emotions

1.2.1 Converging on a Definition

Historically, psychologists have disagreed on the definition of 'emotion'. Kleinginna and Kleinginna (1981) included 92 different definitions and 9 skeptical statements, drawn from psychological dictionaries and well known texts, in their study on how 'emotion' is defined, with each definition emphasizing different causes, manifestations, and purposes of emotion. Since many research studies adopt one definition as fundamental to their research, these varying definitions of emotion have created a rather complex landscape of research.

However, there are several aspects of emotion on which psychologists agree. There is consensus that emotions can occur in response to events in both the external and internal environment (Juslin and Sloboda, 2010). There is a widely-held belief that they can operate without a high level of conscious awareness — you may be unaware of your response to a stimulus or may not notice the stimulus itself (Izard, 2009). And with respect to moods, which typically last for several hours although they can last for days, emotions vary more quickly, and can be more extreme.

Furthermore, there is consensus that emotion is characterized by several subcomponents, although precisely how many subcomponents should be acknowledged, and their relative importance, is less agreed upon. Some psychologists identify three main subcomponents of emotion: motor behavior, physiological responses, and psychological reactions (Damasio, 1999), some identify four (Juslin and Sloboda, 2010), while others argue five distinct subsystems in an emotional episode: cognitive, physiological, motivational, motor expression, and subjective feelings (Scherer, 2005). In recent years, the five-subcomponent model has gained support; each component is elaborated on below.

- **Cognitive component** — The individual's subjective interpretation of a stimulus or situation that relates to their goals, needs, motivations, and values (Juslin and Västfjäll, 2008). This subcomponent is unique in its nature since it can regulate the others. For example, cognitive reappraisal of negative images has been shown to decrease self-reports of negative affect and lead to smaller increases in blood pressure (Jackson et al., 2000). Some theories, and especially *appraisal theory*, posit that cognitive factors, appraisals in particular, are fundamental to and actually cause an emotional response (Lazarus, 1982). Under this theory, a person first appraises a situation, such as viewing the death of a person as a loss, and only then does a specific emotion, such as sadness, set in.
- **Physiological component** — Activation of the autonomic nervous system (ANS). The autonomic nervous system is responsible for regulating involuntary body functions. Measurable changes in the ANS include changes in heart rate, sweating, and breathing rate, and often, these changes vary with the overall strength of an emotional response in meaningful ways. This subcomponent is also at the root of another emotion theory, James-Lange theory, which posits that an emotional response *originates* in physiological arousal, and that feelings and appraisals depend on bodily states. This view was later argued by Antonio Damasio in his seminal works, *Descartes' Error* (1994) and *The Feeling of What Happens* (1999).
- **Motivational component** — The preparation and direction of motor responses. Typical examples include the urge to flee when encountering fearful stimuli, to

place revenge in the case of anger, and to avoid a stimulus in the case of disgust. These tendencies to act in a particular fashion during an emotional response are deemed *action tendencies* and are closely related to the goals of the individual (Frijda, 1986). Action tendencies might not be acted upon, and when they contradict other subcomponents, might slow behavior down.

- **Motor expression** — Body language, and especially facial expressions, are vehicles for emotional expression. They communicate emotional reactions and behavioral intentions. Facial expressions can be involuntary, and often complement speech to help the listener understand what the speaker means. Many reviews of facial expressions caused by emotion agree that the face reveals emotion in a way that is universally understood by all people regardless of their cultural background (Ekman, 1993; Brown, 1991; Carlson and Hatfield, 1992; Izard, 1994); however, this view has also garnered criticism (Russell, 1994).

- **Subjective feelings** — The monitoring of internal state and the subjective experience of the emotion after it has occurred. Through the monitoring of the state of the body and by appraising the stimulus, an individual can describe his emotional state via verbal report, which at present, is the only means to assess this subcomponent of emotional experience since it cannot be observed.

Although these components can act independently of one another, it is hypothesized and widely agreed upon in the psychological community that they are often synchronized (Scherer, 2005). Whenever appraisal and action readiness are evoked, synchronization tends to occur, resulting in clearer subjective feelings and conscious emotional experience (Grandjean et al., 2008).

This thesis measures two of these emotional subcomponents: subjective feelings (measured via questionnaires) and the physiological component (measured by electrodermal activity).

1.2.2 Emotion models: Uses and Limitations

Emotion theories attempt to describe the nature of our emotions and posit testable models of emotion. The models can be broken down broadly into two categories: discrete models, whereby a set number of basic, cross-cultural emotions can combine to form more complex emotions, and dimensional models, which define an emotional experience by where it lies on gradients of affective states. The remainder of this section is a description and discussion of these two categories. Certainly the variations of each model and the debates surrounding them are vast and cannot be fully discussed in a paper of this length. For a review, see Scherer's Chapter 6, 'Psychological Models of Emotion' in *The neuropsychology of emotion*, (2000).

1.2.2.1 Discrete Models

Proponents of discrete models argue that there are several biologically and behaviorally distinct emotions, 'basic emotions', that are intrinsic across all cultures. Happiness, surprise, fear, anger, disgust, and sadness, and in some theories, interest and shame as well, are understood across cultures (Ekman, 1993; Brown, 1991; Carlson and Hatfield, 1992). More complex emotions are built by combining these basic emotions. For example, disgust and anger could combine to create contempt.

The history of discrete models is lengthy. The first framing of differentiated, basic emotions is in Darwin's *The Expression of Emotion in Man and Animals* (1872). Darwin devotes most of the book to describing the function, history, and universality of particular emotions, and devotes each chapter to a different emotion. In what would later grow to be a fundamental claim of discrete models, he posits that each emotion is manifest in a different facial expression, and these expressions are universally produced and recognized. This claim was extended by Tomkins (1962), who argued that not only do facial expressions differ between emotions, but that emotions correspond to entire body states, or 'affect states'. For example, he suggested that a distinct vocal expression for each of the emotions would correspond to its distinct facial expression. His volumes were collected and described as *affect theory*, which has been popularized by studies that find empirical evidence for cross-cultural facial expression recognition, as well as developmental evidence for early onset of discrete facial expression recognition (Izard, 1994; Ekman, 1972).

Perhaps the principal contention of discrete models is that they assume a strong set of observable characteristics across *all* of the subcomponents of emotion. Even though psychologists agree that the subcomponents of emotion often vary synchronously, neuroimaging and physiological studies have not established reliable evidence to link correlations between subcomponents to discrete emotional states. Although some neurological associations are clear, e.g. the amygdala is linked to fear and depression, and disgust to the basal ganglia, many emotion category-location correspondences in the brain are neither consistent nor specific (Barrett and Wager, 2006). Physiologically, there are inconsistencies in how basic measures, such as heartbeat and skin conductance, correlate with discrete emotions. Strong claims were made in the early 1990s that there was sufficient evidence for the differentiation of emotions by physiological data. Notably, Levenson (1992) reviewed the relevant literature and compiled evidence for select patterns of responses, such as how heart rate increases strongly during fear, anger, sadness, and how the heart decelerates during disgust. However, some of his claims are debatable. Cacioppo et al. (2000) commented on Levenson's work with an updated meta-analysis of all studies that compared at least two discrete emotions by using any two physiological measures. He found that although Levenson's claims of heart rate changes matched their analyses, Levenson's claim that fear is associated with sharp decreases in finger temperature and increases in skin conductance was not supported. Overall, Cacioppo's meta-analysis suggests only weak or contradictory physiological support for discrete emotion models.

Furthermore, although discrete models argue that facial expressions may be universally produced, studies have revealed that humans make errors in observing and recognizing them when placed in different contexts, shedding some uncertainty on facial recognition studies that often display faces alone. For example, Carroll and Russell (1996) told participants a story describing an emotional event and then showed them a close-up of a person displaying a facial expression, yet the expression did not always match with the intended affect of the story. When asked to label the facial expression, participants choices tended to correlate more closely with information provided by the story rather than the facial expression alone. Furthermore, despite how clearly the facial expression might have been identified when taken out of context, there was no emotion tested that was not influenceable by context. This study, and others like it (e.g. Aviezer et al., 2008), suggest that knowledge about emotion, and what situations should cause particular emotions, affects facial expression recognition.

1.2.2.2 Dimensional Models

Dimensional theories place aspects of emotional responses along various axes, allowing for finely graded spatial descriptions of emotions. Wundt (1905) suggested a tridimensional model: pleasantness-unpleasantness, rest-activation, and relaxation-attention, which had a strong impact on psychological research in the early half of the 20th century. Two-dimensional models arose in the 1950s, and have risen in popularity since the 1980s, perhaps since they are relatively easy to visualize and analyze. Russell's two-dimensional circumplex model of emotion (see Figure 1.1) was introduced in 1980 and is among the most heavily utilized dimensional models in emotion research. It represents specific emotions as points within a two dimensional space, functions of their relative valence and arousal. The model has proven to account for a large proportion of variance in the emotional labeling of linguistic (Bush, 1973), pictorial (Bradley and Lang, 1994), and musical stimuli (Schubert, 1999).

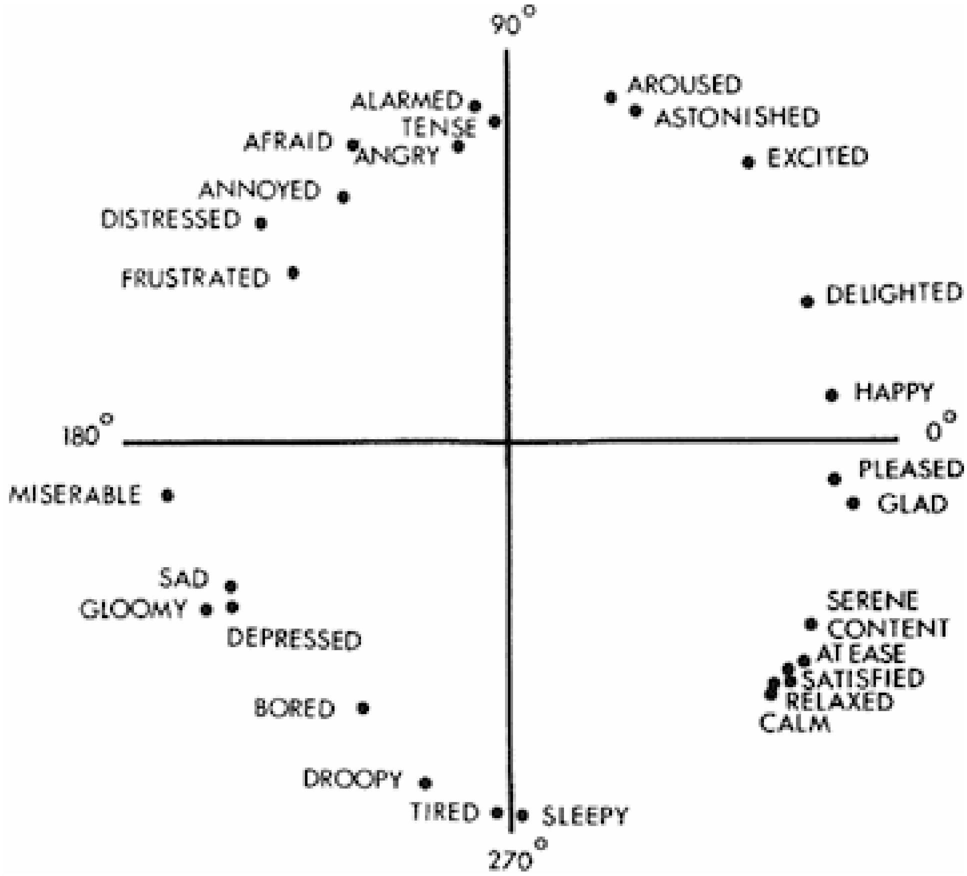

FIGURE 1.1: Russell's (1980) circumplex model of emotion. The horizontal axis represents valence while the vertical access represents arousal.

Some criticisms of dimensional models include that they are too finely-grained to relate usefully to our common experiences, and that the categories offered by discrete models are useful when we describe our everyday emotions. Furthermore, dimensional models do not take into consideration the function of emotion for the individual, and so fail to differentiate strongly between emotions that are close in the arousal-valence (AV) space, but serve very different motivational and social purposes (e.g. anger and fear). However, proponents of dimensional models insist that the models' strengths lie in exactly their deemphasis of these cognitive labels, which often can be applied to very different contexts and thus take on different meanings (Russell, 2003). For example, one can experience fear when encountering a bear and choose to flee, but one can also experience fear when watching a horror movie, but subsequently stay and enjoy the movie. These two experiences of 'fear' are quite different. Although cognitive labels are useful to researchers in that they help to frame research questions, enable conversation with participants, and indeed help in conversation with other researchers, they can be flawed when describing an experienced emotion. As such, a critique of dimensional models is also a strength: they emphasize mood and affect, which can be more precisely measured and tread less into the ambiguity of emotional terms.

Overall, the two-dimensional model has been among the most widely studied and supported representations of affect, has been used often in psychological studies. It has been argued to be more consistent with many recent findings from behavioral, cognitive neuroscience, neuroimaging, and developmental studies of affect, than discrete models (see Posner et al., 2005, for a review). Thus, it will be used in the experiment described in Chapters 2-4.

1.3 Emotions and Music

1.3.1 Musical Emotions - Induced or Perceived?

The overwhelming majority of us listen to music for the emotional responses it elicits in us (Panskepp, 1995). It can bring us to tears, many report having occasional personal and powerful experiences with music, and some of us experience 'chills' while we listen (a phrase which has come to be associated with the general level of physiological activity and has been shown to vary with skin conductance). However, there exists a longstanding debate of the basic nature of the emotions aroused by music. Is the emotion inherent in the structure of the music and perceived by us? Or is it a function of the listener, truly inducing emotions in us in the way that we respond to other stimuli? If emotions induced by music are truly of a different nature than emotions induced by other stimuli, results from emotion studies that use music would be less comparable the greater emotion literature.

This debate, deemed the cognitivist versus emotivist dichotomy, is outlined in *Music Alone* (1990), by Peter Kivy. He states,

> Those I am calling musical emotivists believe that when, under normal circumstances, musical critics, theorists, or just plain listeners call a piece of music (say) "sad,", it is because it makes us sad when we listen to it; and what they mean by "sad" music, I will assume, is music that normally arouses sadness in the normal listeners. The musical cognitivists, like the emotivists, believe that it is proper sometimes to describe music in emotive terms. But unlike the emotivists, they do not think that sad music is sad in virtue of arousing the emotion in the listeners. Rather, they think the sadness is an expressive property of the music which the listener recognizes in it... (p. 146)

Kivy largely holds the cognitivist position, as does musicologist Leonard B. Meyer. In *Emotion and Meaning in Music* (1956), Meyer lends skepticism to evidence that would support the emotivist position - a listener simply declaring his felt emotional response - claiming that there is no definitive way of knowing, when the listener is verbalizing his experience with the music, that he is describing emotions that he himself felt, instead of what he heard expressed by the music. He also claims that neurophysiological responses to music do not provide proof of the emotivist position, since "...no relation can be found between the character or pattern of the musical selection evoking the response and the particular physiological changes which take place" (11).

The cognitivist position does not align with the view that underlies, or in some cases is made explicit in, psychological and neurological studies of musical emotions: emotions evoked by music are of the same nature as emotions evoked by other stimuli. Indeed, for a researcher to fit her work into the larger literature on emotion, it is necessary for the emotions in question to be of comparable nature. There is now extensive evidence for the similarity between musical emotions and emotions induced by other stimuli, demonstrating that music induces responses in each of the emotional subcomponents. Physiologically, music gives rise to responses that are similar to those that result from exposure to other stimuli. Neurologically, areas of the brain that have been cited in other emotion research as being critical to emotion processing are also involved in the processing of musical stimuli, and regarding experiencing subjective feelings, listeners report experiencing emotions, especially positive ones, while listening to music. Music also elicits action tendencies (foot tapping, dancing), and facial expressions. To speak directly to Meyer's point, research shows some correlations between neurophysiological data and reported felt emotion (Panskepp, 1995), as well as the perceived emotion expressed by the music (Lundqvist et al., 2009), suggesting the synchronization of emotional subcomponents while listening to music which, as previously mentioned, is an indubitable feature of an emotional response. Although we do certainly perceive emotions that music expresses, all of this evidence indicates that music also induces emotions in the listener.

Evident by the cumulative research on musically-induced emotions, one of the focuses of music psychologists has been an exploration of the aspects of phenomena that connect music and emotions, regardless of cause. Primarily using Western music as their stimuli, studies have revealed important relationships between music and emotion. Some of the associations may seem more popularly apparent, such as how major keys are associated with positive emotions while minor ones are associated with negative emotions (e.g. Hevner, 1936; Scherer and Oshinsky, 1977), or how fast music is associated with activity while slow music is associated with sadness, while others may appear more surprising. including that timbre affects perception of emotional tension (Nielzén and Olsson, 1993), and that deviating from accurate timing is perceived to be more emotional than adhering strictly to the notated rhythm (Repp, 1997). Such examples are reviewed more formally in Section 1.3.2.

The aforementioned examples correlate structural features and changes of the music to felt emotion, but there are also extra-musical factors, occurring solely in the mind of the listener, that influence emotional response. This framing of musical emotion induction, leaning more on the listener than the music as the source of musical emotion, may explain much of the interpersonal emotional variation that often occurs in music studies - one listener may experience entirely different emotions than another while listening to the same passage. For instance, upon hearing a slow, minor piece, one listener might simply feel sad because he thinks the music sounds sad, but another may experience happiness since the piece was often played by a woman he cares deeply about, and reminds him of her.

These factors external to music activate an emotional response through music-listening or music-making. In addition to those factors that are typically considered intrinsic in the music, they are presented in Juslin and Västfjäll (2008) as a theoretical framework of *how* music induces emotion. Their six mechanisms of how music induces emotion are 1) *brain stem reflexes*, by which emotions result from acoustic characteristics of the music, 2) *evaluative conditioning*, whereby an emotion is induced because the music has repeatedly been paired with other positive or negative stimuli, 3) *emotional contagion*, which refers to the induction of an emotion that was first appraised to be in the music and then is internally 'mimicked' by the listener, 4) *visual imagery*, where a listener pictures visual images (helping to induce an emotion) while listening, 5) *episodic memory*, where the music evokes a memory of a particular event in the listener's life, and 6) *musical expectancy*, where the music violates or confirms the listener's expectations about how it should proceed, and induces emotion. Through this framework, Juslin and Västfjäll hoped to steer research from not only reporting phenomena, but to understanding why the phenomena take the form they do. Indeed, studies built on the six mechanisms might resolve disagreements in the literature, such as if music can induce only basic, or more elaborate emotions, and might explain cases of mixed emotions in response to music, where conflicting emotions might be attributed to different mechanisms.

They also might explain one of the most elusive, yet consistent, findings about musical emotion: listeners often report experiencing positive instead of negative emotion (Juslin et al., 2008; Juslin and Laukka, 2004). For example, Zentner et al. (2008) gathered self reports in which participants, guided by a list of adjectives, listed what emotions they most frequently feel while listening to music. Subsequent principal components analysis of their responses revealed that common affective responses to music could be grouped into one of nine categories: Wonder, Transcendence, Tenderness, Nostalgia, Peacefulness, Power, Joyful Activation, Tension, and Sadness, revealing an overwhelmingly positive response to music. Sloboda et al. (2001) tracked emotional changes over the course of a musical piece, and found that 87 percent of these changes were towards greater positivity. In some cases, the experience of positivity is so apparent it affects the design of the study. In the Likert-scale ratings presented to their participants, Eschrich et al. (2008) changed the affect scale from ‘negative-positive’ to ‘little positive-very positive’ since none of their pieces received a negative rating during pre-tests.

The reasons why people tend to feel positive while listening to music are not yet clear. Oftentimes, negative emotions involve threatening stimuli, dangers, or the possibility of loss, and so it may be that the lack of these dangers while listening to music does not easily translate into felt negative emotion, even though the listener might identify expressed negative emotions in the music. Or, as Juslin and Sloboda (2010) speculate, it could be that writing music that encourages pleasant emotions has been the intention (implicit or explicit) of those that write or perform music. However, crucial to this thesis is the elicitation of a range of emotion from low to high valence, as well as low to high arousal. In light of these findings that the emotions induced while listening to music are mostly positive, extra measures are taken to maximize the probability that the stimuli presented in this experiment induce a wide range of emotions.

1.3.2 Emotion Induced by Low-Level Auditory Features

Many causes of an emotional response to music rely on the previous experiences and imagination of the listener; however, the fundamental characteristics of acoustics are integral to our musical experience. Indeed, apart from programmatic music, in which a composer invites the audience to imagine scenes and narratives while listening, much of presentational music is based on evoking emotion through only sonic and structural features, without any intended external narrative. Thus, composers are limited to sonic properties and musical structure to convey and induce emotion.

Composers use basic acoustics to induce emotion in a range of ways, from subtle to wholly obvious. For instance, Beethoven built up dynamic loudness over long stretches and as a result, the audience is carried, sometimes imperceptibly, through the dynamic range, increasing their arousal and helping to keep their attention over time. In contrast, first-time listeners to the second movement of Haydn’s “Surprise Symphony”, who might have nodded off to sleep during the first 30 seconds of the movement due to its quietness, would be startled into a high-arousal state when the famous ‘surprise’ chord was played.

The effect of loudness on arousal is well known and well documented (e.g. Huron, 2006; Juslin and Västfjäll, 2008).

Music and sounds that are often associated with high arousal states, in addition to changes in dynamics, include sounds that are dissonant (either from the combination of tones that is perceived as unstable or in the amount of roughness that exists in a tone) or have a fast tempo are often associated with high arousal states (e.g. Dillman-Carpentier and Potter, 2007; Balch and Lewis, 1996; Blood and Zatorre, 2001). For instance, in a comprehensive study, Scherer and Oshinsky (1977) investigated emotional responses to synthesized melodies in which various acoustic parameters were adjusted, and found specifically that of all the parameters they manipulated, tempo was the strongest predictor of basic emotions. Fast tempi predicted emotions such as happiness, fear, and anger, all states typically associated with high arousal, while slow tempi predicted sadness, boredom, and disgust, or low-arousal states. Balch and Lewis (1996) assessed how changes in tempo affect several emotional characteristics, but found that only arousal was influenced by tempo changes. Thus, evidence seems to show that affective states induced by tempo may pertain to arousal.

Although the literature on the effects of timbre on emotion is relatively thin, possibly due to the difficulties in quantifying such a complex acoustic property, reports indicate that changes in timbre induce emotion as well. Groux and Verschure (2010) investigated the emotional effects of three perceptually salient timbre characteristics – log-attack time, spectral centroid and spectral flux – and found that increases in spectral centroid and spectral flux produced increases in arousal. Halpern et al. (1986) found that the perceived unpleasantness of sounds, such as a dragged stool, scraping metal, and scraping slate, is in part due to acoustic energy in the middle range of frequencies audible to humans, as opposed to energy in the higher frequencies. This finding was recently confirmed by Kumar et al. (2012), in which participants listened to 74 unpleasant sounds whilst in an fMRI machine. The most unpleasant sounds contained high energy levels in the frequency range of around 2,000 to 5,000 Hz. Although it is evident that these basic acoustic properties induce emotional responses, hopefully systematic research exploring more nuanced aspects of timbre will continue to develop.

Faster sound sequences are more likely to indicate high arousal or high energy states, which hold potential for evoking greater concern. Loud sounds indicate some change in the environment which it could potentially be advantageous to notice. There may be evolutionary explanations for the aforementioned effects. It is advantageous for us to take note of and be able to quickly react to loud, fast, or potentially fearful sounds. This concern for our well being in relation to acoustics and sound patterns is supported by the neurological literature, where the aforementioned musical features are linked to structures that concern our safety. Certain structures in the brain activate the autonomic nervous system, causing changes in attention, heart rate, breathing, and sweating. They do so for a simple purpose: to enable us to react quickly in response to changes in our environment, and especially to potentially threatening stimuli, which is central to our survival. These responses occur relatively early during auditory processing, and so even though we may be cognizant that we are not in danger, the autonomic nervous system is activated. The structure in question is primarily the brain stem, although there are other structures that mediate brain stem activity and are often activated in states of arousal, such as the amygdala. As early as the 1970s, studies linked dissonant sounds with brain stem and amygdala responses since (Berlyne, 1970). Although the effect of dissonance on amygdala activity has not proceeded without debate - for example, no amygdala activity increases were observed by Blood et al. (1999), while participants listened to increasingly dissonant music, or by Royet et al. (2000), who presented both pleasant and unpleasant sounds relative to neutral sounds to the participants - it may have been that sounds used by these studies were only experienced as mildly unpleasant. For the amygdala to respond strongly, it may require a strongly aversive sound.

Given status of brain stem activation as one of the distinct mechanisms of emotional induction in Juslin and Västfjäll (2008), it is expected that the number of studies exploring it's (and other closely related neurological structures') response to music will increase.

1.3.3 Experimental Methodology

This section introduces two well-accepted ways of gathering data for the study of music and emotion. Both methods will be used in this study.

1.3.3.1 Self-report Methods

There is a wide variety of self-report measures used in music-emotion research, including Likert-scales, adjective checklists, non-verbal evaluation tasks, visual analogue scales that allow participants to respond on continuous scales, and free narrative reports. Generally, the benefits of self-report methods include ease and inexpensive cost of testing and analysis, and their ease of replication for subsequent studies. However, they are often open to misinterpretation by respondents. For example, phrasing of questionnaires administered to the participants is a key factor in directing their reports towards the kind of emotion the experimentalist is hoping to measure, and even slight differences in phrasing can alter the results of the study (Konecni, 2008). Furthermore, several studies demonstrated that altering prompts, such as identifying the emotion that is expressed by

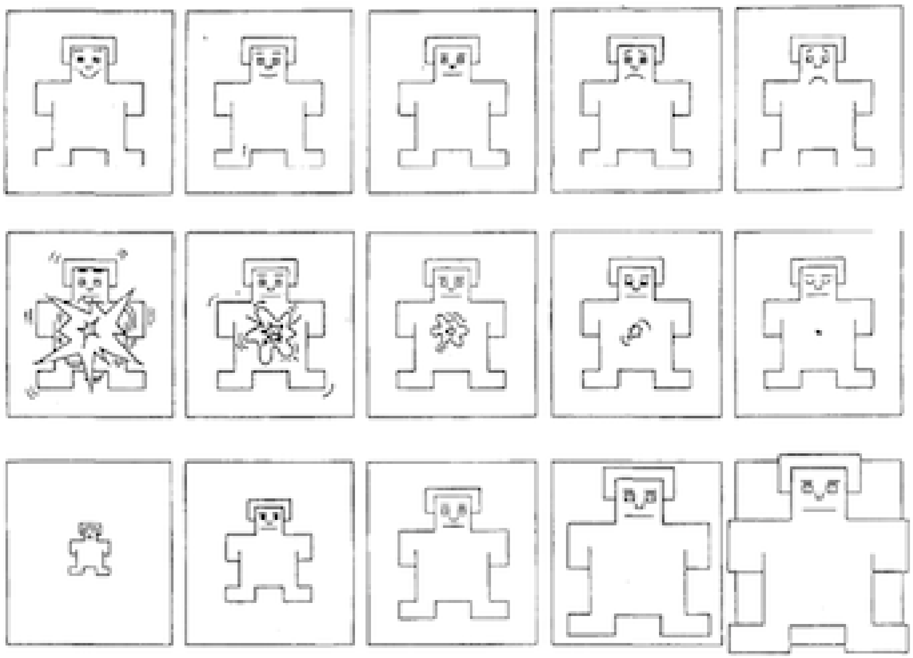

FIGURE 1.2: The Self-Assessment Manikins, Bradley and Lang (1994). Row 1: valence, row 2: arousal, row 3: dominance.

the music to the emotion experienced in the listener significantly affects the responses of the participants (Vieillard et al., 2008; Zentner et al., 2008), underscoring the importance of differentiation and clear instruction to the participants. To avoid semantic confusion and decrease variations in the understanding of the emotions that the experimenter is testing, pictures can be used to accompany descriptors of emotions. For example, the Self-Assessment Manikins (see Figure 1.2, Bradley and Lang (1994)) allows for visual associations of valence, arousal, and dominance by matching them up with drawn caricatures.

1.3.3.2 Psychophysiology

According to Hugdahl (1995, p. 8), "Psychophysiology is the study of brain-behavior relationships in the framework of peripheral and central physiological responses." Appraised emotions are often accompanied by physically 'felt' responses, and researchers measure changes in heart rate, skin conductance, respiration rates, temperature, and blood pressure, among other physiological responses, to quantify the felt response. For an excellent review of the studies that show meaningful physiological changes in response to music across a wide variety of measures, see Juslin and Sloboda (2010). This section will briefly discuss research using electrodermal activity (EDA) since it is used in this thesis.

Overall, EDA is a measure of sweat on the skin, which is controlled by the sympathetic nervous system. This branch of the nervous system is generally known as the ‘fight or flight’ system since it prepares the body to handle a threat by increasing sweat activity to cool itself. It follows then, that EDA tends to be high in situations of high activity, stress, or excitement. However, EDA can fluctuate with arousal even during weak emotional responses or in absence of an apparent threat, and so has been employed in studies of emotion and music (see Juslin and Sloboda, 2010, for a review).

EDA can be broken into two components - skin conductance level (SCL), a measure of the more slowly-changing baseline of sweat activity, and skin conductance response (SCR), a quickly responding measure of an emotional reaction to a particular stimulus, characterized by a sharp, fast deviation in EDA from the baseline. Studies show SCRs do vary with emotional content of the piece within the framework of discrete emotion theory, and as would be expected, responses are higher for the emotions typically characterized with excitement and stress, such as fear and happiness, and are lower in emotions such as sadness and peacefulness (Khalfa et al. (2002); Krumhansl (1997)). EDA also varies with musical structure. Steinbeis et al. (2006) showed that EDA increased in response to harmonic unexpectedness over time and corresponded to the participants’ self-reports: they felt more emotional at the end of the excerpts that contained high levels of harmonic unexpectedness. This speaks directly to the ‘musical expectancy’ mechanism proposed by Juslin and Västfjäll (2008), supporting the claim that that increasing harmonic unexpectedness is increasingly emotional.

Although on occasion, studies that report significant physiological changes during music listening do not find significant changes in EDA (Jellison, 1975; de Jong and van Mourik, 1973; Blood and Zatorre, 2001), there is evidence that musical emotions induce SCRs that vary with arousal. Khalfa et al. (2002) demonstrated that SCRs are significantly greater for melodies that represent fear and happiness as opposed to those that represent sadness and peacefulness, but no significant difference was found between happiness and fear nor between sadness and peacefulness. In the present thesis, EDA will be measured to accompany self-reports about emotions felt in response to music.

1.4 Emotions and Memory

While emotionally charged events tend to be remembered better than nonemotional events (e.g. Cahill and McGaugh, 1995; LaBar and Phelps, 1998), the relationship between emotion and memory is complex. Memories of negatively valenced events may at first seem vivid, but upon closer inspection the memory may only be enhanced for certain aspects of the memory at the expense of other details.

Table 1.1: Memory Definitions

Term	Definition	Source
Encoding	The process by which information is put into memory	
Storage	The process by which information is maintained in memory	Spielberger (2004)
Retrieval	The process by which information is recovered from memory	
Recall	The accessing of stored information without (free recall) or with (cued recall) prompts	Jarvis and Russell (2008)
Recognition	Accessing of memories by identifying things that have been encountered before	
Consolidation	A hypothetical construct referring to the progressive stabilization of the memory trace in long-term storage	Buzsaki (2011)

The processes by which emotions may have an effect on memory are not clear, although research provides evidence for their influence during encoding, consolidation, and retrieval, each of which will be reviewed in this section, followed by a discussion of the roles of arousal and valence in altering these processes. This section includes several memory-related terms, as defined in Table 1.1.

1.4.1 Encoding

Memories of emotionally arousing stimuli are often recalled better than non-arousing stimuli. LaBar and Phelps (1998) showed that recognition of emotionally arousing words is better than that of neutral words, and Cahill and McGaugh (1995) reported that an emotionally arousing story is recalled more fully than a neutral one. This arousal effect on story recall was confirmed by Frank and Tomaz (2000) and Gasbarri et al. (2005). It has also been shown in studies not explicitly tied to arousal. For example, Potter and Callison (2000) exposed participants to 2-minute radio broadcasts that varied in their number of voice changes, where message complexity was defined in terms of the number of voice changes per message. They predicted that participants would report being more aroused when listening to rapid voice changes ($>$ 20 per message) than when listening to fewer, and anticipated that this increase in arousal would lead to better free recall memory for the messages with rapid voice changes. Their results were as predicted, with self-reported arousal increasing for messages with more frequent voice changes, and with better free recall of these messages both immediately after the experiment and during another recall test several days later. Furthermore, although it did not achieve statistical significance, Potter's (1998) skin conductance data (using the same stimuli) suggested higher arousal during messages with rapid voice changes when compared to messages with fewer.

However, heightened arousal does not increase memory for a stimulus uniformly. Attention is drawn to the arousing portions of the stimulus, leading to better processing of those details to the detriment of less-arousing aspects. Often, the most arousing portions of a stimulus have negative valence. For example, Kensinger et al. (2007a) showed that a negative object placed against a neutral background is remembered better than a neutral object against a neutral background, but at a cost to memory for the background. In the case of a neutral object and background, the details of the object are not remembered as well but the background is remembered better. This arousal-attention effect is also extensively demonstrated in the research on weapon focusing, where guns or knives are often the most clearly remembered aspects of a crime scene (Kramer et al., 1990; Loftus, 1979). It seems as though the urge to attend to negative stimuli is strong: Nummenmaa et al. (2006) showed that even under direct instruction to ignore arousing items, those arousing items are still attended to.

The attention-narrowing effect for negative events has been explained from an evolutionary perspective: focusing on negative events is a survival tactic. However, even in research contexts that are comparatively non-threatening, the effect of remembering details of negative events still holds. For example, Kensinger et al. (2007a) presented participants with two sets of pictures of negative and neutral objects such as a picture of a tank, a snake, a balloon, and a bird, some of which varied slightly between sets. After a break, participants were asked to give an assessment of each new picture, evaluating whether it was the same, similar, or new. Results showed that participants were more likely to remember the visual details of negative items compared with those of neutral items.

While there is evidence that negative stimuli lead to attention narrowing, there are suggestions that positive stimuli lead to a *broadening* of attention (Fredrickson, 2001) where the breadth of the attention depends on the motivation of the individual. As Gable and Harmon-Jones (2010) concluded, the lower the motivation, the greater the broadening of attention. This has also been demonstrated by Wadlinger and Isaacowitz (2006) where half of the participants experienced induced positive mood before viewing emotional images during which their eye motions were tracked. Results showed that individuals induced into positive mood fixated more on peripheral stimuli than did control participants.

1.4.2 Consolidation

Newly encoded material takes time to be consolidated into long-term memory. During this time, changes in both physiological and emotional arousal have been shown to alter memories (e.g. McGaugh, 2000; Nielson et al., 1996). Research suggests memories can be modified for the some time after material is learned, with support for 30 minutes as the salient modification window (Nielson and Powless, 2007), although the window may be longer (Powless et al., 2003; Soetens et al., 1995). Furthermore, the effect of emotional arousal may come from a variety of stimuli, which could be semantically unrelated to the memory task. For example, Nielson et al.'s (2005) participants learned a list of common nouns and subsequently viewed a semantically unrelated videotape that was either neutral or emotionally arousing. The arousal group's recollection of the word lists was significantly better than the non-arousal group at both time points measured (30 min and 24 hours after encoding), demonstrating that emotional arousal is capable of moderating memory consolidation, even if from an unrelated source.

The arousing effects of stress experienced shortly after encoding new information may also enhance consolidation. Smeets et al. (2008) presented participants with lists of emotional and neutral words and tested recall 24 hours later. However, participants experienced stress by placing their arm in an ice cold bath for up to three minutes at one of three points during the experiment: either before encoding, immediately after the presentation of the words, or immediately before the recall test; a fourth (control) group did not experience the cold bath. Results showed that the participants who experienced stress immediately after learning the words had the best recall of emotional, but not neutral, words.

Although one can alter stress through such an external mechanism as an ice bath, many studies choose to alter attention and stress by administering pharmacological drugs. Applying stimulants that induce stress, such as adrenaline or cortisol, are shown to enhance memory when administered shortly after learning new material (Cahill and McGaugh, 1998; Kuhlmann and Wolf, 2006; Buchanan and Lovallo, 2001). Complementarily, a study in which participants received a beta blocker before learning, which weakens the effects of stress hormones, did not show emotional memory enhancement when tested one week later (Cahill et al., 1994). In Kuhlmann and Wolf (2006), there was no difference in immediate recall performance between the cortisol and the placebo groups, but the memory of the group administered cortisol improved over time, suggesting that cortisol modulates memory consolidation of both neutral and emotional stimuli, while the initial acquisition process is less affected by the drug. Similarly, administering amphetamine, which typically increases alterness and is the main ingredient in Adderall, after learning a list of words leads to improvement in recognition for those words one day later, but not 20 minutes after learning (Soetens et al., 1995). For most all of these studies, careful experimental design - administering the drug *after* learning new material helps to disambiguate effects of the drugs on encoding and effects on consolidation.

1.4.3 Retrieval

In striking contrast to arousal's benefits on long-term memory, high-arousal stimuli seem to have a detrimental effect on some aspects of short-term memory. Studies reporting this intriguing effect have found deficits in immediate recall ranging from 2 minutes post-learning (Kleinsmith and Kaplan, 1963; Walker and Tarte, 1963) to 20 minutes later (Kleinsmith and Kaplan, 1964) and have manipulated arousal in a variety of ways, including the addition of background white noise (Berlyne et al., 1965), caffeine (Terry and Phifer, 1986), and exercise (Loftus, 1990). Park (2005) conducted two meta-analyses to examine the magnitude of the interaction between arousal and retention delay on various types of memory, e.g., verbal, visual, etc., and found that the interaction was robust. Across the studies examined, low arousal lead to better immediate memory than high arousal and high arousal lead to better delayed memory than low arousal. Furthermore, Smeets et al. (2008), in addition to finding that stress during consolidation (induced by experiencing an ice bath) benefits memory for emotional stimuli, showed that stress induced directly before recall interferes with increased memory for emotional stimuli. The group that experienced the ice bath immediately before recall showed lower recall, especially for emotional words.

Occasionally, some potentially anxiety-inducing, highly-emotional memories are unconsciously forgotten. In this phenomenon termed 'repression', first introduced by Sigmund Freud (1915), memories are blocked from consciousness to protect the psyche and the ego. Although Freud's work focused on the repression of sexual desires, research on repression has suggested that a variety of traumatic events can be forgotten. These events include child abuse, the witnessing of a family member's murder, and military service (van der Kolk and Fisler, 1995). Although events can be spontaneously remembered years later, the reliability of recalled but previously repressed memory is debated in the field. Loftus (1993) emphasizes that the human memory, especially for events of the distant past, is malleable and fallible. Suggestion and leading questions, especially about events that happened in the past, can alter a memory, or even implant a memory of a traumatic experience, and there is no reliable way to test the validity of these false memories (Mazzoni et al., 2001). Despite her skepticism and her arguments against the reliability of repressed memories, Loftus encourages further research to disentangle the factors that influence the warping of traumatic events in the mind, and the creation of false memories (Loftus and Pickrell, 1995).

1.4.4 The Role of Arousal and Valence

Much of the research cited so far discusses how arousal modulates memory. However, the causes of emotion-enhanced memory become more complex when you consider that negative events often occur in conjunction with high arousal. For example, so-called 'flashbulb memories' - a vivid, highly detailed memory of an event - seem most common for dramatic, unexpected, and shocking events, such as 9/11, the death of John F. Kennedy, and the explosion of the space shuttle Challenger (Brown and Kulik, 1977; Hirst et al., 2009), which all are arguably negatively valenced and high arousal occasions. Disambiguating the cause of emotional-moderated memory between these two emotional axes, as well as exploring any interactions between the dimensions, has been of interest to psychologists.

The cumulative evidence shows that arousal is more critical in attentional processes and long-term memory modulation than valence. Sheth and Pham (2008) took pairs of images, taken from a database that provides ratings of affect for a large set of emotionally evocative, internationally accessible, color photographs, and presented them side by side on a screen in what is known as a binocular rivalry setup. Findings showed that arousing images dominate perception. Mather and Nesmith (2008) showed that participants were more likely to remember the locations of positive and negative arousing pictures than the locations of non-arousing pictures, indicating better binding of location to picture. The attention-narrowing effect has been strongly attributed to arousal (reviewed by Dolan and Vuilleumier, 2003 and first posited by Easterbrook, 1959). And, as cited previously, watching either a positive or negative arousing video clip enhances consolidation of high priority items encoded just before the video (Nielson and Powless, 2007).

However, some studies do show effects of valence on memory. Often, both positive and negative stimuli enhance recall or recognition (Kensinger et al., 2002), although negative stimuli tend to be remembered more vividly, while positive items tend to 'feel' more familiar and are comparatively more error-prone. This has been demonstrated by Kensinger et al. (2007b), in which a population of older adults showed better general recognition for positive and for negative items as compared to neutral ones, but enhanced memory for detail that was restricted to negative items (see also Ochsner, 2000; Dewhurst and Parry, 2000). Outside of the lab, Kensinger and Schacter (2006) asked Red Sox and Yankees fans to recall the details of the final game of the 2004 playoffs, where the Red Sox won. Red Sox fans, who found the outcome positive, showed more memory inconsistencies, and more overconfidence, than Yankees fans did, suggesting that negative valence can lead to fewer reconstructive-memory errors than positive emotion. However, when studying not quality of detail but sheer number of memories recalled, in some studies, negative items are more frequently recalled than positive ones (e.g. Ortony et al., 1983; Charles et al., 2003).

While no models exist yet to describe the effect of valence on memory, two supported models explain some of the enhancing and inhibiting effects of arousal. One such model is the Yerkes-Dodson Law, which is a proposition that arousal's and performance's relationship is that of an inverted U-curve: performance is optimized at intermediate levels of arousal, and it is lower at high or low levels of arousal (Yerkes and Dodson., 1908). Research supports the Yerkes-Dodson Law (Broadhurst, 1957; Anderson, 1994; Dickman, 2002; Bregman and McAllister, 1982), but a cause of the correlation has not yet successfully been established (Anderson et al., 1989). Since arousal is hypothesized to hinder some aspect of short-term memory but facilitate both speed of processing and long-term retrieval, it has also been modeled by what is called the "tick rate hypothesis" (Humphreys and Revelle, 1984; Revelle and Loftus, 1990). Directly analogous to the clock speed of a computer, the hypothesis proposes that arousal increases the rate at which the environment is sampled. By increasing the sampling rate, the number of chances to associate the stimulus with the external and internal environment also increases, but to a decrement in availability in immediate memory due to the increased interference associated with a more rapid sampling rate. Such a model explains not only the delay in memory enhancement for arousing stimuli, but also why retrieval failures are observed under conditions of examination stress. It may also explain why, when relaxation instructions are given immediately prior to recall, performance is significantly improved (Pascal, 1949): the lack of 'increased interference' from arousal allows participants to attend to the task at hand.

1.5 Effect of Musically-Induced Emotions on Long-Term Memory

While the number of studies exploring music and emotions is rising, there remains unexplored the relationship between musically induced emotions and, as described the previous section, another broad, active area of research: how emotion moderates memory. In light of the compelling arguments and mounting evidence that musical emotions are in fact induced and are of a similar nature as emotions evoked by other stimuli, studies on how emotions induced by music influence subsequent recognition of that music may fit well into, and bring relevant and interesting insights to, the greater emotion and memory literature.

At present, research on how emotion for music influences subsequent recall or recognition of that music focuses on memory for previously familiar, potentially autobiographical, music. Certainly, individuals have strong memories of particular events or periods on their lives, and there is evidence that music associated with personal, emotional events are recalled better. This is commonly known as the 'Darling-they're-playing-our-tune' effect, demonstrated by Schulkind et al. (1999), in which older adults preferred, knew more about, and had stronger emotional responses to music popular in their youth. This research area is particularly active for those afflicted with Alzheimers and dementia since memory for music can be spared by these debilitating diseases. Cases have been documented where, in the face of severe cognitive impairment, patients respond to familiar melodies, sing the lyrics, and recognize when a melody has been distorted (Cuddy and Duffin, 2005).

Previously familiar music can also be recognized quite quickly. In Bigand et al. (2009), familiar songs were identified in vivid and rapid detail – excerpts as short as 250 ms can be identified as familiar. Even when presented with melody alone, recognition time is short. In Dalla Bella et al. (2003), musicians and nonmusicians were presented with segments of melodies of increasing duration of familiar and unfamiliar melodies, and asked to provide a judgment of familiarity after each note. For highly familiar tunes (i.e. 'happy birthday'), nonmusicians needed on average of 4 notes (SE = .4), or 2.3 seconds, to perceive a melody as familiar. Although musicians claimed familiarity with the piece in fewer notes than nonmusicians, requiring an average of 3.2 notes (SE = .3), or 1.8 seconds, both groups identified pieces quickly, suggesting that identification may only require very local knowledge.

Dalla Bella et al. (2003) makes an interesting point: pieces might be remembered better if the participant is more familiar with the genre as a whole. This concept is echoed in the literature on expertise, where experts remember unfamiliar materials from their domain of expertise better than nonexperts (Chase and Simon, 1973); however, the fast identification time by nonmusicians in Dalla Bella et al. (2003) suggests that musical understanding does not require formal training. Compared to skills such as chess or checkers, where one needs to be taught the rules, nondeclarative musical knowledge can be accessed by all members of a culture that have been previously exposed to that style of music without being explicitly taught. Thus, we would expect nonmusicians to perform well in music psychology studies that do not test explicit musical skill, especially if they have been previously exposed to the genre tested. This effect has been demonstrated by testing the memory for traditional (in a familiar style) and nontraditional tunes in Alzheimer's patients, where episodic memory for traditional tunes was better than that for novel tunes (Bartlett et al., 1995). This was replicated in a study on a healthy population in Mcauley et al. (2004), in which participants listened to novel and familiar melodies on one of two days either once or three times. On the second day, they were given two tests: one of frequency and one of recency. For the recency test, participants discriminated between melodies they last heard on that day and those they last heard on the previous day, and for frequency test, participants discriminated between melodies they heard three times and those they heard only once. They found that 'familiar melodies afforded accurate judgments about both recency and frequency, whereas novel melodies afforded accurate judgments about frequency, but not recency', supporting the use of episodic memory in the recognition of familiar melodies, but the use of a generalized memory in the recognition of novel melodies. In this way, perhaps music is unique in that many enjoy and understand music without necessarily having declarative knowledge of its structure.

There are relatively few studies on how emotion for music modulates its subsequent recognition of it. A recently published study addressing this topic is Aubé et al. (2013). The participants in this study listened to 64 instrumental clips which followed the rules of Western tonality and were specially written for this study, designed to express fear, sadness, happiness, or peacefulness. The participants rated the arousal and valence expressed by the music, as opposed to the emotions that the music elicited in them. During the encoding phase, half of the stimuli were presented twice, and the entire set was presented to the participants on the second visit, which was a few days later (M = 3.8, SD = 1.8). The study revealed an effect of emotional expression on memory accuracy for music ($p < .001$), and post-hoc comparisons reveals that this effect was due to better memory for happiness and fear, when compared to neutral and sadness ($p < .001$). Furthermore, confidence measures of recognition were collected on the second day, and it was found that participants were more confident in their correct answers for fearful and happy musical clips.

Their results contradict other, structurally similar research, performed by Susan Eschirch and Eckart Altenmüller (Eschrich, 2008). After one experiment using J.S. Bach piano music tested over a dual-lab visit spaced one to two weeks apart resulted in low recognition rates, subsequent experiments used excerpts of symphonic film music, and the visits were spaced one week apart in one experiment, and then two days apart, with an additional encoding session in the middle day. Half of the stimuli were presented on the first day, and all were presented on the second day. Participants were clearly asked to indicate how they felt while listening to the music on arousal and valence scales. Confidence measures were also collected for recognition on both visits. Although they found an effect of valence on recognition, there was no such effect for arousal. They attributed this to several potential causes in experimental design. First, they found that the emotion levels elicited in their participants were not as high as expected. In an attempt to control for any structural features the music might have on recognition, potential stimuli that contained 'strange sounds or harmonies' were not included in the final dataset. As Juslin and Västfjäll (2008) have noted, violations of musical expectancy may be one of the mechanisms behind musically-induced emotion, and so by discarding pieces with unexpected features, they may have lowered the overall potential level of emotionality in their participants. Second, the pieces unintentionally evoked solely positive emotions in the listener, and since arousal effects are usually quite strong in the case of certain negative emotions such as fear or anger, the positivity of the music may have precluded arousal effect.

1.6 Aims and Hypotheses

My overall aim in this thesis is to investigate the effect of valence and arousal on episodic memory for musical stimuli. Using a dual-lab visit design and pre-tests of the stimuli to increase the likelihood that a wide range of affects will be induced in the listener, my main hypotheses are:

1. Music pieces which elicit high arousal (excitement) are recognized better than pieces eliciting moderate or low arousal
2. The effect of arousal on recognition of stimuli will be stronger than the effect of valence.

Additional research questions include:

1. If there is an effect of valence, does the strength of the effect varies across the dimension (i.e. are positively valenced stimuli more likely to be recognized than stimuli with negative valence)?
2. Will there be an effect of musical structure on recognition?
3. Will reports of arousal or EDA measures be more predictive of enhanced memory for unfamiliar musical stimuli?

Chapter 2

Method

2.1 Overview

The experiment consisted of two sessions during which participants indicated their felt emotional responses (using arousal and valence ratings) to a series of musical excerpts as well as indicated whether or not they had heard the piece before. Physiological data (EDA) was collected as a second means of measuring arousal. During the first session, sixteen pieces were played, and during the second, those same pieces were played in addition to sixteen other pieces not previously heard in the first session. Throughout this analysis and discussion, the pieces played on the first and second day will be called 'experimental' excerpts, and the pieces played on the second day will be called 'filler' excerpts. The relationships between self-report arousal-valence ratings, changes in recognition score, and EDA were analyzed, with particular attention paid to for the effect of first-session metrics on changes in recognition. This experiment was approved by the Faculty of Music's committee.

2.2 Stimuli

Stimuli were chosen based on several criteria. They were to be purely instrumental; from a reasonably familiar musical idiom; have minimal soloistic pop-outs and novel solos to minimize the effect of structure or variable instrumentation on recognition; be very likely unfamiliar to participants; and with minimal potential affective variation within a given selection. I researched and selected 48 initial stimuli from orchestral music from the 19th-21st centuries. In an attempted to ease the participants' task of providing single arousal and valence ratings during the experiment, I tried to select pieces with consistent timbre and consistent perceived emotion throughout the excerpt.

While almost all excerpts were extracted from commercially available CD recordings, in an effort to include music that would be highly unlikely to be familiar, several student recordings of orchestral compositions were also included in the initial stimulus set - a result of my request to composers at my previous institution (the University of Michigan) to send orchestral recordings of theirs for inclusion in the study.

Since EDA may increase in response to sudden, loud noises (Dawson et al., 2000), excerpts included a 2 sec fade in and fade out so as not to startle the participant.

Five participants who did not ultimately participate in the final experiment were asked to indicate how the initial stimuli made them feel, using the same interface, phrasing of questions, and headphones (BOSE Ae2i audio headphones) that would eventually be used in the main experiment. Arousal and valence ratings were selected from a 9-point scale with values ranging from -4 to 4. Below zero ratings signify negative valence and low arousal and above zero ratings signify positive valence and high arousal. They also indicated whether or not they had heard the piece before. These ratings were collected for several reasons:

- To increase the likelihood that the pieces chosen for the main study would be unfamiliar to the participants in the main study.
- To ensure a similar distribution of arousal and valence ratings in the experimental and filler excerpts.
- To ensure that the pieces ultimately selected represented a range of possible elicited emotions.

One participant's data was unusable due to improper preparation of the Max/MSP patch. Three of the four remaining participants indicated they had never heard any of the pieces before, while one participant selected "Not Sure" for three of the excerpts. Since the participants were unfamiliar with the excerpts, the initial emotion ratings informed the selection of the final stimulus set. The mean arousal and valence ratings, as well as the standard deviation, were calculated for each stimulus. From these ratings, 32 excerpts were chosen from the original 48, including 8 excerpts from each quadrant in arousal-valence space. Any excerpt with a very high standard deviation of ratings excluded from selection. They are presented in Table 2.1. A subset of 16 excerpts was selected, constituting the music played during the first session. The remaining 16 were introduced during the second session. The distribution of the two subsets each represented a range of possible affects, and the affects were comparably distributed between subsets (see Figure 2.1). The final excerpts ranged from 35 seconds to 1 minute 11 seconds (M = 46.94 sec, SD = 7.63 sec). The final stimulus set included two student compositions that are not commercially available. A list of the 32 excerpts used in the main study, including the details of the recordings they were taken from, can be found in Appendix A.

TABLE 2.1: Pre-experimental ratings of excerpts included in main experiment

ID	Composer	Excerpt Name	Practice Session	Session 1	Session 2	Valence	Arousal	Quadrant
1	Schuman, William	In Praise of Shahn		X	X	.75	1.5	1
2	Vaughan Williams, Ralph	Symphony No. 5 - mvt 1		X	X	.25	1	1
3	Ware, Evan	Refuge excerpt 2		X	X	1.25	1.5	1
4	Sessions, Robert	Suite from Black Maskers		X	X	0	.25	1, 4
5	Bax, Arnold	Tintagel		X	X	1	-.5	2
6	Bruckner, Anton	Symphony No. 4 - mvt 3		X	X	1.5	-.5	2
7	Druckman, Jacob	Chiaroscuro		X	X	.25	-.5	2
8	Schwantner, Joseph	Aftertones of Infinity		X	X	1.25	0	1,2
9	Ware, Evan	Refuge excerpt 1		X	X	-1	-.25	3
10	Adams, John	Naive and Sentimental Music - mvt 2		X	X	-.5	-.5	3
11	Adams, John	Naive and Sentimental Music - mvt 3		X	X	-1.5	-.25	3
12	Sibelius, Jean	Symphony No. 6 - mvt 1		X	X	-.5	-.75	3
13	Adams, John	Naive and Sentimental Music - mvt 1		X	X	-.5	1.25	4
14	Kodály, Zoltán	Dances of Galanta		X	X	-1.25	.75	4
15	Kernis, Aaron J.	Too Hot Toccata		X	X	-1.25	1.75	4
16	Barber, Samuel	Symphony No. 1		X	X	-.75	1.5	4
17	Kernis, Aaron J.	Symphony in Waves - mvt 5			X	.75	2.5	1
18	Theofanidis, Christopher	Rainbow Body			X	1.5	.75	1
19	Scriabin, Alexander	Symphony No. 3 - mvt 1			X	1	1.5	1
20	Schoenberg, Arnold	Pelleas and Melisande			X	1	-.5	2
21	Chambers, Evan	The Old Burying Ground			X	-.5	1	2
22	Alwyn, William	Overture to a Masque			X	1.25	-1.5	2
23	Sibelius, Jean	Symphony No. 6 - mvt 1			X	1.75	-.25	2
24	Lutoslawski, Witold	Symphony No. 2 - mvt 2			X	-.25	0	2,3
25	Scriabin, Alexander	Le Poeme de lExtase			X	-.25	-.25	3
26	Schoenberg, Arnold	Farben			X	-.5	-1	3
27	Dvořák, Antonin	Symphony No. 7 - mvt 1			X	-1.5	-1	3
28	Berg, Alban	Lyric Suite - mvt 4			X	-.75	.75	4
29	Stravinsky, Igor	Ode (Triptych for Orchestra) - mvt 1			X	.25	.75	4
30	Penderecki, Krzysztof	Symphony No. 2 - mvt 1			X	-1.25	3.25	4
31	Lutoslawski, Witold	Symphony No. 2 - mvt 2			X	-.75	.25	4
32	Vaughan Williams, Ralph	Symphony no 5 - mvt 3			X	-1.75	.75	4
33	Glass, Philip	The Light	X			1.75	.5	1
34	Theofanidis, Christopher	Rainbow Body	X			2.25	-.25	2
35	Johnson, Samn	On Sumum Stowum	X			-1.5	-1	3
36	Schoenberg, Arnold	Variations Op. 31 - variation 3	X			-1.25	1.5	4

2.2.1 Structural Feature Analysis

An effort was made during initial stimulus selection to exclude any features of the music that might be explicitly recognizable, and so, except for the occasional solo from the winds and brass, the excerpts included had a thick orchestral texture. Naturally though, across the final stimulus set, there was a wide range of tempi, modes, and use of dissonance in the music. As discussed in Section 1.3.2, these variables lead to a number of different induced emotions. In an attempt to explain some of the emotion ratings, and to confirm that no single sonic characteristic of the music interfered with recognition, measures of tempo, timbre, and loudness were extracted from the audio. Specifically, the extracted features were tempo (in beats per minute); pulse clarity; dynamic intensity, or root-mean-square energy of the excerpt; spectral regularity, the degree of variation of the successive peaks of the spectra of the excerpt; and sensory dissonance, or an estimate of the total roughness in the spectra. All features were extracted using mirtoolbox, a MATLAB toolbox for music information retrieval (Lartillot and Toiviainen, 2007). As

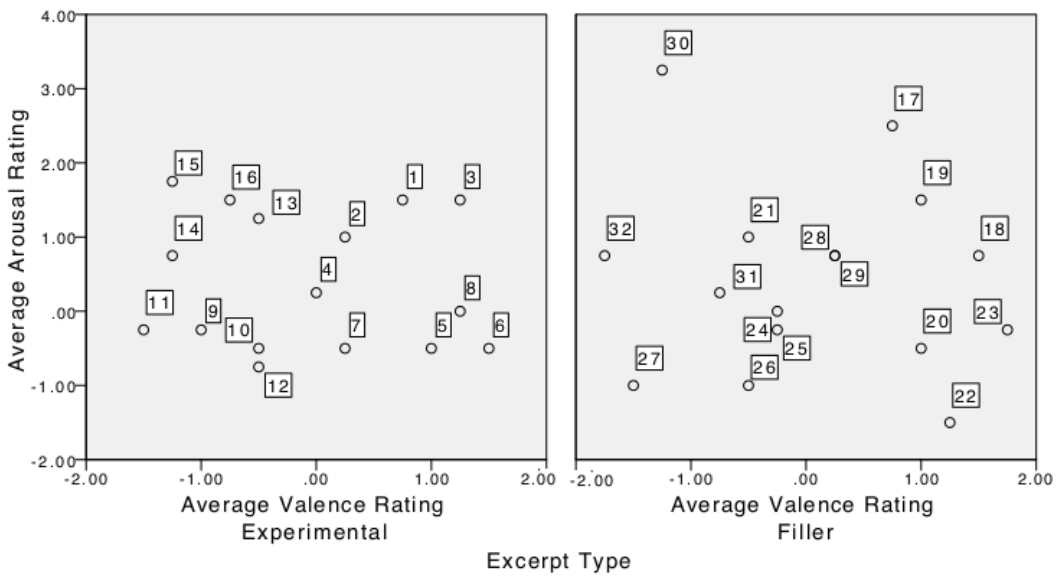

FIGURE 2.1: Pre-experimental judges' arousal and valence ratings and their subsequent division into two sets for the main experiment. Left panel: experimental stimuli used in sessions 1 and 2. Right panel: filler stimuli used only in session 2. Excerpts are labeled by their ID numbers from Table 2.1.

a second means of measurement, tempo was also evaluated by a professional orchestral musician.

2.3 Design

The experiment was presented through a Max/MSP patch that I tailored for this experiment. The screen participants saw is shown in Figure 2.2. Participants responded to the question "How did you feel while listening to this piece," displayed at the top of the interface. Beneath this question stood two rows of self-assessment manikins (Russell, 1980) to aid in gauging their emotional response, one indicating valence and the other arousal, and nine-point Likert-scale buttons beneath each row of self-assessment manikins by which participants entered their emotional responses. Another question was displayed at the bottom of the interface, "Have you heard this piece before?", with three possible responses: "Yes", "No", and "Not sure".

Responses were counterbalanced by reversing the presentation of each line of manikins and their answer choices for half of the participants. ("No" remained in the middle of the three answer choices to the familiarity question, in both versions of the patch.) The presentation of the stimuli was randomized via a function in Max/MSP. The second session occurred approximately 24 hours after the first.

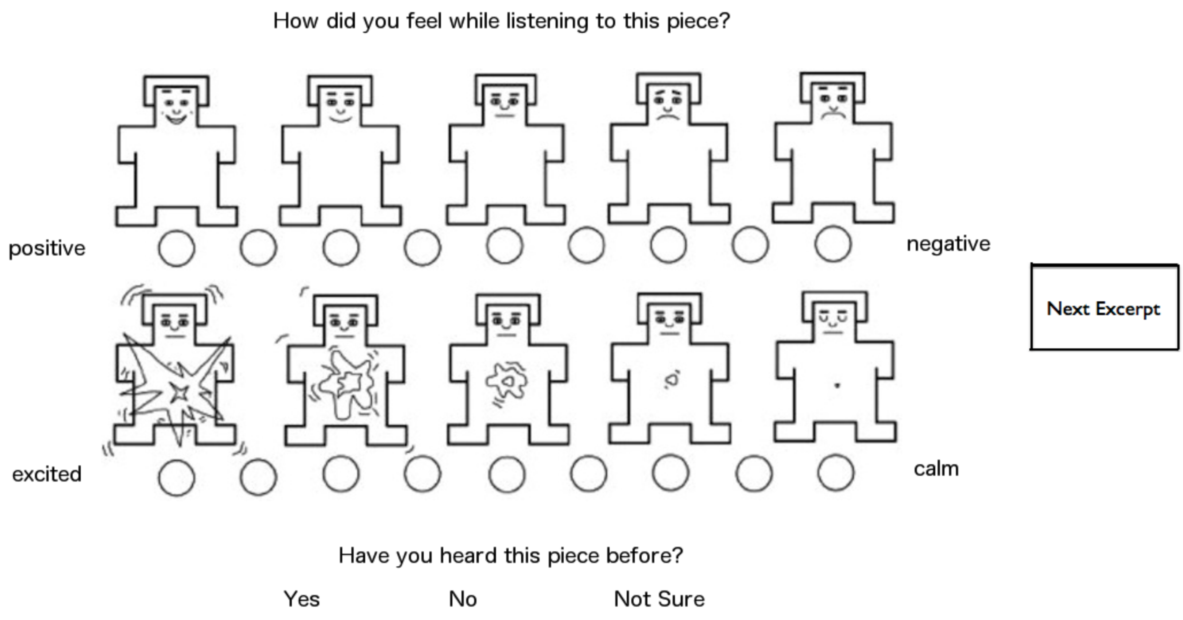

FIGURE 2.2: The screen view of the Max/MSP patch through which the experiment was presented.

2.4 Procedure

Participants were tested individually in a comfortable, quiet environment. For 15 participants, the test room for both sessions was the sound-proof recording studio at the Centre for Music and Science at the University of Cambridge Faculty of Music; for two participants, it was in their own homes in Cambridge; and for one participant, it was in a private room in a university building. Upon arrival at the first session, they filled out the demographic questionnaire, and I showed and described the interface through which they would be answering questions. They were fitted with the EDA wristband (Q Affectiva sensor; www.affectiva.com/), which did not receive any special preparation such as cleaning with alcohol or application of conductive gel. They then had the opportunity to ask questions. After their questions were answered, they were given a series of four practice excerpts, presented through the same interface as that they would use later. They were given another opportunity to ask questions, and once they felt comfortable, they signed the consent form, I left the room, and they began the experiment. During the second session, they were reminded of the instructions, shown the interface again, and were asked if they had any questions. Similarly, I left the room during the experiment.

The display was visible but 'faded' while the excerpt was playing, and changed to bold on the screen as soon as the excerpt had ended, indicating to the participants that they could respond. After participants had logged one answer for each question, a button appeared that allowed them to move on to the next excerpt. Until they chose to move on, participants could modify their choices. Each time the display bolded and faded, the computer's CPU time was logged.

Participants were not told it was a memory test, nor given any information about the second session except that they would listen to more excerpts. All participants gave informed consent to participate after the procedures were explained.

2.5 Participants

Participants of the two-session experiment included 19 young adults. Data from one participant was unusable due to failure to follow instructions, so data of 18 participants, 7 female, was included. Participants were recruited by means of emails sent through University of Cambridge listservs. The participants contacted me, stated their interest in participating, and offered two dates, 24 hours apart, for which they were available. The participants were paid 10 pounds for their participation. Ages ranged from 21 to 33 (M= 25.1, SD= 3.64). They had an average of 5.11 years of formal musical training (SD = 5.17). Four currently play recreationally (M=2.25 hours per week), while twelve have not played recently (M = 7.09 years, SD = 5.36 years), and two have never played an instrument. All declared themselves to have normal hearing except one participant who reported having hypersensitive hearing (no other details were given); the volume of the excerpts played in the experiment was reduced for her comfort.

Due to difficulties coordinating the EDA with the CPU times captured by the Max/MSP patch, 3 participants did not have analyzable EDA measurements from either day and 6 participants had no analyzable EDA for the second session only. Those 6 participants are included in any portion of the analysis regarding the influence of first day arousal on second day recognition. For clarification, Table 2.2 provides the number of participants per component of the experiment whose data was valid and included in analysis.

2.6 Analysis

The collected EDA raw data was sampled at 8 Hz by Q sensor and analyzed in Ledalab v3.4.3 (www.ledalab.de/; Benedek and Kaernbach, 2010), a MATLAB-based software package written explicitly for the analysis of skin conductance data. Each session of

Table 2.2: Number of participans' data available for each component of the experiment

Experimental Component	Number of Participants
First Session Self-Report	18
Second Session Self-Report	18
First Session EDA	15
Second Session EDA	9

EDA data was synced with the CPU times from the Max/MSP patch into Ledalab, providing event markers of when the participant was listening to music. The data was smoothed and underwent continuous decomposition analysis, which divides the data into slowly varying tonic signals (skin conductance level: SCL) and fast varying phasic signals (skin conductance responses: SCRs). See Benedek and Kaernbach (2010) for a description of continuous decomposition analysis using Ledalab. Minimum-amplitude criterion for inclusion of SCRs was 0.05 μS (microsiemens) in accordance with common practices. The tonic and phasic data were extracted between the event markers during which music was playing. Figure 2.3 shows an example of the breakdown of phasic and tonic components of EDA data.

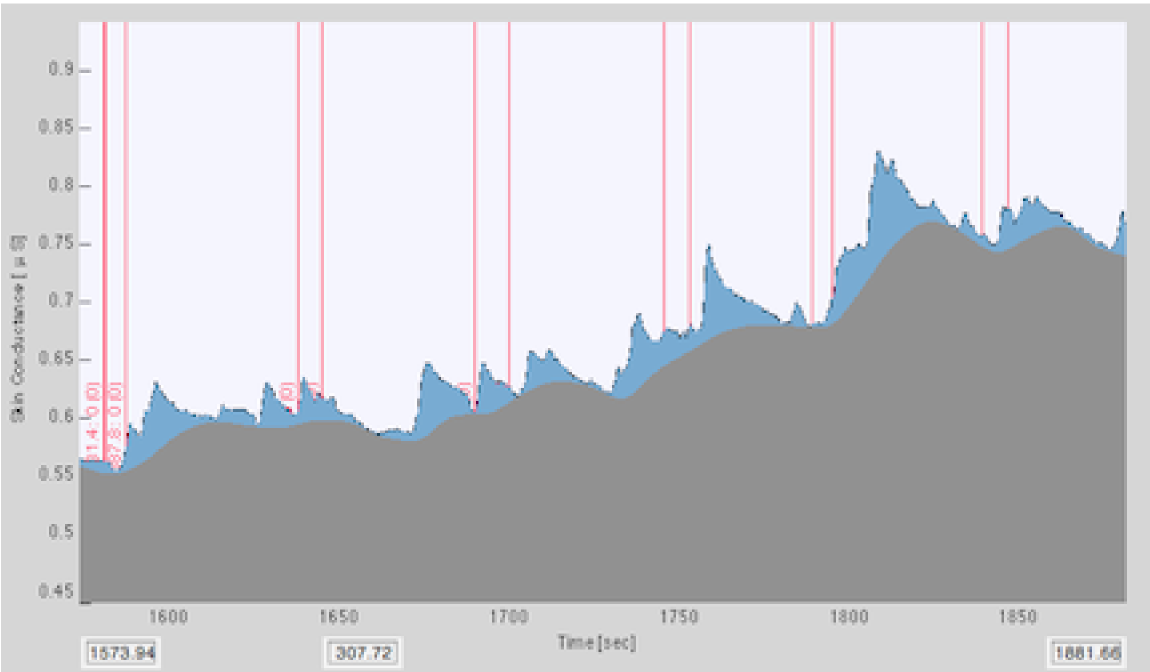

Figure 2.3: EDA signal and continuous decomposition analysis from Ledalab, showing 6 cases from session 2 of participant 3. Blue: phasic; grey: tonic. Pink vertical lines delineate listening and response phases for each excerpt. Wider space: listening phase; closer space: response phase.

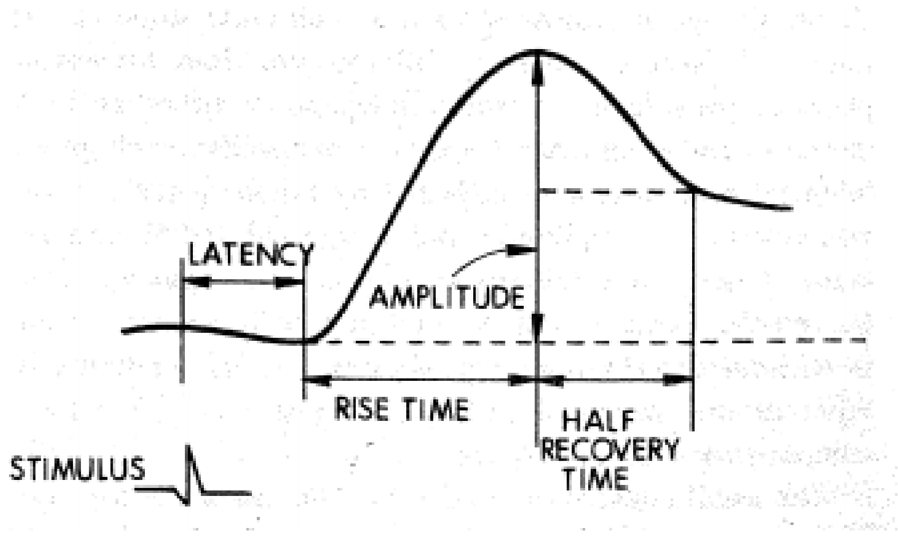

Figure 2.4: Graphical representation of the principle components of SCR (Dawson et al., 2000).

Since the excerpts are long in comparison to the typical window of an SCR (1-5 s after the start of the stimulus), and measuring SCR's for the entire duration of the excerpt was necessary to provide a complete picture of the arousal level, measurements of the strength of SCRs, as opposed to latency, were analyzed. The following measurements were gathered for analysis:

- nSCR - Number of significant (above-threshold) SCRs within the response window.
- SCRAmpSum - Sum of the SCR-amplitudes [μS].
- mSCR - Mean phasic component within the response window [μS]. This score represents phasic activity most accurately and is hypothesized to be most closely related to emotional activity while listening to music (Khalfa et al., 2002).
- mTonic - Mean tonic activity within the response window [μS].

Chapter 3

Results

Data were entered into SPSS for analysis and hand checked for accuracy. Since observing any change in recognition performance requires two sessions of data, all statistical analyses included only experimental excerpts except where otherwise noted. Throughout this analysis, a 'case' refers to the data associated with one participant listening to one piece. So, with 18 participants each listening to 16 excerpts during session one, there are 288 cases in session one.

Shapiro-Wilks tests for normality were significant for SCR data and emotion ratings for both days ($\rho < .001$), so statistical analyses robust to normality violations, Spearman's rank-order correlations, ordinal regressions, and classification trees were used.

3.1 Overall recognition performance

A high number of pieces were unrecognized the first day, accounting for 72.6% of all cases (N = 288). Participants indicated that they were unsure if they had heard the piece before in 22.6% of the cases and, and in 4.9% (N=14), claimed to recognize the excerpt. In the interest of possibly eliminating any one excerpt if it was known to many participants, the nature of the cases of first-day recognition were examined. Seven participants claimed to be familiar with at least one excerpt on the first day. Three pieces which were known to two participants and one was known by three. However, in only 7 cases was the piece recognized on both days, indicating that in the rest of the cases, the familiarity judgments were unreliable. Since the cases of recognition on both days were so few compared to the sample size, and since the first-day recognition cases were distributed over several pieces and participants, it was decided to include all pieces of music and cases in the analysis.

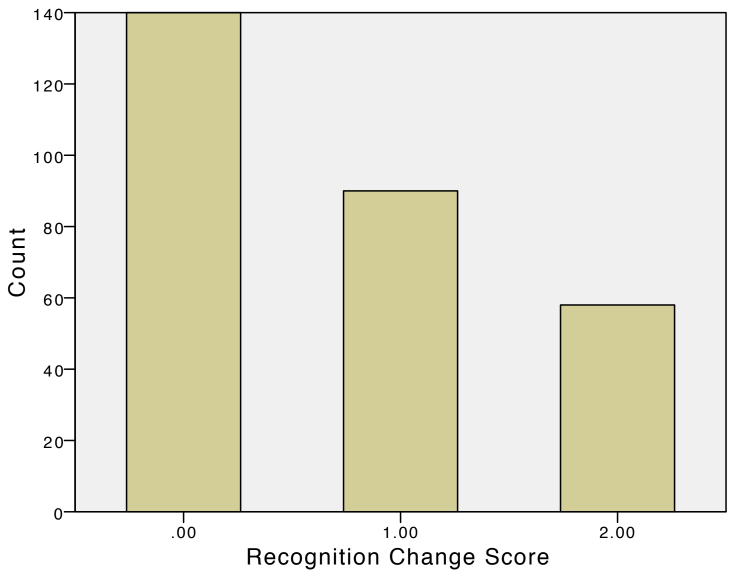

Figure 3.1: Total number of cases for each recognition change score. A score of 0 indicates no change in recognition (plus 24 negative scores, see text for explanation), a score of 1 represents an increase from 'No' to 'Not Sure' or from 'Not Sure' to 'Yes', and a score of 2 represents an increase from 'No' to 'Yes'.

The recognition choices, 'Yes', 'Not Sure', and 'No' were coded as '2', '1', and '0' respectively and for each case, the measure of recognition of the first day was subtracted from that of the second day. This resulted in a 'recognition change' score for the experimental excerpts, which is used throughout the analysis to evaluate change in recognition. Across all participants, there were 24 cases of a participant claiming to have a lower level of familiarity on the second day than she did on the first day, resulting in a negative recognition change score. Since these are cases where familiarity did not improve, their negative familiarity change scores were coded as 0's, indicating no increase in familiarity.

Recognition change was examined. Performance was moderate, as shown in Figure 3.1. In 48.6% of cases the recognition score was 0, in 31.3% of cases the recognition score was 1 (moving from 'No' to 'Not Sure' or from 'Not Sure' to 'Yes'), and the remaining category, increasing from 'No' to 'Yes', accounted for 20.1% of all cases.

3.2 Arousal-Valence Ratings

A reliability analysis was conducted to determine the consistency of the arousal and valence ratings over the two sessions. Valence ratings appeared to have good internal consistency (Cronbach's Alpha = 0.76), while arousal ratings were moderately consistent (Cronbach's Alpha = 0.69). Pieces also appear to be well distributed in arousal-valence

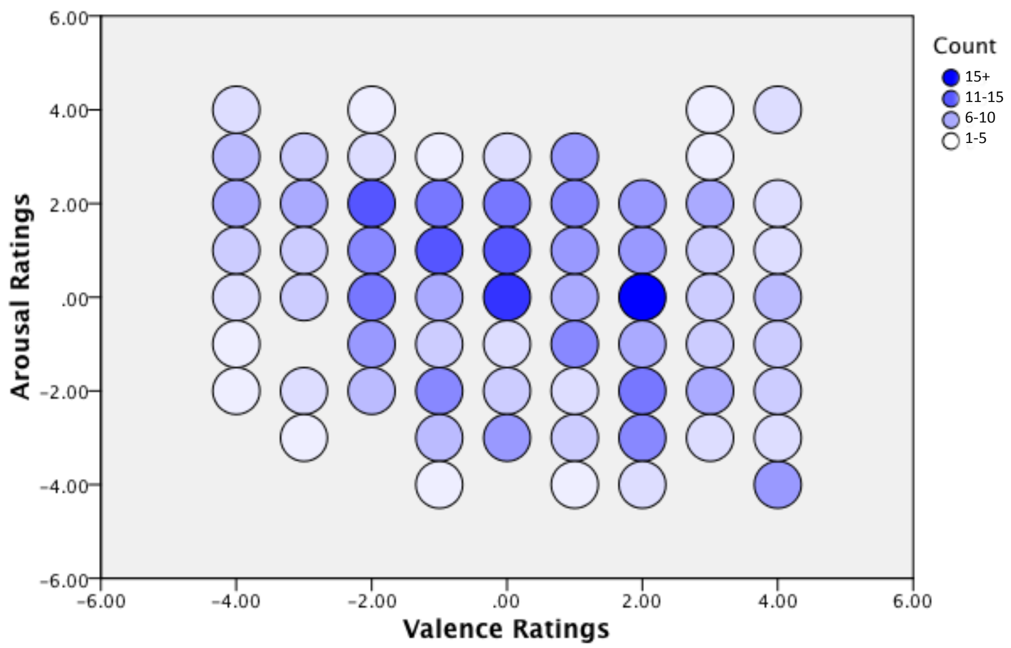

FIGURE 3.2: Binned distribution of arousal and valence ratings for all excerpts during the first session. Each circle represents an arousal-valence pairing, and the shading of the circle represents how many cases exist for that pairing. The darker the shade, the higher the number of cases. The ratings were gathered on 9-point scales, where 0 is neutral and increases with increasing positivity and arousal. Thus, +4 and -4 were the maximum and minimum choices for both axes.

space: as expected, Figure 3.2 shows most cases clustered around the neutral arousal-valence space with decreasing numbers of cases towards the more extreme poles of the arousal-valence ratings decreases.

There was a small though highly significant positive correlation between first session arousal ratings and recognition change ($r_s(286) = .212, p < .001$), while first session valence ratings and recognition change were weakly negatively correlated ($r_s(286) = -.126, p < .05$).

An ordinal logistic regression analysis was conducted to predict recognition change from session one to session two using arousal and valence ratings from the first session as predictors. Table 3.1 shows regression coefficients and Wald statistics for arousal and valence ratings and Figure 3.3 shows bar charts of the mean arousal and valence ratings during the first session, grouped by recognition change. The figure illustrates how cases coded with a recognition change score of 2 also have a relatively high mean for first session arousal ratings. Recognition change scores of 0 and 1, are closer to neutral arousal ratings.

Overall, the model was statistically significant, indicating that the predictors as a set reliably influenced recognition (chi-square = 14.624, df = 2, $p < .005$). Nagelkerke's pseudo-R^2 revealed that arousal and valence ratings account for only 5.7% of the variance in recognition change. Critically, however, the Wald criterion indicated that only arousal ratings significantly predicted increase in familiarity ($p = .003$). Valence was not a significant predictor of recognition change.

TABLE 3.1: Logistic regression of arousal and valence ratings as predictors of recognition change

					95% Confidence Intervals	
	β	S. E.	Wald χ^2 test	Sig.	Lower	Upper
Arousal	.181	.062	8.67	.003	.061	.302
Valence	-.081	.052	2.40	.122	-.183	.022

3.3 Psychophysiological Measures

Relationship between Session 1 and Session 2 EDA. All EDA measurements were compared between days for participants with full datasets. The mSCR measure (mean phasic activity over the course of the excerpt) from sessions 1 and 2 were weakly correlated ($r_s(158) = .185, p < .05$), as were nSCR (number of above threshold SCR's) for sessions one and two ($r_s(158) = .190, p < .05$). The mean tonic activity for both sessions was very strongly correlated ($r_s(158) = .728, p < .001$). The correlation between days of the remaining measure, sum of the amplitudes of SCRs, approached significance ($r_s(158) = .147, p = .066$).

EDA and Arousal Ratings. Although session 2 mSCRs and their corresponding session two arousal ratings were weakly correlated ($r_s(303) = .141, p < .05$), there was no relationship between the two measures in session 1 ($r_s(239) = .036, p = .581$), nor with arousal ratings and the other three EDA measures on either day.

To explore the nature of the correlation between second-day arousal ratings and mSCR data, separate correlations were executed between excerpts presented on both days and excerpts presented only the second day. Session 2 mSCRs and session 2 arousal ratings were weakly correlated for the excerpts played on both days ($r_s(159) = .170, p < .05$), but there was no correlation between excerpts played only during the second session and mSCR's ($r_s(144) = .103, p = .217$).

EDA and Recognition Change. None of the four measures of EDA collected on the first day was significantly correlated with recognition change.

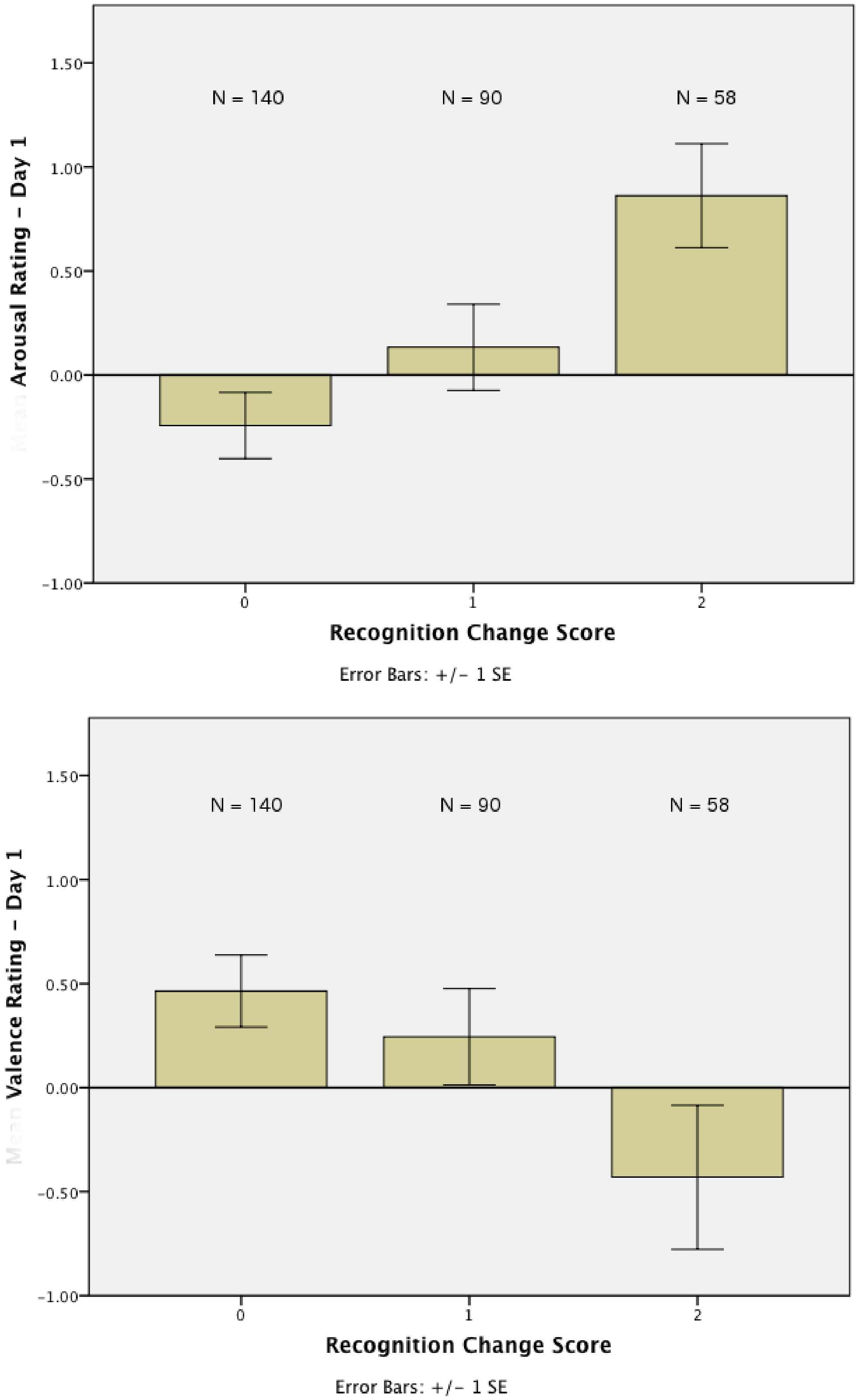

FIGURE 3.3: Bar graphs indicating the mean arousal and valence ratings from session one when grouped by recognition change score. This figure illustrates how pieces with a higher recognition change score had higher first-session arousal ratings than lower recognition change scores, whose average arousal ratings were comparatively lower.

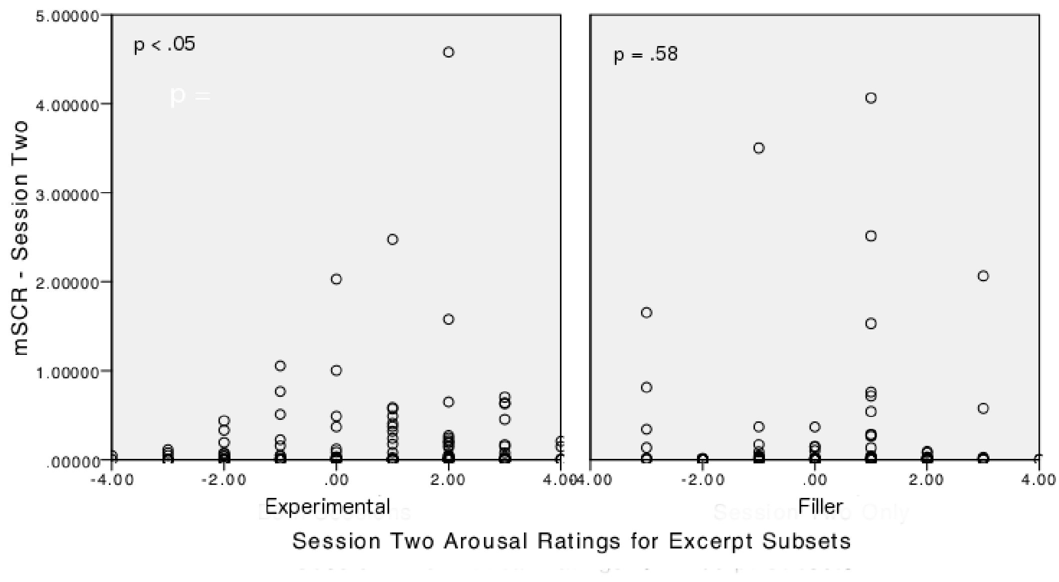

Figure 3.4: Scatter plots of session two arousal ratings and mSCRs for experimental excerpts (played on both sessions), and filler excerpts (played on session two).

3.4 Musical Structure Analysis

A classification tree analysis was run with all of the extracted musical features from mirtoolbox as independent variables and with recognition change as the independent variable, to see if these musical features influenced the recognizability of the piece. Classification and Regression Trees (CART) are a flexible and useful non-parametric alternative to standard regression models, used to study the relationship between a dependent variable and a set of predictor variables by splitting the data into segments that are as homogeneous as possible with respect to the dependent variable. In the present analysis, a node without any branches signifies that the node, given the restricting parameters that were previously set, could not be significantly classified into another variable. I tried a range of restricting parameters, ranging from 30-100 cases in the parental node and 15-50 cases in the terminal nodes. The tree did not grow when recognition change was used as a dependent variable, revealing that no structural features of the music had an influence on recognition change.

The analysis was rerun using arousal ratings as the dependent variable, and again with valence ratings, to see if any features had a significant effect on emotion. Again, a range of restricting parameters was tested and ultimately the following parameters were chosen: minimum number of cases in parental node = 50, and in terminal nodes = 25. While no structural features predicted valance ratings, three structural variables together predicted the arousal ratings: pulse clarity, spectral roughness, and tempo.

However, in this tree, higher tempo (>152.4 bpm) was associated with lower arousal. Since the literature strongly correlates high arousal with faster tempi, the tempo ratings provided by the orchestral musician were substituted into the classification tree in the place of the tempo ratings from mirtoolbox. The resulting tree had only pulse clarity and spectral regularity as predictors. As shown in Figure 3.5, the most important variable for predicting arousal was "pulse clarity" (mean of arousal = 1.167, N = 108, on the arousal self-report rating scale ranging from -4 to 4). Node 2 in 3.5 indicates that pieces with a clearer pulse (> .203) were rated as more arousing. The further important predictive variable was spectral regularity, where higher spectral regularity (> .812) was associated with low arousal.

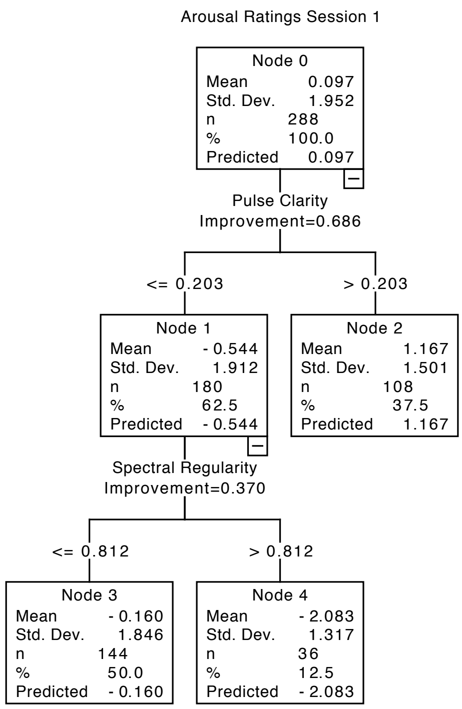

FIGURE 3.5: Classification tree analysis of arousal ratings with structural musical features as independent variables. Pulse clarity is the strongest predictor of arousal ratings, followed by spectral regularity.

The nature of the relationship between the two tempo measures and arousal ratings was investigated. While there was a strong positive correlation between tempo and arousal ratings when tempo was evaluated by the orchestral musician ($r_s(288) = .387, p < .001$), there was a weak negative correlation between tempo and arousal ratings when tempo was evaluated using mirtoolbox ($r_s(288) = -.165, p = .005$).

There was no significant correlation between excerpt length and arousal and valence ratings for either day.

Chapter 4

Conclusions

4.1 Arousal and Valence Ratings

The present results conform well to the greater memory literature and support both initial hypotheses, firstly that increased arousal during encoding enhanced subsequent recognition and secondly, that higher feelings of arousal drive improvements in recognition, while valence ratings, although significantly correlated with recognition, do not seem to have such a predictive effect.

Although this effect of arousal is inconsistent with a set of recent studies that found an effect of valence but no effect of arousal on recognition (Eschrich et al., 2008), the differences in chosen stimuli may explain the conflicting results. This study included a range of potential affects in the stimulus set, from amiable to very provocative in harmonies, rhythm, and style. It was the intention that, by doing so, the stimuli would induce a wide range of emotional states in the listener with regard to both the arousal and valence dimensions. The memory literature generally shows that, when arousal is varied enough, and especially when high arousal states are induced in the listener, effects of valence on memory are eclipsed; however, when arousal is low, effects of valence are found. Eschrich et al. (2008) posited that the lack of negatively valenced stimuli, which may have induced higher-arousal states, may have precluded an arousal effect. This study followed their suggestion, and an arousal effect was found.

4.2 EDA Discussion

The observed arousal effect, however, was limited to self-report ratings, since increases in EDA did not predict recognition change. This is somewhat surprising, since many past experiments found EDA, and especially mSCRs, to be a good indicator of felt emotion, and thus it was anticipated that EDA measures would not only correlate with, but significantly predict recognition change. While the lack of an overall influence of EDA data may demand reservations to the main claim that felt arousal influences recognition change in music, closer analysis and observation of the data reveal explanations for why the EDA measures did not support the hypotheses.

The lack of correlation between first-session EDA and first-session arousal ratings suggests that the EDA may not accurately reflect the participants' comprehensive emotional experiences There are three arguments to support this suggestion.

First, although the second session correlation between mCSR and arousal ratings was significant, closer inspection shows that the excerpts played only during the second session, i.e. the filler stimuli, did not correlate with arousal ratings; significant correlations were only found for the experimental stimuli, which were being heard for the second time in the second session (see Figure 3.4). The significant correlation for the experimental excerpts may then be a result of the increases in excitement due to recognizing a previously-played excerpt as opposed to excitement that results directly from musical listening. This interpretation is strongly supported by the fact that there was no correlation for the experimental stiuli and EDA in the first session, where the pieces were largely unfamiliar to the listeners. The EDA, then, seems to be related to task requirements more than to the listening experience.

Second, it could be that listeners' physiological responses were simply not strong enough for the sensors to pick up. Occasionally, studies that report significant physiological changes during music listening do not find significant changes in EDA (Jellison, 1975; de Jong and van Mourik, 1973; Blood and Zatorre, 2001). For instance, Rickard (2004) exposed participants were exposed to relaxing music, arousing (but not emotionally powerful) music, an emotionally powerful film scene, and a music piece selected by participants as emotionally powerful. A range of physiological and subjective measures of arousal was recorded before and during the treatments. While the music selected by the participants produced significantly higher SCR than any other condition, the music that was rated as 'arousing' produced no distinguishable difference in SCR than the music deemed to be 'relaxing'. Even Blood and Zatorre (2001), who screened their participants so that they only included participants who reported experiencing chills while listening to music, found heart rate and EMG activity to significantly correlate with reported chills, but not EDA. One would expect that after such screening, EDA would correlate with reports of experienced chills, but the screening required may need to be even more extensive, as in Salimpoor et al. (2009), who conducted three rounds of screening (email, telephone, in-person interview) to assess whether participants met their requirements: that the participant consistently experience chills while listening to instrumental music, and that chills were pleasurable and did not decrease with multiple listening. In actuality, such intense screening may be required because there are many people who simply do not experience chills. In some studies that played music and assessed chills, fewer than 25% of the participants reported chills or shivers (Grewe et al., 2007), and of those that do, the number of chills experienced over the course of the experiment was quite small. Grewe et al. (2009) found that the number of chills people experienced ranged from 0 to 88, but the median was 2 and the mean was 16, which is significantly skewed. Thus, there are a number of studies where the emotional response simply was not strong enough to produce an effect of EDA. It could be that this study is one of them.

There is one key requirement of this study that may have made it especially susceptible to a lack of strong EDA response: that the music be unfamiliar. A number of studies have shown that the familiarity of the music in question and the strength of the emotions felt while listening are linked. For instance, Gabrielsson and Lindström (2003) found that people experience stronger and more diverse emotions when listening to familiar music, and in Liljeström et al. (2012), self-chosen music aroused more intense and positive emotions in listeners than randomly sampled music. The main finding of Blood and Zatorre (2001) was that intense pleasure can occur while listening to music, but was only found during the condition in which the participant was listening to a piece of his own choosing. Thus, playing only unfamiliar music in the present study might engender only a weak the physiological response, thus producing no measurable effect of EDA on recognition change and arousal ratings.

The third and final explanation for the incongruent EDA results is technical: either due to human error, or more systemic issues with the EDA sensor, the EDA may not have been collected accurately. Support for this explanation is found simply by observing the variability in the raw data. In one participant's data, only 2 SCRs were recorded across all excerpts from the first session, while during those same excerpts on the second session, 48 SCRs were recorded. Even if the participant changed his behavior before the second session (engaged in physical activity, or had a coffee), such an increase sheds doubt on the validity of the measurements. While this is the most unsettling and obvious inconsistency in the SCR data, the number of SCRs overall was quite low – only 17.8% of first session cases had any SCRs. The lack of EDA changes and the discrepancy between the aforementioned participants' first- and second-session EDA measures suggests that EDA may have been changing far more rapidly than the sensor picked up.

In sum, it was unexpected that the EDA measures did not predict recognition change. While it is quite possible that this was due either to a fault in the product or a fault in its use, it may also be that our participants were mainly part of the large number of people who simply do not experience strong physiological changes in response to music.

There are several ways to increase the likelihood of meaningful EDA measures in the future. First, it is suggested that even if the participants are not screened for how often they experience chills, such an inquiry should be included in the questionnaire insofar as it might explain any lack of EDA response. Furthermore, the wrist may be a suboptimal place for data collection. Reports have suggested that the palms of hands and soles of the feet are best suited for measuring skin conductance as they are easily accessible and sweating on these surfaces has been shown to be strongly related to mental processes in response to both positive and negative events (Boucsein, 1992), instead of for thermoregulation. Further studies should consider placing electrodes on either the palms of the hands or soles of the feet to maximize the changes of collecting meaningful EDA responses. Finally, a product should be used that ideally includes software for analysis to avoid any errors in porting data or event markers from one software to another. There exist sensors that can work closely with the experimental interface, marking changes in events or conditions in real time, including the Biopac MP36R & AcqKnowledge software, and PsychLab.

4.3 Structural Features

It is unsurprising that none of the structural features had an effect on recognition. Care was taken during the selection process to choose excerpts where the structural features would not ‘give the pieces away’ during the second session (i.e. someone recognizing a piece solely because of a lone violin solo or loud bass drum hits). The lack of formation of a regression tree confirms that the selection was quite successful; however, it is also possible that the selected features were too few in number and were not conducive to finding an effect. While no features had a strong influence on valence ratings, several had an effect on arousal ratings. Pulse clarity had the strongest effect, with pieces with clearer pulses leading to higher levels of arousal. A similar effect was also found in Eschrich (2008), where having ‘strong accents’ most strongly predicted arousal.

Certainly the initial finding (using mirtoolbox-generated tempo markings) that pieces with high tempo were rated as less arousing was unexpected. However, when using tempo markings provided by a musician, tempo was strongly positively correlated with arousal ratings. Since the association between increases in tempo and increases in arousal is robust in the literature, and the positive correlation between human-created tempo markings and arousal ratings was strong in this experiment, the most likely explanation for the negative correlation between mirtoolbox-generated tempi and arousal ratings is that the algorithm 'found' beats that are perceived as subdivisions of the main pulse, and thus misappropriated a fast tempo to what are actually felt as slower excerpts.

4.4 Outlook

Although the effect of arousal was clear in the self-report ratings, the analysis revealed several experimental and methodological difficulties that may have affected some of the results.

Although self-report methods are used regularly by music psychologists for many purposes, and great strides could not have been made in the field without the feelings of self-report gathered through questioning, we should be wary of introspective judgements (e.g. Nisbitt and Wilson, 1977), especially when applied to emotion as studies have shown it to be flawed. There are concerns that even reports of emotion given while the emotion is experienced can be biased among certain groups of individuals. For instance, it is thought that individuals who measure high on social desirability may be less willing and/or capable of reporting negative emotional states (Paulhus and Reid, 1991). While screening for such measures would not be feasible for many studies, awareness that self-reports may not be entirely trustworthy motivates the use of multiple measures for data collection.

Few measures are without flaws, and since the construct of "emotion" is quite multifaceted, the use of more accurate and valid measures leads to a greater chance that the data will form a meaningful description of emotion. This study employed only EDA and self-report measures, but extending a similar study to employ other frequently-used measures of ANS activation such as heart rate, blood pressure, and heart rate variability, may be a worthwhile endeavor.

The properties of the stimuli would seem to be crucial. This study took steps to ensure that the excerpts would be unfamiliar. During pre-tests of the stimuli, ratings of familiarity were very low, with only one of the five pre-experimental subjects indicating any degree of familiarity with the excerpts, and with that subject only claiming "Not Sure" on three excerpts. However, during the main experiment, the number of cases for which the participant claimed to have heard an excerpt previously (either selecting "Not Sure" or "Yes") during the first session was remarkably high, accounting for 27.5% of the first-session cases. This in turn impacted the 'recognition change' variable used to gauge increase in familiarity. The causes of the higher number of recognized excerpts during the first session is unclear, but a reasonable explanation is that it is attributable to the participants' desire to 'perform well', and to not admit that all of the music was indeed unfamiliar. To combat this, subsequent studies may include some highly familiar pieces in the first session to which a participant might indicate familiarity, curbing the temptation to indicate familiarity for a piece they are in fact, not familiar with. This issue also might be addressed by changing the answer choices to the question, 'Have you heard this piece before?'. The inclusion of a 'Not Sure' option allowed further leeway for participants that may have complicated the results. Instead, future studies that are testing for familiarity should include only definitive choices to questions of recognition or familiarity ('Yes' and 'No'), with a subsequent question of confidence on a several-point scale.

Throughout this thesis, arousal has been afforded special status and was explored through the addition of EDA and low-level auditory features perhaps more extensively than valence was. As previously noted, this preferential treatment was due to the memory literature that strongly supports arousal as the driving factor in memory, and the recent findings that this arousal effect does not apply in the case of musical stimuli. While my structural analysis mainly related to arousal, a more comprehensive evaluation of structural features on recognition, and especially those that may more closely pertain to valence, could be very interesting. Of course, when using pre-recorded music of a complex nature, it may be difficult to account for all of the possible variables that may influence recognition; however, features that relate closely to valence include mode and frequency of harmonic changes, and measures of these parameters can be found in music information retrieval software packages.

Lastly, it would be of great interest to know whether or not the findings of this study are generalizable to music of other cultures. Music is highly culturally specific, rooted in tonal dynamics that do not exist in many other styles. The skills to understand, and potentially be moved by, Western classical music are acquired through the process of enculturation. A similar statement may be made for Indian raga, Balinese gamelan music, or traditional Pakistani folk music. So, while this study focused on Western classical music and had participants who were all exposed to this music from an early age, subsequent studies using other styles of music may result in support for a global interaction between music, emotion, and memory.

4.5 Summary

The results of this experiment do point to an interaction between increases in arousal and the subsequent recognition of music, despite some difficulties and the focus on this chapter on improvements for the future. In sum, this behavioral study showed a significant positive relationship between arousal ratings and increase in recognition. While a weak negative relationship existed between valence ratings and recognition performance, arousal proved to be the only strong predictor. The results of previous research from which this hypothesis was formulated was reviewed in Chapter 2, as were justifications of the present experimental design. The potential improvements that can be made in experimental design as well as the small number of studies on this combination of topics indicate that further research is necessary to truly evaluate the strength of the effect of arousal and valence in recognition memory for music. However, the broad implications of the literature as a whole, to which this thesis contributes, is clear: the intensity of emotions that people feel while listening to music can make it more memorable.

Appendix A

List of Pieces and Recordings Used

Composer; **Piece**; Conductor: Ensemble; *Album*; Portion extracted; [Excerpt length]

Adams, John; **Naive & Sentimental Music, I. Naive & Sentimental Music**; Esa-Pekka Salonen: Los Angeles Philharmonic Orchestra; *Adams: Naive & Sentimental Music*; 6:30-7:20; [50s]

Adams, John; **Naive & Sentimental Music, II. Mother Of The Man**; Esa-Pekka Salonen: Los Angeles Philharmonic Orchestra; *Adams: Naive & Sentimental Music*; 12:55-13:44; [49s]

Adams, John; **Naive & Sentimental Music, III. Chain To The Rhythm**; Esa-Pekka Salonen: Los Angeles Philharmonic Orchestra; *Adams: Naive & Sentimental Music*; 1:30-2:19; [49s]

Alwyn, William; **Overture to a Masque**; David Lloyd-Jones: Royal Liverpool Philharmonic Orchestra; *Alwyn: Orchestral Music*; 2:45-3:26; [41s]

Barber, Samuel; **Symphony No. 1, Op. 9**; Neeme Järvi: Detroit Symphony Orchestra; *Barber: Symphony No. 1, The School for Scandal Overture; Beach: Gaelic Symphony*; 15:30-16:19; [49s]

Bax, Arnold; **Tintagel**; Bryden Thomson: London Symphony Orchestra; *Bax: Tintagel*; 0:00-1:11; [1m11s]

Berg, Alban; **Lyric Suite, IV. Adagio Appasionato**; Claudio Abbado: Vienna Philharmonic Orchestra; *Alban Berg Collection [Disc 1]*; s4:15-4:55; [40s]

Bruckner, Anton; **Symphony No. 4 In E Flat, “Romantic”, III. Scherzo: Bewegt, Trio, Nicht Zu Schnell, Keinesfalls Schleppend (Urfassung)**; Kent Nagano: Bavarian State Opera Orchestra; *Bruckner: Symphony #4*; 6:00-6:42; [42]

Chambers, Evan; **The Old Burying Ground**; Kenneth Kiesler: University of Michigan Symphony Orchestra; *Chambers: The Old Burying Ground*; 0:00-0:56; [56s]

Druckman, Jacob; **Chiaroscuro**; Lukas Foss: Juilliard Orchestra; *Schwantner/Druckman/Albert*; 0:00-0:46; [46s]

Dvořák, Antonin; **Symphony No. 7, I. Allegro Maestoso**; George Szell: The Cleveland Orchestra; *George Szell; Symphony No.7 & Smetana: Moldau Suite*; 3:53-4:37; [45s]

Kernis, Aaron J.; **Too Hot Toccata**; Carlos Kalmar: Grant Park Orchestra; *Kernis: Newly Drawn Sky/Too Hot Toccata/Symphony In Waves [Grant Park Orch/Kalmar]*; 4:14-4:46; [35s]

Kernis, Aaron J.; **Symphony in Waves, V. Finale**; Carlos Kalmar: Grant Park Orchestra; *Kernis: Newly Drawn Sky/Too Hot Toccata/Symphony In Waves [Grant Park Orch/Kalmar]*; 3:59-4:52; [53s]

Kodály, Zoltán; **Dances of Galanta**; Fritz Reiner: Pittsburgh Symphony Orchesta; *Schostakovich: Symphony No. 6; Kodály: Dances of Galanta*; 0:08-1:01; [53s]

Lutoslawski, Witold; **Symphony No. 2, II Direct**; Esa-Pekka Salonen: Los Angeles Philharmonic Orchestra; *Witold Lutoslawski: Fanfare, Concerto For Piano And Orchestra, Chantefleurs Et Chantefables, Symphony 2*; 4:55-5:43; [48s]

Lutoslawski, Witold; **Symphony No. 2, II Direct**;Esa-Pekka Salonen: Los Angeles Philharmonic Orchestra; *Witold Lutoslawski: Fanfare, Concerto For Piano And Orchestra, Chantefleurs Et Chantefables, Symphony 2*; 1:15-2:04; [49s]

Penderecki, Krzysztof; **Symphony No. 2, I. Moderato**; Antoni Wit: Polish National Radio Symphony Orchestra; *Penderecki: Symphonies #2 & 4*; 2:35-3:10; [35s]

Schoenberg, Arnold; **Pelleas and Melisande**; Pierre Boulez: Chicago Symphony Orhcestra; *Arnold Schoenberg: Pelleas und Melisande; Variations Op. 3*; 3:40-4:31; [51s]

Schoenberg, Arnold; **Farben**; Michael Gielen: SWF Symphony Orchestra Baden-Baden; *Fuenf Orchestastücke op. 16*; 0:00-0:44; [44s]

Schuman, William; **In Praise of Shahn**; Otto-Werner Mueller: The Juilliard Orchestra; *Works by Schuman, Copland, Sessions*; 11:40-12:24; [44s]

Schwantner, Joseph; **Aftertones of Infinity**; Leonard Slatkin: The Juilliard Orchestra; *Schwantner/Druckman/Albert*;6:50-7:35; [45s]

Scriabin, Alexander; **Le Poeme de l'Extase, op.54**; Leopold Stokowski: Philadelphia Orchestra; *Leopold Stokowski, Conductor*; 3:01-3:52; [51s]

Scriabin, Alexander; **Symphony No. 3 in C minor, op.43; "Le Divin Poétme"; I. Lento - Luttes (Allegro)**; Eliahu Inbal: Radio-Sinfonie-Orchester Franfurt; *Symphony no 3 - Poétme de l'Extase - Pome du feu (Prométhée) (Disc 3)*; 7:57-8:33; [36s]

Sessions, Robert; **Suite from Black Maskers, II. Scene**; Paul Zukofsky: The Juilliard Orchestra; *Works by Schuman; Copland; Sessions*; 0:10-1:04; [54s]

Sibelius, Jean; **Symphony No. 6 in D minor Op.104, I. Allergo molto moderato**;Sakari Oramo: City of Birmingham Symphony Orchestra; *Symphonies Nos. 1 & 3*; 0:00-0:43; [43s]

Sibelius, Jean; **Symphony No. 6 in D minor Op.104, I. Allergo molto moderato**; Sakari Oramo: City of Birmingham Symphony Orchestra; *Symphonies Nos. 1 & 3*; 2:37-3:20; [43s]

Stravinsky, Igor; **Ode (Triptych for Orchestra), I. Eulogy**; Robert Craft: Orch. of St. Luke's; *Stravinsky: The Composer, Vol. V*; 1:00-1:44; [44s]

Theofanidis, Christopher; **Rainbow Body**; Robert Spano: Atlanta Symphony Orchestra; *Rainbow Body*; 5:28-6:31; [1m3s]

Vaughan Williams, Ralph; **Symphony No 5. in D, I. Preludio**; Roger Norrington: London Philharmonic Orchestra;*Vaughan Williams: Symphonies #3 & 5*; 3:28-4:04; [36s]

Vaughan Williams, Ralph; **Symphony No. 5 In D, III. Romanza** ;Sir Adrian Boult: London Philharmonic Orchestra;*Vaughan Willians: Symphonies #3 & 5*; 7:57-8:43; [46s]

Ware, Evan; **Refuge**; Warren Puffer Jones: University Of Michigan Symphony Orchestra; *Student Composer's Concert - 25/2/2010*; 7:48-8:34; [46s]

Ware, Evan; **Refuge**; Warren Puffer Jones: University Of Michigan Symphony Orchestra; *Student Composer's Concert - 25/2/2010*; 0:40-1:25; [45s]

Appendix B

Participant Demographics

ID	Gender	Age	Years of formal music training	Instrument(s) and duration of playing	Do you currently play or sing actively? If no, how many years since you did?	What music do you listen to? (first 4 listed)
1	female	26	3	voice, 3 guitar, 10	Yes, 2hr/wk	all
2	male	30	2	bass, 8 synth, 5 guitar, 7	No, 7 years	rock, jazz, classical, drone
3	male	22	12	piano, 12 trumpet, 6	No, 5 years	rock, jazz, folk, classical
4	female	23	4	voice, 7 flute, 2	No, 3 years	pop, rock, classical, musicals
5	male	22	0		No	classical, pop
6	male	33	1	piano, 1 guitar, 1	No, 20 years	hip hop, rock, classical
7	female	29	11	piano, 11 guitar, 2 voice, 2	No, 12 years	classical, rock, pop

ID	Gender	Age	Years of formal music training	Instrument(s) and duration of playing	Do you currently play or sing actively? If no, how many years since you did?	What music do you listen to? (first 4 listed)
8	male	27	8	bass, 15 bass guitar, 15	No, 4 years	classical, jazz, pop, rock
9	female	23	3	voice, 3	Yes, 1 hr/wk	all
10	male	24	12	bass, 10 piano, 3 voice, 3 trumpet, 4	No, 2 yr	classical, jazz, pop, musicals
11	male	25	11	clarinet, 6 piano, 15 guitar, 4	Yes, 2 hr/wk	pop, world
12	female	21	0		No	pop, musicals, classical
13	male	22	0	guitar, 2	No, 2 years	classical, rock, pop, latin
14	male	24	0	guitar, 2	No, 8 years	metal, rap, classical, dubstep
15	male	22	2	violin, 2	No	rap, jazz, latin, classical
16	male	23	8	clarinet, 8	No, 4 years	all
17	female	24	15	sitar, 17 piano, 1	Yes, 4 hr/wk	world, country, classical
18	female	32	0	guitar, 7	No, 10 years	classical, bards

Appendix C

Python Scripts

Here I present the Python scripts I wrote and used to help automate my data processing insofar as they might be helpful to others in future studies.

The following script concatenated the four datafiles Max/MSP stored for each participant – their valence, arousal, familiarity ratings, and numbered excerpt that they were listening to – into a new file, "Aggregate" and sorted them by ascending excerpt number. This facilitated data entry by hand into SPSS.

```
def main():
        sounds = open("Sound_day1").read().split()
        familiarity = open("Familiarity_day1").read().split()
        arousal = open("ArousalRatings_day1").read().split()
        valence = open("ValenceRatings_day1").read().split()
        aggregate = open("Aggregate", 'w')
        data = []
        for a, b, c, d in zip(sounds, valence, arousal, familiarity):
                x = a, b, c, d
                data.append(x)
        sorted_by_first = sorted(data, key=lambda tup: tup[0])
        aggregate.write(str(sorted_by_first))
```

The below script, although much simpler, converted the CPU times output by Max/MSP (in ms) into seconds, which is the unit of time measure that Ledalab (the analysis software for EDA data) reads.

```
def main():
        time = open("TimeCPU_day1").read().split()
        TimeCPU = open("TimeCPU_day1convert", "w")
        for x in time:
                f = (float(x) / 1000)
                TimeCPU.write(str(f) + '\n')
```

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