Distribution Agreement

Signature:

______________________________ _______________

Melissa Auth April 14, 2010

Emotional Enhancement of Memory for Music and Faces

by

Melissa J. Auth

Adviser: Dr. Stephan Hamann

Department of Psychology

____
Dr. Stephan Hamann
Adviser

____
Dr. David Edwards
Committee Member

____
Dr. Steve Everett
Committee Member

____
April 12, 2010

Emotional Enhancement of Memory for Music and Faces

By

Melissa J. Auth

Adviser: Dr. Stephan Hamann

An abstract of
A thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2010

Abstract

Emotional Enhancement of Memory for Music and Faces
By Melissa J. Auth

Participants listened to short musical excerpts that were paired with the brief presentation of neutral faces at the conclusion of each excerpt to examine the effects of emotional arousal on declarative memory for music and incidentally presented faces. Emotional arousal was assessed concurrently using subjective ratings and psychophysiology. Memory for the musical excerpts and faces was later tested with a recognition memory test that additionally assessed separate components of recognition memory: recollection and familiarity. Emotionally arousing musical excerpts, like visual and verbal stimuli, show enhanced declarative memory relative to neutral excerpts, and this effect was stronger for recognition accompanied by recollection, rather than only familiarity. Though memory levels for incidentally presented faces was low for several subjects, an emotional enhancement of recollection for face stimuli that had been initially experienced during emotionally arousing music was also found, consistent with predictions.

Emotional Enhancement of Memory for Music and Faces

By

Melissa J. Auth

Adviser: Dr. Stephan Hamann

A thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Arts with Honors

Department of Psychology

2010

Acknowledgements

I would like to thank a number of people, without whom this study would not have been possible. Firstly, I would like to thank Dr. Stephan Hamann for his constant guidance and support throughout the entire year. I would like to thank Katye Vytal who has been there for me throughout the entire year to give me direction and has supervised this project from beginning to end. I would like to thank Cory Inman who has spent countless hours teaching me and answering all my questions. I would like to thank Jennifer Wilson who has also answered so many questions and been extremely encouraging throughout the entire semester. I would like to thank Carolina Campenella for being supportive and always willing to help. I would like to thank Dr. Steve Everett for providing insight into the musical aspects of the experiments and for discussing any musical inquiries I have. Finally, I would like to thank Dr. David Edwards for his ongoing support and guidance, and for inspiring me to major in Psychology.

TABLE OF CONTENTS

Emotional Enhancement of Memory for Music and Faces

The enhancing effects of emotion on memory have long been an active topic of psychological study. Emotion can frequently enhance declarative memory, or memory for facts and events that can be consciously recalled (Squire, 1994). Considerable empirical evidence has demonstrated that emotional arousal, defined as the strength or intensity of an emotion, is the primary aspect of emotional response that determines its effect on declarative memory, although valence, defined as the pleasantness or unpleasantness of an emotional reaction, can play a more minor role in modulating this relationship (LaBar & Cabeza, 2006). For example, Bradley, Greenwald, Petry, and Lang (1992) conducted a study where photographs varying widely in emotional arousal were presented to subjects, and emotional responses at encoding and subsequent recognition memory for the pictures was later assessed. Photographs that were rated as more emotionally arousing were better remembered and had faster recognition times than photos rated as less arousing, whereas valence did not significantly affect memory, after the effects of arousal were controlled for.

A key issue that has attracted considerable recent attention is the identification of brain mechanisms that are involved in the encoding and retrieval of emotionally arousing declarative memory specifically. Evidence from neuropsychological and functional neuroimaging studies has established that the amygdala is a critical brain structure involved in the emotional enhancement of declarative memory (for a review, see LaBar & Cabeza, 2006). LaBar & Phelps (1998) reported that patients who had unilateral amygdala lesions resulting from unilateral temporal lobectomy surgery failed to show emotionally enhanced memory for emotional words when compared to healthy control subjects. The deficit for the amygdala-lesioned patients was observed despite intact subjective and physiological responses to the emotionally arousing words, as assessed by skin-conductance responses, a commonly used measure of emotional arousal, suggesting that the emotional memory deficit was not due to a lack of normal emotional responses in the unilateral temporal lobectomy group.

Converging evidence from neuroimaging has been reported from several studies using a variety of imaging modalities. For example, a positron emission tomography (PET) study found that the degree of bilateral amygdala activation during encoding of emotional pictures was positively correlated for enhanced subsequent memory for the emotionally arousing visual stimuli (both aversive and pleasant) relative to neutral visual stimuli (Hamann, 2001; Hamann, Ely, Grafton, & Kilts, 1999). The enhancing effect of emotional arousal on memory also can extend to neutral stimuli that are presented at the same time as an emotional event. This effect is also amygdala-dependent, as demonstrated by a functional magnetic resonance imaging (fMRI) study which showed that emotionally arousing stimuli presented at the same time as a target item enhanced memory for that item, even in cases where the target item was neutral (Medford, Phillips, Brierley, Brammer, Bullmore, & David, 2005).

Although the effect of emotional arousal has been explored across several domains with different types of stimuli, including films, photographs, words, and emotional stories, the potential enhancing effects of emotional arousal on declarative memory has received relatively less attention in the domain of emotion elicited by music. Several studies have confirmed the widely held popular notion that music can induce substantial emotional subjective and physiological arousal. For example, Grewe, Nagel, Kopiez, and Altenmüller, (2007) reported that musical excerpts elicited considerable emotional arousal as indexed by a variety of methods including psychophysiology (SCR), bodily movements, and ratings. Emotion has been regarded as a key aspect of music (Khalfa, Isabelle, Jean – Pierre, & Manon, 2001; Pansaak, 1995; Krumhansl, 1997) and investigating the effects of music-elicited on memory has the potential to shed new light on both the effects of music on cognition and on emotional memory processes (Koelsh, 2010).

While the degree to which emotional arousal enhances the encoding of declarative memory for music is still unclear, several studies have started to explore this relationship. One study showed that music enhanced emotional experience elicited by affective pictures when music and visual stimuli were presented together (Baumgartner, Esslen, & Jäncke, 2006). Another recent study specifically addressed emotional arousal of music with respect to music memory but, contrary to the study's predictions, a significant emotional memory effect as a function of arousal was not found (Eschrich, Muüte, & Altenmüller, 2008). This finding is also inconsistent with the previous literature reviewed above, which has demonstrated that emotional arousal enhances declarative memory, independently of valence (LaBar & Phelps, 1998; Kensinger & Corkin, 2003; Bradley, Greenwald, Petry, & Lang, 1992, as cited in Eschrich et al., 2008).

In examining the potential effects of music-elicited emotion on memory, it is important to consider the possibility that emotion may not affect all aspects of declarative memory in a similar way. Indeed, several studies of emotional declarative memory have distinguished between two types of recollective experience, one which is specifically influenced by emotional arousal, and another which is typically not influenced by emotional arousal. This distinction is motivated by the dual trace theory of recognition memory, in which remembering items involve different recollective experiences. The dual trace theory proposes that declarative memory is not a unitary construct, but instead is comprised of two different components which, although both enable accurate decisions regarding prior occurrence, differ in their recollective experience and content. By this view, the recollection component of declarative memory involves remembering of the contextual information associated with the previous episode, whereas the familiarity component is characterized by knowing that an item has been previously experienced, but in the absence of the ability to recollect contextual information (Tulving, 1985).

Sharot & Yonelinas (2004) examined the effect of emotional arousal on declarative memory, focusing on the question of whether emotional arousal affects the recollection component of recognition memory to a greater extent than the familiarity component. Participants viewed a series of intermixed emotional and neutral pictures in an encoding session and their memory for the pictures was subsequently tested using recognition tests both immediately after and 24 hours after the encoding session. The recollection and familiarity components of recognition for the pictures was assessed using the remember/know procedure, in which subjects are asked to judge whether, for items they judge to be “old’ (previously presented in the encoding session), they additionally can recollect contextual information such as their thoughts, feelings, or spatial information associated with the occurrence of the item (i.e., a “remember” response, indicating recollection), or whether they simply know that the item is old, but are unable to recollect additional contextual information (i.e., a “know” responses, indicating familiarity). As predicted, the emotional memory effect (enhanced memory for emotional items) was observed for the recollective component of recognition but not the familiarity component (Sharot & Yonelinas, 2004). These and other studies reporting similar findings (Perfect, Mayes, Downes, & Van Eijk, 1996; Gardiner & Java, 1990; Tulving, 1985) provide evidence for a distinction between the effects of emotional arousal on the recollection and familiarity components of declarative memory.

The primary goal of the current study was to examine the effects of the subjective and physiological emotional responses elicited by music on declarative memory. Based on considerable prior evidence from the literature linking emotional arousal to enhanced memory for emotionally arousing stimuli, we hypothesized that emotionally arousing musical excerpts, operationally defined as those rated highly by subjects on subjective measures of emotional arousal, would show enhanced memory when tested on a subsequent recognition memory test, relative to neutral, nonemotional musical excerpts. Based on the results of previous studies that have linked the effect of emotional arousal specifically to the enhancement of the recollection component of declarative memory, we hypothesized that emotional arousal would specifically benefit this recollective aspect of recognition memory for music. Like other, similar studies of emotional memory (Sharot and Yonelinas, 2004), we assessed recollection and familiarity using the remember/know recognition procedure.

As noted above, emotional arousal has been shown to not only enhance memory for stimuli which are themselves emotionally arousing, but also to enhance memory for stimuli that are presented at the same time as emotionally arousing stimuli. To examine the effect of emotional arousal elicited by music on recognition memory for neutral stimuli presented simultaneously with the emotional musical stimuli, neutral face stimuli were presented during the last three seconds of each musical excerpt. It was predicted that recognition memory for these incidentally presented face stimuli would also be enhanced when the musical excerpt was emotionally arousing, relative to cases where the musical excerpt was neutral. In line with our prediction about the emotional memory effect for musical excerpts, we hypothesized that the effect of emotional arousal would be primarily to enhance the recollection component of recognition memory for the face stimuli, as opposed to the familiarity component. That is, we expected that the emotional arousal elicited by the musical excerpts would specifically benefit recognition as assessed by remember judgments, rather than familiar judgments.

To assess emotional arousal, we measured both subjective arousal responses and physiological arousal responses. To assess whether the musical excerpts rated as emotionally arousing also elicited significant physiological responses consistent with emotional arousal, skin conductance response (SCR) was used to measure physiological levels of emotional arousal while participants listened to musical excerpts. SCR, which indexes sympathetic nervous system activity through changes in eccrine gland activity in the skin, is the most widely used and commonly accepted psychophysiological measure of emotional arousal, and it allows dynamic changes across time in arousal levels to be assessed on a second-by-second basis (Grewe et al., 2007).

In summary, to examine the effects of emotional arousal on declarative memory for music and incidentally presented faces, in the present study, participants listened to short musical excerpts that were paired with the brief presentation of neutral faces at the conclusion of each excerpt. Emotional arousal was assessed concurrently using subjective ratings and psychophysiology. Memory for the musical excerpts and faces was later tested with a recognition memory test that additionally assessed separate components of recognition memory, recollection and familiarity.

Methods

Participants

A total of 28 participants were recruited from the undergraduate Emory University population. Three students from an introductory Psychology course received research credits for their participation; all other participants received no incentive or compensation. Participants' (14 women, 14 men) ages ranged from 18 to 23 years old ($M = 21$). Of these participants, two participants' data were not included in the analysis due to computer malfunction, one for failure to understand the ratings instructions, one for significant prior exposure to the musical stimuli used in the study, and one for lack of significant skin conductance responses, leaving a total of 23 participants with usable data (10 women, 13 men). English was the first language for all participants except two, whose first languages were Spanish and Lithuanian.

All participants gave informed written consent to participate in the experimental protocol. The experimental protocol was approved by Emory University's Institutional Review Board.

Design

A within-participants design was used for this study. Three dependent quantitative variables (music recognition memory scores, face recognition memory scores, and skin conductance response to the musical stimuli) were examined with respect to the independent variable (magnitude of emotional arousal induced by music). To establish normative ratings on arousal and valence elicited by musical stimuli, arousal ratings were obtained from a group of pilot subjects, who did not participate in the main experiment. These arousal ratings were used to select the neutral and emotional music stimuli for use in the main experiment. Valence ratings were obtained on a 5-point Likert scale (*1 = highly negative, 2 = negative, 3 = neutral, 4 = positive, 5 = highly positive*). Arousal ratings were also obtained on a 5-point Likert scale (*1 = no arousal, 2 = low arousal, 3= moderate arousal, 4 = arousing, 5 = highly arousing*). Subjective arousal ratings were made by two groups of pilot subjects (Emory University undergraduates, age range 18 to 22 years).

Stimuli

The musical experimental stimuli consisted of 50 fifteen-second target musical excerpts, which were used during the encoding phase. 50 five-second musical recognition distractor excerpts were presented only during the recognition memory test and were chosen to be similar to the target musical excerpts on style and arousal. The face photo stimuli consisted of 50 grayscale photos of young adult male and female faces (equal proportion of males and females in the set) which were presented only during the encoding phase, during the last 3 seconds of each musical excerpt, and 50 distractor face stimuli with similar characteristics to the 50 encoding face stimuli. These distractor face photos were presented only during the face recognition test. All face photos were shown with a width of 2.5" and height of 3.5".

The musical excerpts used in the present study were taken from a variety of jazz, classical, and meditative genres in order to minimize similarity between different excerpts. The excerpts were all instrumental and contained no vocal elements or words. Excerpts were edited to have the same duration and volume (using the Garageband for

Mac software, Apple Computer, Inc., Palo Alto, CA). The initial set of musical excerpts, from which the final set of excerpts were selected via collection of normative ratings, were selected on the basis of the fact that they were included in previous studies as neutral or emotionally arousing stimuli, or based on assessment of musical content by the experimenters. Based on the normative ratings, the musical excerpts were categorized as neutral (25 stimuli) or emotional (25 stimuli). To reduce primacy and recency effects, two neutral buffer musical excerpts were also selected that had normative arousal ratings of 3: one excerpt was selected for presentation at the beginning of the series of musical excerpts and the other for presentation at the end. For a list of musical excerpts used and their normative ratings, see Table 1.

For the music recognition session, the first five seconds of the target (encoded) excerpts were selected. In addition, 50 five-second distractor excerpts were selected. For each target excerpt, a distractor excerpt was selected by the experimenter to match an encoded excerpt as best it could without being indistinguishable from the encoded excerpt.

Procedure

The experiment consisted of an encoding session, a delay interval imposed between the encoding and retrieval sessions, followed by two recognition sessions: one assessing recognition for the musical excerpts, the other assessing recognition for the incidentally presented faces. The orders for the excerpts and faces in both the encoding and recognition session were pseudo-randomized. Participants were randomly assigned to one of 3 groups, where groups differed by the order in which the musical stimuli were presented in the encoding session and the music recognition session.

Participants were first greeted and were administered informed written consent by the experimenter. After any questions were answered, to prepare for the application of skin-conductance electrodes, participants had their pointer and middle fingers lightly abraded by the researcher (to obtain a better skin conductance response) and then participants washed their hands. Two silver-chloride electrodes were then attached to their pointer and middle finger on their left hand to measure their skin conductance response. Next, instructions for the encoding session were read to the participant. Participants were asked again if they had any questions. To check whether participants could generate a significant skin conductance response to a stimulus known to elicit large skin conductance responses in most participants, participants were instructed to take two deep breaths in succession. Subjects were required to have a substantial deflection from the baseline for at least one of the deep breaths to be considered SCR responders (one participant failed to have a substantial deflection from the baseline, and while they completed the entire experiment, their results were not included.) Participants then started the encoding session.

During the encoding session (see Figure 1), participants heard 52 fifteen-second sound excerpts and were asked to make a series of ratings immediately after each excerpt. The ratings from the first and last excerpts, which were only included to serve as buffer items to reduce primacy and recency effects in memory, were excluded from the data analysis. At the beginning of each trial, a black fixation cross, which served to alert subjects of the upcoming musical excerpt, was first displayed on a white screen for 1 second. Next, the fixation cross disappeared and the musical excerpt was played for fifteen seconds. A neutral face was presented in the center of the computer screen during the last 3 seconds of each musical excerpt. Participants were told to watch the screen for the entire trial, but did not perform any task involving the face. Immediately after each musical excerpt, participants then rated the musical excerpt on two different 5-point Likert scales, on emotional valence, and emotional intensity/ arousal. They were then asked to decide on their pre-experimental familiarity with the excerpt (*1 = not familiar, 5 = definitely known*) and if they had moved their body significantly during the excerpt (*1 = moved*; *no response = did not move*) which could effect their skin conductance measurement. Participants were allowed three seconds to make each rating. Immediately after the twelve seconds of just ratings, a crosshair appeared again and the next excerpt started. There were two possible orders for excerpts during the encoding session. Musical excerpts and faces were presented in a pseudo-randomized order such that no more than three emotional or neutral excerpts were played in a row, and no more than three male or female faces were shown in a row.

After the encoding session, participants washed their hands and completed a distracter task which consisted of completing two surveys. A music questionnaire was designed to assess musical experience and background (see Appendix A). The Positive and Negative Affect Schedule (PANAS) survey (Watson, Clark, & Tellegen, 1988) was strictly a distracter task. The total time delay was 20 minutes, which started immediately after the encoding session.

After 20 minutes, participants were read instructions for the music recognition test (see Figure 2) designed to test memory for the musical excerpts. The remember/ familiar/ new task required participants to indicate whether the excerpt was remembered (i.e., that they were able to recollect specific information about the excerpt), familiar (i.e., that they knew the excerpt was OLD but could not recollect any specific information about the excerpt's presentation), or new (i.e. that the excerpt had not been played in the first session). A one second crosshair appeared, and then went away when the musical excerpt played for five seconds. Participants had three seconds in between each set of excerpts to make their remember/ familiar/ new rating. Immediately following the rating, a crosshair appeared again and the next excerpt started. There were two possible orders for the recognition excerpts. The five second excerpts were presented in a pseudo – randomized order so that no more than three arousing or neutral excerpts played in a row, and no more than three OLD or NEW excerpts played in a row.

After they completed the music recognition test, participants were then read instructions for and completed the face recognition task (see Figure 2) which incorporated the same remember/ familiar/ new format of recognition. The 50 neutral faces from the encoding session were presented randomly amongst 50 distractor neutral faces. A one second crosshair appeared and then a face was shown for three seconds. Participants had three seconds after each face to make their remember/ familiar/ new rating. Immediately following the rating, a crosshair appeared again and the next face was shown. The faces were presented in a pseudo-randomized order so that no more than three male or female faces were shown in a row, and no more than three OLD or NEW faces were shown in a row. Participants were then debriefed and informed of the true nature of the study.

Ratings and recognition responses were recorded in computer log files using the experimental program PsyScope. Stimuli were presented on either a MacBook 10.5

laptop or a Mac desktop. The volume of the excerpts was at the same level for each participant.

Galvanic Skin Response

Skin Conductance was measured on an MP System 150 (Biopac Inc., Goleta, CA). LEAD108A electrode leads were used to measure skin conductance via an unshielded pinch lead 12” electrode connected to silver/silver-chloride electrodes. The gain was set to 1000. Data was obtained using AcqKnowledge software package (see Appendix B) (Biopac Systems Inc., Goleta, CA, U.S.A.)

Results

Behavioral Ratings

Musical excerpts were categorized as either emotionally arousing or neutral based on normative ratings obtained with pilot subjects tested prior to the main experiment. Both normative ratings and individual subjective arousal ratings were made using 5-point Likert scales (see Figure 3). On average, individual subjective ratings were in accordance with the normative pilot ratings 66.5% of the time (i.e., when a participant rated a normed emotional excerpt as emotional or a normed neutral excerpt as neutral).

Recognition Memory

Across participants, the mean proportion of recognition for emotional versus neutral excerpts was calculated. Corrected overall recognition scores (not categorized on the basis of recollection and familiarity components) were calculated separately for the emotional and neutral stimulus categories, based on the corresponding proportion of false alarms (the number of NEW items incorrectly identified as OLD, divided by the total number of new items) subtracted from the total proportion of hits (the number of correctly identified OLD items divided by the total number of old items). In addition, the recognition memory responses were further analyzed on the basis of recollection vs. familiarity. Corrected remembered proportion scores (denoted as *R*) for musical excerpts were calculated using the same method described for corrected overall recognition scores, except that only the number of hits and false alarms judged as remembered were used for the calculation. For the calculation of corrected recognition for the familiarity component of recognition, familiarity scores (*K*) for music were calculated using the formula K = Khit/(1 – Rhit) – Kfa/(1 – Rfa). This equation controls for the statistical dependence of remember and familiar responses (Yonelinas & Jacoby, 1994). Because participants did not make subjective arousal ratings of the distractor clips, recognition scores based upon individual subjective arousal were corrected using an estimate based on the false alarm rate calculated from the categorization of distractor items as emotional or neutral by the pilot subject group. In an additional analysis, musical excerpts were categorized as emotional or neutral based on averaged subjective arousal ratings (average arousal ratings for each excerpt, averaged across all experimental participants). These recognition scores were also corrected with false alarms that were categorized on emotion based on pre-ratings.

Face recognition scores were calculated in a similar manner to the musical excerpts. Faces were categorized as either emotional or neutral according to the arousal of the musical excerpt they were paired with during the encoding phase. Therefore, there were also three ways of categorizing the emotion for the face recognition scores as well (normative ratings, individual subjective ratings, and averaged subjective ratings). Overall hits, remember judgments, and familiarity judgments were calculated separately for faces paired with emotional excerpts and faces paired with neutral excerpts. Because the distractor faces were all neutral, and no music had been paired with them during encoding to categorize them emotionally, overall ‘false alarm’ scores were used to correct all recognition scores.

Infrequently, recognition scores were not recorded when a participant did not make a response within the three-second time frame provided. This occurred on average of 1.4% for the music recognition trials, and 0.5% for face recognition trials. Excerpts that were rated as ‘highly familiar’ (i.e., the participant knew the song prior to the experiment) were also omitted, and on average, less than 1% of excerpts were rated familiar (0.78%).

Manipulation Checks

Several manipulation checks were conducted to test whether the subjective arousal ratings and physiological measurements differed between the emotionally arousing and neutral excerpts (which had been chosen based upon normative ratings).

Subjective arousal ratings for normed emotionally arousing excerpts (M =3.605, SEM = .081) were significantly higher than for normed neutral excerpts (M =2.475, SEM = .074), $t(22) = 9.914$, $p = .000$.

Skin conductance measurements were obtained during the first twelve seconds of each encoded excerpt (excluding the last three seconds due to the onset of the face). Area under the curve (AUC) and maximum amplitude measurements were extracted matching each of the fifty excerpts in micro siemens. Area under the curve measured the total area under the skin conductance waveform in the 12-second time window, while the maximum amplitude was defined as the maximum (peak) difference from that occurred in this same 12-second window. Using a commonly employed transformation to control for inter-subject differences in overall response magnitude, the SCR measurements were then transformed by conversion to z scores, and AUC and maximum amplitude z scores were averaged for emotionally arousing and neutral excerpts for each participant. Averages were obtained separately, based on both normative and subjective arousal categorizations of emotion.

When categorized by normative ratings, the difference between skin conductance AUC for emotional (M = -.000, SEM = .018) and neutral (M = -.096, SEM = .016) excerpts was significant $t(22) = 3.341$, $p = .003$. For maximum amplitude, there was a trend toward a significant difference between emotional (M = -.027, SEM = .022) and neutral (M = -.101, SEM = .020) excerpts, $t(22) = 1.937$, $p = .066$. When categorized by individual subjective arousal ratings, however, there was not a significant difference between emotional (M = -.037, SEM = .036) and neutral (M =.049, SEM = .029) excerpts for AUC, $t(22) = .198$, $p = .845$. In addition, there was no significant difference for maximum amplitude for emotional (M = -.096, SEM = .033) and neutral (M = -.046, SEM = .031) excerpts, $t(22) = -.834$, $p = .413$. There was also no difference between AUC for emotional (M = -.021, SEM = .026) and neutral (M = -.076, SEM = .022) excerpts when emotion was categorized by averaged subjective ratings, $t(22) = 1.216$, $p =$ .237. For maximum amplitude, there was also no difference between emotional (M = -.057, SEM = .023) and neutral (M = -.072, SEM = .024) excerpts, $t(22) = .336$, $p = .740$.

Because the z score means were negative, an additional analysis using the raw scores (instead of the transformed z scores) was conducted to confirm that the SCRs reflected increases above baseline when raw scores were examined. When categorized by normative ratings, the difference between skin conductance AUC for emotional (*M* = .549, *SEM* = .114) and neutral (*M* = .520, *SEM* = .111) excerpts was significant $t(22) = 2.536$, $p = .019$. For maximum amplitude, there was not, however, a significant difference between emotional (*M* = .099, *SEM* = .015) and neutral (*M* = .093, *SEM* = .015) excerpts, $t(22) = 1.600$, $p = .124$. When categorized by subjective arousal ratings, there was not a significant difference between emotional (*M* = .549, *SEM* = .115) and neutral (*M* =.537, *SEM* = .110) excerpts for AUC, $t(22) = .706$, $p = .448$. In addition, there was no significant difference for maximum amplitude for emotional (*M* = .101, *SEM* = .015) and neutral (*M* = .103 , *SEM* = .015) excerpts, $t(22) = -.308$, $p = .716$.

Table 1.
Paired Samples tests for Music Recognition

Emotional categorization based on normative arousal ratings						
Recollective Experience	Arousal category	Mean	Std. Error Mean	df	*t*	*p*
Uncorrected Overall	Emotional	.814	.022	22	2.271	.033*
	Neutral	.757	.025			
Corrected Overall	Emotional	.598	.026	22	-.656	.519
	Neutral	.617	.021			
Corrected Remembered	Emotional	.429	.031	22	5.90	.000*
	Neutral	.271	.030			
Corrected Familiar	Emotional	.463	.041	22	-2.151	.043*
	Neutral	.551	.028			
Emotional categorization based on individual subjective arousal ratings						
Recollective Experience		Mean	Std. Error Mean	df	*t*	*p*
Uncorrected Overall	Emotional	.846	.020	22	3.441	.002*
	Neutral	.745	.029			
Corrected Overall	Emotional	.618	.025	22	.174	.863
	Neutral	.612	.023			
Corrected Remembered	Emotional	.472	.042	22	5.298	.000*
	Neutral	.277	.026			
Corrected Familiar	Emotional	.440	.062	22	-1.622	.119
	Neutral	.548	.033			
Emotional categorization based on averaged subjective arousal ratings						
Recollective Experience		Mean	Std. Error Mean	df	*t*	*P*
Uncorrected Overall	Emotional	.821	.020	22	3.232	.004*
	Neutral	.761	.026			
Corrected Overall	Emotional	.597	.026	22	-.881	.388
	Neutral	.622	.020			
Corrected Remembered	Emotional	.428	.034	22	5.002	.000*
	Neutral	.278	.029			
Corrected Familiar	Emotional	.450	.043	22	-2.253	.035*
	Neutral	.556.	.031			

Note. * = $p \leq .05$

Based on normative ratings (see Figure 4), there was no significant effect of emotion on overall corrected recognition. There was a significant effect of emotion on corrected remembered recognition in the direction hypothesized (emotional excerpts were better remembered than neutral excerpts). For corrected familiar recognition, there was also a significant effect of recognition, in that neutral excerpts were rated as familiar more than emotional excerpts.

Based on individual subjective ratings (see Figure 5), there was no significant difference in overall corrected recognition between emotional and neutral excerpts. There was an emotional memory effect in the hypothesized direction for remembered recognition. There was not a significant effect of emotion on familiar recognition.

Based on averaged subjective ratings (see Figure 6), there was no significant difference in overall corrected recognition between emotional and neutral excerpts, yet there was for remembered recognition.

In all three categorizations of emotion, there were significant emotional memory effects for overall uncorrected recognition.

The emotional memory effect (i.e. difference between emotional recognition and neutral recognition) was calculated for each participant, for each of the six types of recollective experience listed above (overall, remembered, familiar based on either normative or subjective ratings). Correlation analyses were conducted between each of these measures and the difference between mean subjective arousal ratings for the emotional and neutral excerpts, yet there were no significant correlations.

The difference between the mean SCR for emotional excerpts and neutral excerpts was also obtained for each participant, where SCR was measured by area or max amplitude, and emotion was categorized based upon normative and subjective arousal ratings. Correlation analyses between each of these four difference scores were each correlated with each of the six emotional memory effects listed above, yet there were no significant correlations.

For the analysis based on subjective individual participant ratings, we divided stimuli into emotional and neutral categories based on the rating on the 5-point Likert scale indicating emotional arousal. Specifically, stimuli with ratings of 4 or 5 were classified as emotional, whereas those rated 1, 2, or 3 were categorized as neutral. To ensure that the recognition scores based on subjective arousal categorization of emotion were valid, two other methods were used to categorize emotion based on subjective arousal. One method involved excluding all excerpts rated as a '3' on arousal, since it is possible that participants still found these excerpts arousing, but not necessarily highly arousing. A similar pattern occurred when all excerpts with a subjective arousal rating of 3 were excluded from recognition: emotional excerpts (M = .848, SEM = .020) were still better remembered overall than neutral excerpts (M = .687, SEM = .031), $t(22) = 4.338$, p = .000. This was also the case in remembered recognition in that emotional excerpts (M = .522, SEM = .037) were still better remembered than neutral excerpts (M = .271, SEM = .035), $t(22) = 5.454$, p = .000. For familiar recognition, there was a trend in that neutral excerpts (M = .418, SEM = .031) were almost better remembered than emotional excerpts (M = .327, SEM = .038), $t(22) = -1.850$, p = .078.

Another method that was used to divide the subjective arousal ratings into neutral and emotional excerpts was instead of excluding all '3' arousal ratings, to classify those excerpts rated as a 3 by their valence rating. If the excerpts that had a 3 on arousal also had a 1, 2, 4, or 5 rating on valence, they were deemed emotional, but if they had a 3 (or neutral) rating, they were deemed 'neutral.' And again, a similar pattern occurred: for overall recognition, emotional excerpts (*M* = .838, *SEM* = .022) were better remembered than neutral excerpts (*M* = .738, *SEM* = .031), *t*(22) = 2.919, *p* = .008. For remembered recognition, emotional excerpts (*M* = .489, *SEM* = .035) were better remembered than neutral excerpts (*M* = .304, *SEM* = .036), *t*(22) = 4.305, *p* = .000. For familiar recognition, there was a trend in that neutral excerpts (*M* = .435, *SEM* = .030) were almost better remembered than emotional excerpts (*M* = .350, *SEM* = .034), *t*(22) = -1.901, *p* = .070.

Table 2.
Paired Samples tests for Face Recognition

Emotional categorization based on normative arousal ratings						
Recollective Experience	Arousal Category (for Music)	Mean	Std. Error Mean	df	*t*	*p*
Corrected Overall	Emotional	.200	.040	22	1.120	.275
	Neutral	.171	.034			
Corrected Remembered	Emotional	.133	.023	22	2.976	.007*
	Neutral	.085	.020			
Corrected Familiar	Emotional	.138	.035	22	.189	.852
	Neutral	.132	.032			
Emotional categorization based on subjective arousal ratings						
Recollective Experience	Arousal Category (for Music)	Mean	Std. Error Mean	df	*t*	*p*
Corrected Overall	Emotional	.190	.041	22	.517	.610
	Neutral	.177	.035			
Corrected Remembered	Emotional	.105	.023	22	-.417	.681
	Neutral	.113	.021			
Corrected Familiar	Emotional	.141	.037	22	.487	.631
	Neutral	.126	.028			
Emotional categorization based on averaged subjective arousal ratings						
Recollective Experience		Mean	Std. Error Mean	df	*t*	*p*
Corrected Overall	Emotional	.209	.035	22	2.711	.013*
	Neutral	.157	.037			
Corrected Remembered	Emotional	.123	.018	22	1.674	.108
	Neutral	.097	.024			
Corrected Familiar	Emotional	.152	.029	22	1.918	.068
	Neutral	.107	.033			

Note. * = $p \leq .05$

Overall corrected recognition for faces did not differ significantly between faces paired with emotional music or neutral music either when emotion was categorized by normative arousal ratings (see Figure 7) or when emotion was categorized by subjective ratings (see Figure 8). For corrected remembered recognition, there was a significant emotional memory effect for faces when emotion of the musical excerpts was categorized by normative arousal ratings, but not by subjective arousal ratings. Overall corrected recognition was higher for faces paired with emotional music than for faces paired with neutral music when based upon averaged subjective arousal ratings, but there was no emotional memory effect for the recollective component. Corrected familiar recognition for faces did not differ significantly between faces paired with emotional or neutral music, regardless of emotional categorization.

Table 3.
Paired Samples tests for Face Recognition, excluding subjects with low hit rates

Emotional categorization based on normative arousal ratings						
Recollective Experience	Arousal Category (for Music)	Mean	Std. Error Mean	df	*t*	*p*
Corrected Overall	Emotional	.289	.055	12	.659	.523
	Neutral	.262	.041			
Corrected Remembered	Emotional	.184	.027	12	2.525	.027*
	Neutral	.132	.026			
Corrected Familiar	Emotional	.212	.051	12	.210	.837
	Neutral	.200	.041			

Note. * = $p \leq .05$

Because a number of participants (n = 10) had low hit rates (below 50%), we conducted a follow-up analysis to confirm that the results did not differ when only subjects who had above-chance hit rates were included,. This analysis confirmed that there was still a significant emotional memory effect for corrected remember judgments , and no significant effect for overall recognition or corrected familiar judgments.

Table 4.
Paired Samples tests for Face Recognition

Emotional categorization based on subjective arousal ratings, excluding all ratings of '3'						
Recollective Experience	Arousal Category (for Music)	Mean	Std. Error Mean	df	*t*	*p*
Corrected Overall	Emotional	.190	.042	22	.833	.414
	Neutral	.167	.038			
Corrected Remembered	Emotional	.105	.023	22	-.137	.892
	Neutral	.107	.021			
Corrected Familiar	Emotional	.141	.037	22	.867	.395

	Neutral	.114	.033

The subjective arousal ratings that categorized the faces on emotion deemed excerpts rated 1, 2, or 3 as neutral and excerpts rated 4 or 5 as emotional. Because other methods were used to divide the Likert scores into emotional and neutral categories, an additional analysis on face recognition was obtained, where all faces paired with excerpts with arousal ratings of ‘3’ were excluded. Changing to this method of emotional classification did not yield any emotional memory effects for overall, remembered, or familiar corrected recognition.

Additional analyses were conducted to see if there were any significant effects of gender, instrumental background (i.e. if participants currently played an instrument), musical studies (i.e. if participants were music majors or not), and participants’ ability to sing on pitch. These four variables were operationalized by participants’ answers on the music questionnaires and were all categorical (i.e. yes/ no). There was a significantly larger emotional memory effect for non – music majors (M = .172, SEM = .029) than for music majors (M = .060, SEM = .020) for the recollective component of recognition, when emotion was categorized on normative ratings, $t(13.27) = -3.165$, $p = .007$. There was also a significantly larger emotional memory effect for participants who claimed they could not sing on pitch (M = .176, SEM = .036) than for participants who claimed they could sing on pitch (M = .044, SEM = .038), $t(20.79) = -2.529$, $p = .020$. This was the case when recognition was based upon subjective arousal ratings.

Discussion

The main goal of the current study was to examine the effect of the subjective and physiological responses elicited by music on declarative memory. We hypothesized that emotionally arousing musical excerpts would show enhanced recognition memory on a subsequent recognition memory test, relative to neutral, non-emotional musical excerpts. Overall recognition was higher for emotional than for neutral excerpts when emotion was categorized by subjective arousal ratings but not when emotion was categorized by normative arousal ratings. The emotional memory effect (for subjective arousal categorization) is consistent with the idea that, in general, emotional stimuli are better remembered than neutral stimuli (Bradley, Greenwald, Petry, & Lang, 1992; Lang, Shillon, & Qinqwen, 1995, Hamann, Ely, Grafton, & Kilts, 1999). Although there was no significant emotional memory effect for overall corrected recognition when categorized by all three ratings (normative, individual subjective, and averaged subjective), there were significant emotional memory effects for the recollective component of recognition. The different results for false-alarm corrected recognition scores vs. proportion hits (uncorrected scores) stem from the higher false-alarm rate for emotional music stimuli. Thus, although participants were more likely to correctly identify emotional music excerpts as old, they also were more likely to mistakenly identify a new excerpt as old (i.e., make a false alarm response to a new item). This increased tendency to judge emotional stimuli as having been previously encountered has been reported in several previous studies (e.g., Sharot and Yonelinas, 2004) and has been interpreted as reflecting both higher semantic similarity between emotional stimuli (because they share the characteristic of being emotionally arousing) and a recognition bias for emotional stimuli. For example, studies of memory for highly emotional events such as the space shuttle Challenger disaster have shown that subjects frequently overestimate their memory confidence for emotional stimuli.

We also hypothesized that emotional arousal would specifically benefit the recollective aspect of recognition memory, operationalized in this study by “remember” judgments in the context of the remember/ familiar recognition task, as opposed to an effect on the familiarity component of recognition memory. This prediction was supported by the results. There was a significant emotional memory effect for the corrected recollective (or remembered) component of recognition for musical excerpts but not for the corrected familiarity component. This was the case for all emotional categorization methods (normative, individual subjective arousal, and averaged subjective arousal). This finding is consistent with previous studies in other stimulus modalities that have found that emotional arousal enhances the recollective component of recognition rather than the familiarity component (Sharot & Yonelinas, 2007; Sharot, Delgado, & Phelps, 2004).

We also hypothesized that recognition memory for the face stimuli incidentally presented with the music would be enhanced when the musical excerpt was emotionally arousing, but not when the excerpt was neutral. Overall recognition did not differ for faces presented with emotional music and faces presented with neutral music. This was the case for both categorizations of emotion. While our hypothesis was not supported by the overall recognition results, there was nonetheless a numerical difference between overall face recognition in the predicted direction (i.e. faces paired with emotional music had a higher recognition score numerically than faces paired with neutral music).

Finally, we hypothesized that the effect of emotional arousal would be primarily to enhance the recollection component of recognition memory for the face stimuli. An emotional memory effect was found for remembered face recognition when emotion was based upon normative ratings only, which supported this hypothesis. Because of the fact that several participants had hit rate percentages below chance, a follow-up analysis was conducted which excluded these participants. Even with the removal of these subjects, remembered recognition was still significantly higher for faces paired with emotional music than for faces paired with neutral music. This finding relates to the above mentioned study which found that emotional music can enhance the emotional experience of visual items (Baumgartner, Esslen, & Jäncke, 2006). Perhaps the increased emotional experience of these neutral visual items is what led them to have enhanced recognition. For familiar recognition based upon normative ratings, there were no significant memory effects, as predicted.

When emotion was categorized by subjective arousal, there were no emotional memory effects for faces in overall, remembered, or familiar recognition. Because there were several ways to divide the subjective arousal 5-point Likert scores into “emotional” and “neutral” categories, recognition scores for the faces were also computed where faces presented with excerpts having arousal scores of ‘3’ were excluded. This emotional classification still did not yield any emotional effects for overall, remembered, or familiar recognition. This finding suggests that regardless of how subjective arousal scores are divided into “emotional” and “neutral” categories, there are no emotional memory effects for faces.

When emotion was categorized by averaged subjective arousal, there was an emotional memory effect for overall corrected recognition, but not for the remembered and familiar components of recognition.

Overall, recognition memory levels were generally low for faces, which could have limited the size of any potential emotional memory effects. That is, many items were so poorly encoded that even with emotional enhancement, they would still fall below some threshold for correct recognition judgment.

Manipulation Checks

The manipulation checks were important for determining whether the chosen stimuli were actually emotionally arousing or less emotionally arousing ("neutral") to the participants. Arousal for the musical excerpts was obtained by subjective arousal ratings, and physiological skin conductance response. The subjective arousal ratings and skin conductance response (AUC) for the emotional normed excerpts were significantly higher than for the neutral normed excerpts, which suggests that there were psychological and physiological felt differences in emotional arousal between the 'emotional' and 'neutral' excerpts selected for the study.

An interesting finding was that while there was an emotional memory effect for skin conductance response AUC (and a trend toward an effect for maximum amplitude) when emotion was categorized by normative ratings, there was no effect for AUC and maximum amplitude when emotion was categorized by subjective arousal ratings and averaged subjective arousal ratings of the participants in the experiment. This is somewhat surprising since one might expect that subjective arousal ratings would be more closely related to individuals' physiological arousal responses than normative ratings based on the subjective ratings of other subjects.

The finding of an emotional memory effect for music recognition memory (where emotion was categorized by subjective arousal ratings) contrasts with Eschrich and colleagues' finding that arousal had no effect on recognition memory for music (2008). The researchers examined whether the degree to which valence, arousal, and emotionality of musical excerpts would influence whether the excerpts were later remembered. Participants rated musical excerpts on valence, arousal, and emotional intensity and were randomly assigned to one of two groups; a time – estimation group or an emotion group. The groups differed in that the time-estimated group estimated the length of the excerpts while the emotion group ranked the excerpts on valence, arousal, and emotional intensity. During a recognition task, participants indicated whether each excerpt was old or new, and there was no difference in recognition between the time – estimated group and the emotion group. Within the emotion group, valence was shown to be a significant predictor of recognition memory yet arousal did not have an effect on memory. Several differences in experimental design could have led to this discrepancy. The most notable difference is that while Eschrich and colleagues only used film music, the present study utilized music from several additional genres, including jazz and classical. Due to the difference in musical selection, it is possible that there was a larger arousal gap between emotional and neutral excerpts in the current study.

While an emotional memory effect for the familiar component of face recognition was not found (which agreed with the hypothesis), there was in fact a significant memory effect in the other direction (i.e. neutral excerpts were more remembered as familiar than emotional excerpts). This held true for both normative and subjective categorizations of emotion. When recognizing a neutral excerpt, participants were more likely to give a familiar response than a remember response. This pattern is consistent with the hypothesized effects of emotion on declarative memory. Neutral musical excerpts would be predicted to have a lower recollection component relative to emotional musical excerpts, and depending on the base rate for recollection and familiarity for the musical stimuli, this could be reflected as a higher proportion of familiar judgments for neutral stimuli. Another possible explanation for this effect could be that the low arousal and similarity of the neutral excerpts made them hard to differentiate from one another. During the recognition test it might be difficult to differentiate between target and distractor clips if they are too similar.

The results of this study are consistent with past literature that shows differences between neural processing of emotional and non-emotional stimuli. The amygdala was found to be significantly more active for emotional stimuli than neutral stimuli during a retrieval session (Dolan, Lane, Chua, & Fletcher, 2000) and also appears to modulate the hippocampus for emotional stimuli (Hamann, 2001). While the amygdala is generally linked to the processing of emotion, the hippocampus is integral for declarative memory (for a review, see Phelps, 2004). Not only is hippocampal and amygdala activity correlated during encoding of emotional stimuli (Hamann et al., 1999), but patients with damage to the hippocampus selectively show normal emotional enhancement of explicit memory (Hamann & Squire, 1997; Hamann, Cahill, & Squire, 1997). This view corresponds with the memory-modulation hypothesis which suggests that it is the modulating effect of the amygdala on other memory structures through stress hormones that enhances memory for emotional rather than neutral events (McGaugh, 2004).

Limitations

A general limitation for this area of research had to do with musical stimuli selection. While trends in musical preference allow for a general understanding of what would be emotional and neutral, individual music preferences vary enormously across individuals. Since the ages and backgrounds of the participants were known (all university undergraduates), music was pre-selected by the experimenter as “emotional” and “neutral” based on knowledge of what most university undergraduates are exposed to. Pre – raters from same subject pool helped to narrow down the excerpts the extremes on an arousal spectrum and eliminate those excerpts that were too familiar. Regardless of this selection process, the results of the study would be stronger if a larger number of excerpts were chosen originally, and if more people were able to initially choose and pre – rate the excerpts.

Another limitation of the current study is the short length of the musical excerpts both in the encoding session. It is important to note that music is not an instantaneous event but a continuous and changing perceptual stimulus. Music builds on itself with respect to time, and each note, rest, and gesture gains significance within the context of the whole. A major chord amongst other major chords has a different effect than a major chord presented in the context of minor chords. When comparing perceived cognitive arousal with different musical features, one study found that musical texture tends to correlate positively with arousal (Schubert, 2004). Texture is described as the number of voices or instruments present at a given time in a score. It was also observed in the same study that for some scores, which gradually decreased in texture, musical arousal still remained high (i.e. at the end of a piece when instruments begin to decrease in volume). This suggests the idea that emotional arousal at a specific moment in music is at least somewhat dependent on what has been played before and what is anticipated to come. Participants might have been more likely to feel an emotional affect for the music if the excerpts were longer. In addition, participants listened to music individually in a laboratory setting, which is atypical of the way these participants listen to music, and could have influenced the way participants perceived the music.

Another weakness of the study was the fact that a small proportion of recognition responses were omitted due to the design of the paradigm. Only 1.2% of responses were omitted on average during music recognition and 0.5% during face recognition; thus, it is unlikely that this factor was an important determinant of the results. Finally, face recognition memory levels were low, which limited the ability to observe emotional memory effects.

Future Research

For future research testing music perception and memory, musical selection is one of the key aspects that attention should be paid to. It would be beneficial to have a larger group of pre-raters to rate musical excerpts from a larger selection of musical excerpts to begin with. In addition, it would be wise to have excerpts analyzed by professional musicians on tempo, timbre, and melody to better understand the musical elements present in 'emotional' and 'neutral' music. The robustness of the current findings should also be examined with a wider range of participants (e.g. adults, children, musicians, etc)

Conclusions

In conclusion, the current study found support for the hypothesis that emotionally arousing musical excerpts, like visual and verbal stimuli, show enhanced declarative memory relative to neutral excerpts, and this effect is stronger for recognition accompanied by recollection, rather than only familiarity. Though memory levels for the incidentally presented faces was low for several subjects, an emotional enhancement of recollection for face stimuli that had been initially experienced during emotionally arousing music was also found, consistent with predictions.

Generalizing to real-world situations from the current results, one would expect highly emotionally arousing music to be more vividly recollected in everyday life, and memory the faces of persons seen at the same time as the emotionally arousing music would be expected to benefit from emotional arousal, especially when later memory tests tap recollection. The implications for the growing field of music cognition are that emotional arousal in music is a key factor that determines whether music will be later remembered. Thus, emotionally salient, arousing music likely has an enhanced influence other aspects of music processing, and would be expected have a stronger influence on shaping future musical preferences.

References

Anderson, A.K. (2005) Affective influences on the attentional dynamics supporting awareness, *Journal of Experimental Psychology, 134,* 258 – 281.

Anderson, A.K., Wais, P.E., & Gabrieli, J.D. (2006) Emotion enhances remembrance of neutral events past. *Proceedings of the National Academy of Sciences, 103,* 1599 – 1604.

Baumgartner, T., Esslen, M., & Jäncke, L. (2006). From emotion perception to emotion experience: Emotions evoked by pictures and classical music. *International Journal of Psychophysiology, 60,* 34 – 43.

Bechara, A., Tranel, D. Damacio, H., Adolphs, R., Rockland, C., & Damasio, A.R. (1995) Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. *Science, 269*, 1115 – 1118.

Berns, G.S., Capra, C.M., Moore, S., Noussair, C. (2010) Neural mechanisms of the influence of popularity on adolescent ratings of music. *NeuroImage, 49,* 2687 – 2696.

Bigand, E., Viellard, S., Madurell, F., Marozeau, J., & Dacquet, A. (2005). Multidimensional scaling of emotional responses to music: The effect of musical expertise and of the duration of the excerpts. *Cognition and Emotion, 19,* 1113 – 1139.

Bradley, M.M., Greenwald, M.K., Petry, M.C., & Lang, P.L. (1992) Remembering Pictures: Pleasure and arousal in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 379 – 390.

Brattico, E. & Jacobsen, T. (2009) Subjective appraisal of music: Neuroimaging evidence. *The Neurosciences and Music III: Disorders and Plasticity, 1169*, 308 – 317.

Coutinho, E. & Cangelosi, A. (2009) The use of spatio-connectionist models in psycho-physiological studies of musical emotions. *Music Perception, 27,* 1 – 15.

Cross, I. (2001) Music, cognition, culture and evolution. *Annals of the New York Academy of Sciences, 930,* 28 – 42.

Dewhurst, S.A. & Conway, M.A. (1994) Pictures, images, and recollective experience. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1088 – 1098.

Dirk – Jan, P. & Jansen, E. (2001) Perceptual mechanisms in music processing. *Music Perception, 19,* 169 – 198.

Eschrich, S., Münte, T.F., & Altenmüller, E.O. (2008) Unforgettable film music: The role of emotion in episodic long-term memory for music. *BMC Neuroscience, 9,* 48 – 55.

Gardiner, J.M. & Java, R.I. (1990). Recollective experience in word and nonword recognition. *Memory & Cognition, 18,* 23 – 30.

Grew, O., Nagel, F., Kopiez, R., & Altenmüller, E. (2007). Emotions over time: synchronicity and development of subjective, physiological, and facial affective reactions to music. *Emotion, 7,* 774 – 788.

Guy, S.C. & Cahill, L. (1999) The role of overt rehearsal in enhanced conscious memory for emotional events. *Consciousness and Cognition, 8,* 114 – 122.

Hamann, S.B. & Squire, L.R. (1997) Intact perceptual memory in the absence of conscious memory. *Behavioral Neuroscience, 111,* 850 – 854.

Hamann, S.B. (2001) Cognitive and neural mechanisms of emotional memory. *TRENDS In Cognitive Science, 5,* 394 – 400.

Hamann, S.B., Cahill, L., & Squire, L.R. (1997) Emotional perception and memory in amnesia. *Neuropsychology, 11,* 104 – 113.

Hamann, S.B., Ely, T.D., Grafton, S.T., & Kilts, C.D. (1999). Amygdala activity related to enhanced memory for pleasant and aversive stimuli. *Nature Neuroscience, 2,* 289 – 293.

Husain, G., Thompson, W.F., & Schellenberg, G. (2002) Effects of musical tempo and mode on arousal, mood, and spatial abilities. *Music Perception, 20*, 151 – 171.

Kensinger, E.A. & Corkin, S. (2003) Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words?. *Memory & Cognition, 21,* 1169 – 1180.

Khalfa, S., Isabelle, P., Jean – Pierre, B., & Manon, R. (2002). Event-related skin conductance responses to musical emotions in humans. *Neuroscience Letters, 328,* 145 – 149.

Kivy, P. (1990) *Music alone: Philosophical reflections on the purely musical experience.* Ithaca, NY: Cornell University Press.

Koelsch, S. (2010) Towards a neural basis of music-evoked emotions. *Trends in Cognitive Science, 14,* 131 – 137.

Krumhansl, C.L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology, 51,* 336 – 352.

Labar, K.S. & Cabeza, R. (2006) Cognitive neuroscience of emotional memory. *Nature, 7,* 54 – 64.

Labar, K.S. & Phelps, E.A. (1998). Arousal – mediated memory consolidation role of the medial temporal lobe in humans. *Psycholical Science*, *9*, 527 – 540.

Labar, K.S., LeDoux, J.E., Spencer, D.D., & Phelps, E.A. (1995). Impaired fear conditioning following unilateral temporal lobectomy in humans. *Journal of Neuroscience, 15,* 6846 – 6855.

Lang, A., Shillon, K., & Qinqwen, D. (1995) The effects of emotional arousal and valence on television viewers' cognitive capacity and memory. *Journal of Broadcasting & Electronic Media, 39,* 313 – 327.

LeDoux, J.E. (1993) Emotional memory systems in the brain. *Behavioral Brain Research, 58,* 69 – 79.

Litle, P. & Zuckerman, M. (1986) Sensation seeking and musical preferences. *Personality and Individual Differences, 4,* 575 – 578.

McGaugh, J.L. & Rozendaal, B. (2002) Role of adrenal stress hormones in forming memories in the brain. *Current Opinions in Neurobiology, 12,* 205 – 210.

McGaugh, J.L. (2004) The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annual Review of Neuroscience, 27,* 1 – 18.

McGaugh, J.L. (2006) Make mild moments memorable: add a little arousal. *TRENDS in Cognitive Sciences, 10,* 345 – 347.

Medford, N., Phillips, M.L., Brierley, B., Brammer, M., Bullmore, E.T., & David, A.S. (2005) Emotional memory: Separating content and context. *Psychiatry Research: Neuroimaging, 138,* 247 – 258.

Miranda, E.R., Kirby, S., & Todd, P. (2003) On computational models of the evolution of music: From the origins of musical taste to the emergence of grammars. *Contemporary Music Review, 22,* 91 – 110.

Panksepp, J. & Bernatzky, G. (2002) Emotional sounds and the brain: The neuro-affective foundations of musical appreciation. *Behavioral Processes, 60,* 133 – 155.

Pansaak, J. (1995) The emotional source of “chills” induced by music. *Music Perception, 13,* 171 – 207.

Peretz, I. & Hyde, K.L. (2003) What is specific to music processing? Insights for congenital amusia. *Trends in Cognitive Neuroscience, 8,* 362 – 367.

Peretz, I. & Zatorre, R.J. (2005) Brain organization for music processing. *Annual Review of Psychology, 56,* 89 – 114.

Perfect, T.J., Mayes, A.R., Downes, J.J., & Van Eijk, R. (1996). Does context discriminate recollection from familiarity in recognition memory?. *The Quarterly Journal of Experimental Psychology, A3,* 797–813.

Phelps, E.A. (2004). Human emotion and memory: interactions of the amygdala and hippocampal complex. *Current Opinions in Neurobiology, 14*, 198 – 202.

Quamme, J.R., Yonelinas, A.P., & Norman, K.A. (2007) Effect of unitization on associative recognition in amnesia. *Hippocampus, 17,* 192 – 200.

Schwartz, K.D. & Fouts, G.T. (2003) Music preferences, personality style, and developmental issues of adolescents. *Journal of Youth and Adolescence, 32,* 205 – 213.

Shapiro, R.J. & Arnell, K.M. (1992) Temporal suppression of visual processing in an RSVP rask: an attentional blink? *Journal of Experimental Psychology, 18,* 849 – 860.

Sharot, T. & Yonelinas, A. (2008) Differential time-dependent effects of emotion on recollective experience and memory for contextual information. *Cognition, 106,* 538 – 547.

Sharot, T., Delgado, M.R.,& Phelps, E.A. (2004). How emotion enhances the feeling of remembering. *Nature Neuroscience, 7,* 1376 – 1380.

Shubert, E. (2004) Modeling perceived emotion with continuous musical features. *Music Perception, 2004,* 561 – 585.

Slobada, J.A. (1991). Music structure and emotional response: Some empirical findings. *Psychology of Music, 19,* 110 – 120.

Squire, L.R. (1994) Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. In E. Daniel, L. Schacter, & E.E. Tulving (Eds.), *Memory Systems 1994* (203 – 231). Cambridge, MA: Harvard University Press.

Strange, B.A., Hurlemann, R., & Dolan, R.J. (2003) An emotion-induced retrograde amnesia in humans is amygdala and β-adrenergic dependent. *Proceedings of the National Academy of Sciences of the United States of America, 100,* 13626 – 13631.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology, 26,* 1–12.

Watson, D., Clark, L.A., & Tellegen, A. (1988) Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 47,* 1063-1070.

Yonelinas, A. (1994) Receiver-operating characteristics in recognition memory: evidence for a dual- process model. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 20,* 1341 – 1354.

Yonelinas, A.P. & Jacoby, L.L. (1994) Dissociations of processes in recognition memory: Effects of interference and of response speed. *Canadian Journal of Experimental Psychology, 48,* 516 – 534.

Yonelinas, A.P., Kroll, N.E.A., Dobbins, I.G., & Soltani, M. (1999) Recognition memory for faces: When familiarity supports associative recognition judgments. *Psychonomic Bulletin & Review, 6,* 654 – 661.

Table 1

All Musical Excerpts Used in the Encoding Phase (Target Excerpts) and in the Music Recognition Phase (Distractor Excerpts)

Emotionally Arousing Excerpt

Target Excerpt	Arousal	Valence	Distractor Excerpt	Arousal	Valence
GumptionClip1	4.50	4.88	Anticipation5secClip	5.00	3.00
PiratesClip2	4.50	4.50	DrumsAndBases5secClip	5.00	3.00
AgExpansionClip2	4.38	2.13	StreetTalk5secClip	4.50	2.75
RidetoParisClip1	4.38	1.13	ChildPsychology5secClip	4.33	2.50
ArrivalatAsiansClip2	4.25	3.63	AccidentClip2	4.25	2.50
ShowtimeClip2	4.25	4.00	MoosetheMooch5secClip	4.25	2.50
25DollarsWorthClip2	4.13	1.88	OrchardHouseClip2	4.25	2.50
BuildingaFamilyClip1	4.13	4.13	soulsugarclip2	4.25	2.50
PerpetuumMobileClip2	4.13	3.75	TakenClip1	4.00	2.50
RobotArmyClip1	4.13	1.63	fightinn5sec	3.75	2.25
FlightsofFancyClip1	4.00	4.50	JustAnotherDay5secClip	3.75	2.00
MontanaClip1	4.00	2.50	ThePowerofMidnightClip1	3.75	2.00
BaseAttackClip2	3.88	1.63	XizorsThemeClip1	3.75	2.00
DarkKnightClip2	3.88	1.63	ificouldkiss5sec	3.50	2.00
OrchardHouseClip1	3.88	4.50	Mozart15secClip	3.50	2.00
ReunionClip2	3.88	3.00	VertigoClip1	3.50	2.00
ShawshankClip2	3.88	2.88	Agexpfunky	3.25	2.00
AccidentClip1	3.75	2.38	FlightsofFancyClip2	3.25	1.75
AugustsRhapsodyClip2	3.75	3.00	GumptionClip2	3.25	1.75
BetterHaveSomeKYClip2	3.75	1.88	KarmaYoga5secClip	3.25	1.75
ChevaliersClip1	3.75	2.25	RobotArmyClip2	3.25	1.50
MakeUpKissesClip1	3.75	4.13	AugustsRhapsodyClip1	3.00	1.50
TakenClip2	3.75	2.50	LeNozzedeFigaro5secClip	3.00	1.25
XizorsThemeClip2	3.75	2.13	PerpetuumMobileClip1	3.00	1.25
VertigoClip2	3.63	1.38	PiratesClip1	3.00	1.00
Mean	4.00	2.88	Mean	3.74	3.36
Std. Error Mean	0.05	0.23	Std. Error Mean	0.12	0.20

Neutral Excerpts

Target Excerpt	Arousal	Valence	Distractor Excerpt	Arousal	Valence
MysterieClip2	2.63	3.63	ReunionClip1	3.00	2.00
AppalachianWaltzClip1	2.50	3.63	ShowtimeClip1	3.00	3.75
ClementiEFlatClip1	2.50	3.38	sowasred5sec	2.75	4.25
CleopatraClip1	2.50	2.63	arrivalatasianfunky	2.50	2.50
CouldItBeClip1	2.50	4.13	Beethoven35secClip	2.50	4.75
OnlyYouClip2	2.50	3.88	FalseAlarm5secClip	2.50	2.75
ThisTimeAroundClip1	2.50	2.88	InTheBedroomClip1	2.50	3.25
AugustRushClip1	2.38	2.38	MakeUpKisses5secClip	2.50	4.00

Beethoven1Clip1	2.38	2.25	rancherswife5sec	2.50	3.00
HavanaClip2	2.38	3.75	CleopatraClip2	2.25	3.00
NocturneinCsharpClip2	2.38	2.88	AugustRushClip2	2.00	3.00
HerEyesHisHeartClip2	2.25	3.63	BaseAttackClip1	2.00	3.50
TheFourSeasonsClip2	2.25	4.13	ChevaliersClip2	2.00	4.50
InTheBedroomClip2	2.13	1.88	EmptyStoreClip1	2.00	3.50
Mozart2Clip2	2.13	3.75	ForeverInLove5secClip	2.00	3.00
SecretsClip1	2.13	3.25	MarionsThemeClip1	2.00	2.50
ThisIsMeClip1	2.13	3.13	ThisisMeClip2	2.00	2.75
MarionsThemeClip2	2.00	2.50	25dollarsworthClip1	1.75	1.75
ThePowerofMidnightClip2	2.00	3.00	Granum5secClip	1.75	3.75
EmptyStoreClip2	1.88	3.25	ThatSomebody5secClip	1.75	3.25
InnerPeaceClip1	1.88	2.38	Apasionado	1.50	3.75
KyrieEleisonClip1	1.88	3.13	MediterraneanNights5secClip	1.50	3.25
AndILoveHerClip2	1.75	2.88	KyrieEleisonClip2	1.25	2.75
EcstacyClip2	1.75	3.13	NocturneInEflat5secClip	1.25	3.50
RomanticSaxophoneClip1	1.63	2.50	SlumberMyDarling5secclip	1.00	2.25
Mean	2.20	3.12	Mean	2.07	3.18
Std. Error Mean	0.06	0.12	Std. Error Mean	0.11	0.15

Note. Mean arousal scores did not differ between emotional target and distractor excerpts, $t(48) = 1.949$, $p = .060$, or between neutral target and neutral target and distractor excerpts, $t(48) = 1.031$, $p = .309$. Valence ratings did not differ between emotional target and distractor excerpts, $t(48) = -1.581$, $p = .120$, or neutral target and distractor excerpts, $t(48) = -.341$, $p = .735$.

Figure Captions

Figure 1. Encoding session visual representation.

Figure 2. Recognition session visual representation.

Figure 3. Mean normed and subjective arousal ratings.

Figure 4. Music recognition performance based on normative emotional categories.

Figure 5. Music recognition performance based on subjective emotional categories,

Figure 6. Music recognition performance based on averaged subjective emotional categories.

Figure 7. Face recognition performance based on emotion of associated music, categorized by normative arousal ratings for the music.

Figure 8. Face recognition performance based on emotion of associated music, categorized by subjective arousal ratings for the music.

Figure 9. Face recognition performance based on emotion of associated music, categorized by averaged subjective arousal ratings for the music.

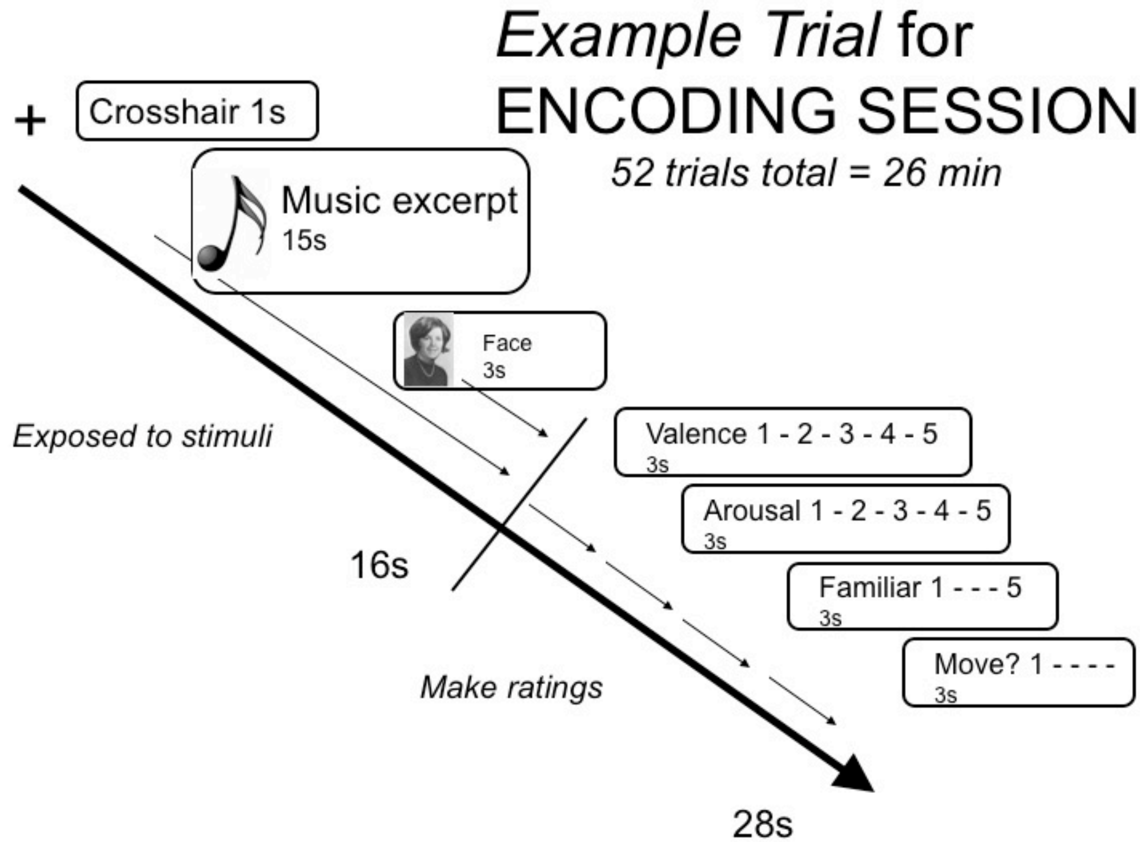


Figure 1. This figure is a visual representation of a the encoding session.

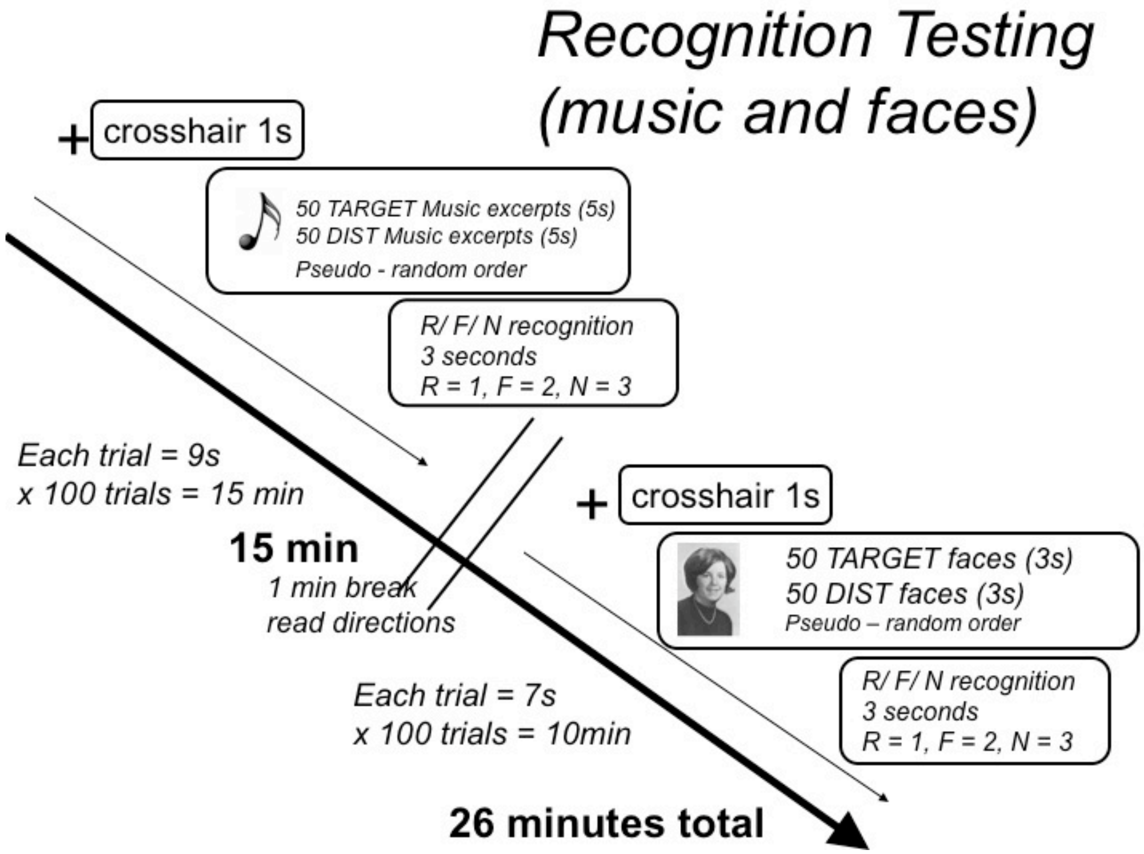


Figure 2. This figure visually represents the music and face recognition sessions.

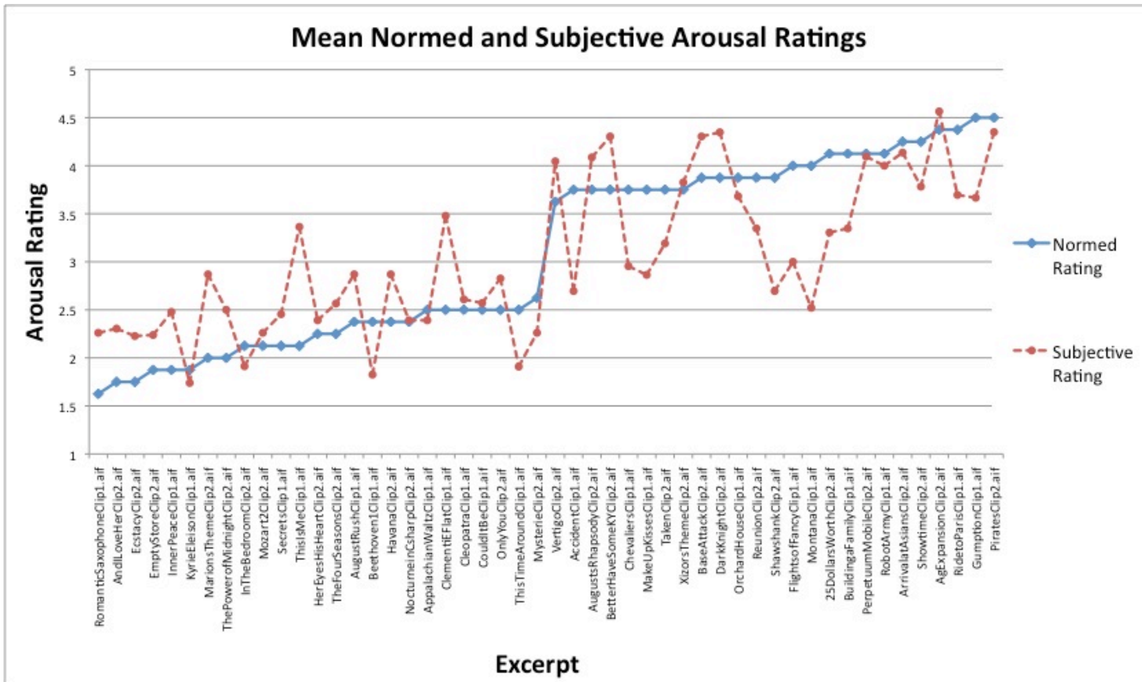


Figure 3. This graph shows the 50 target excerpts in ascending order of emotional arousal based on normative ratings (solid line), and the average emotional arousal based upon subjective ratings (dotted line). Both ratings were made on 5-point Likert scales.

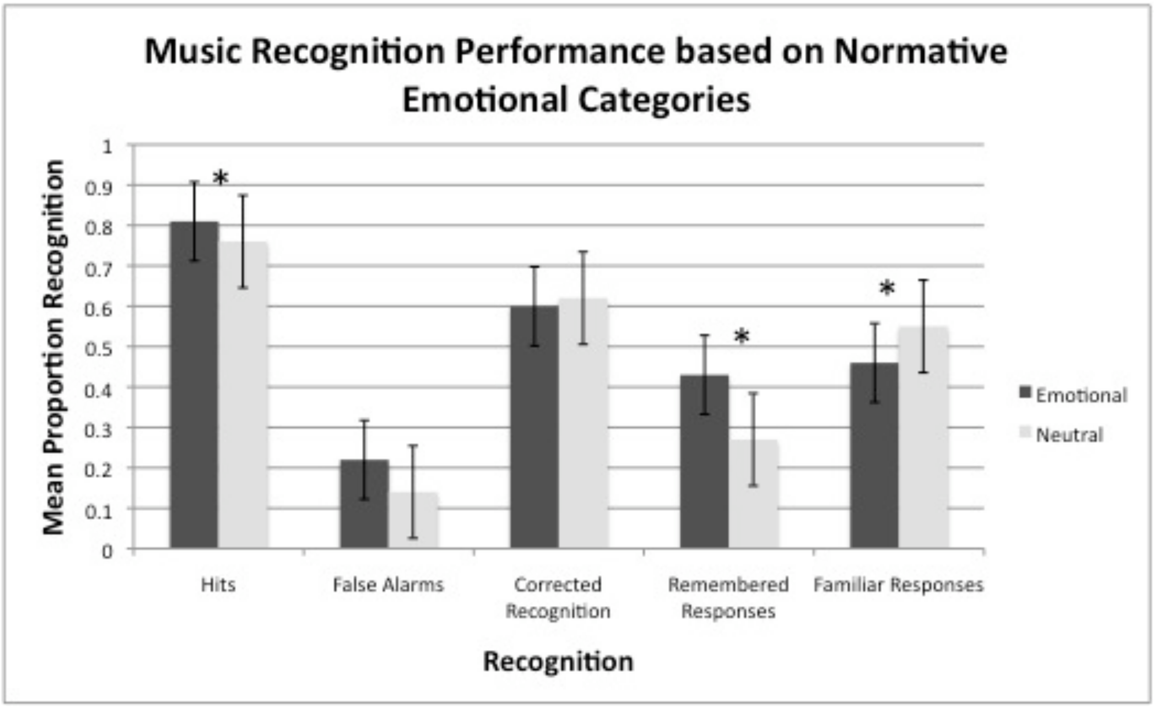


Figure 4. This figure shows proportion hit scores, false alarms, corrected recognition scores, and corrected recognition scores broken down by recollective experience for remember judgments and familiar judgments of music. Emotion was categorized by normative arousal ratings for the music. Error bars indicate the standard error of the mean.

Note. * = $p \leq .05$

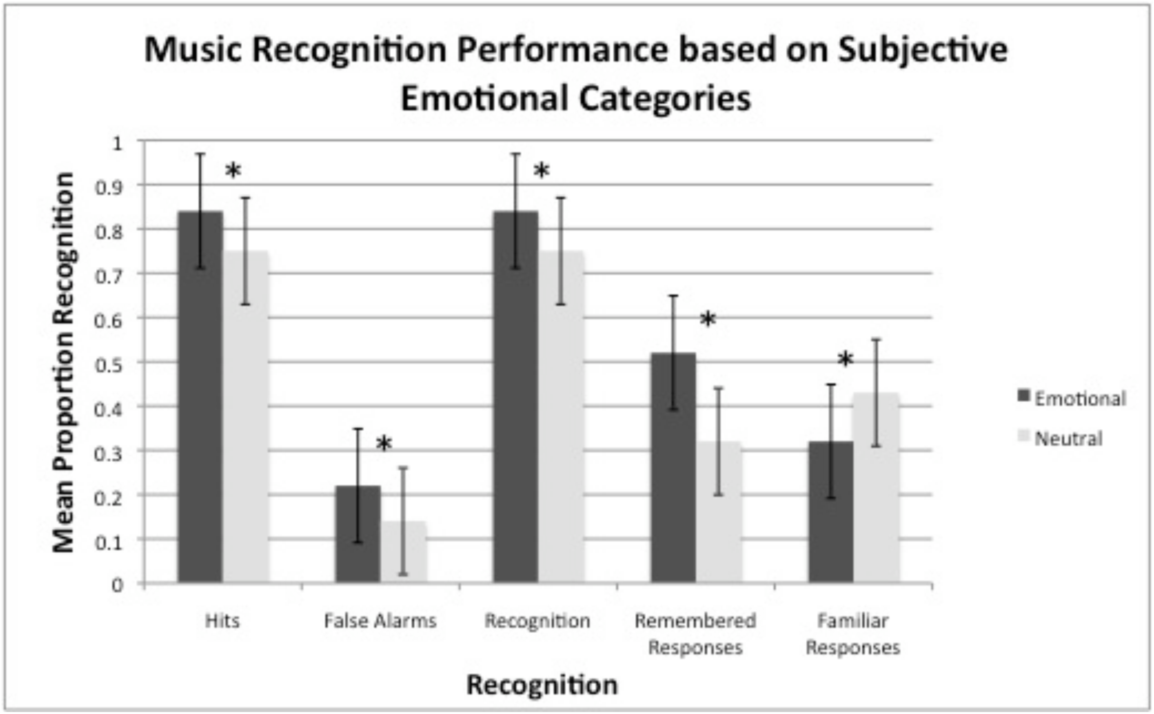


Figure 5. This figure shows proportion hit scores, false alarms, recognition scores, and recognition scores broken down by recollective experience for remember judgments and familiar judgments of music. Emotion was categorized by subjective arousal ratings for the music. False alarms are categorized as emotional and neutral based on pre-ratings from pilot subjects. Error bars indicate the standard error of the mean.

Note. * = $p \leq .05$

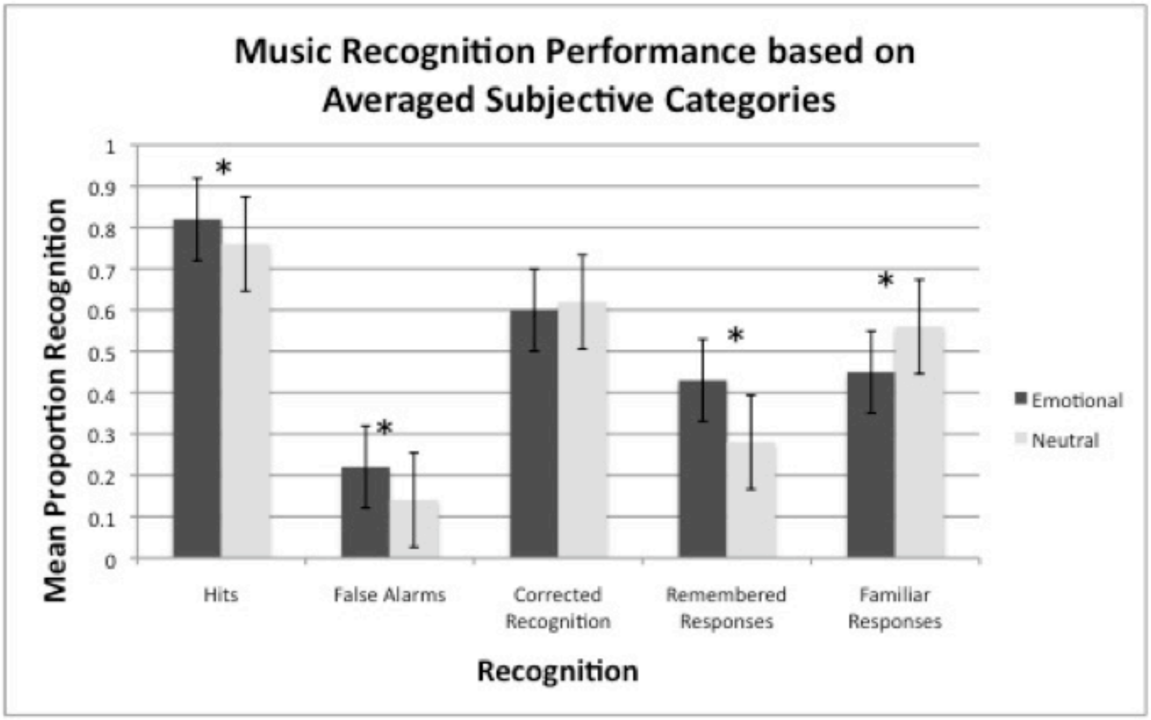


Figure 6. This figure shows proportion hit scores, false alarms, recognition scores, and recognition scores broken down by recollective experience for remember judgments and familiar judgments of music. Emotion was categorized by averaged subjective arousal ratings for the music. False alarms are categorized as emotional and neutral based on pre-ratings from pilot subjects. Error bars indicate the standard error of the mean.

Note. $* = p \leq .05$

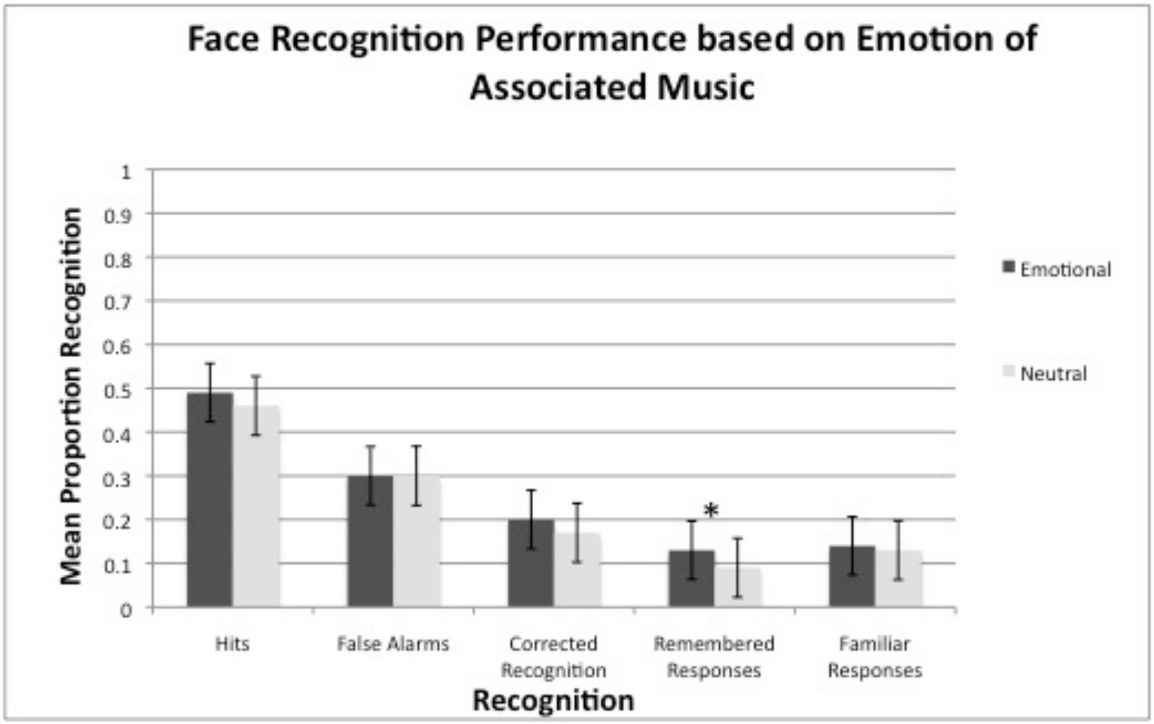


Figure 7. This figure shows proportion hit scores, false alarms, corrected recognition scores, and corrected recognition scores broken down by recollective experience for remember judgments and familiar judgments of faces. Emotion category was determined according to the music that the faces were paired with and categorized by normative arousal ratings for the music. Error bars indicate the standard error of the mean.

Note. * = $p \leq .05$

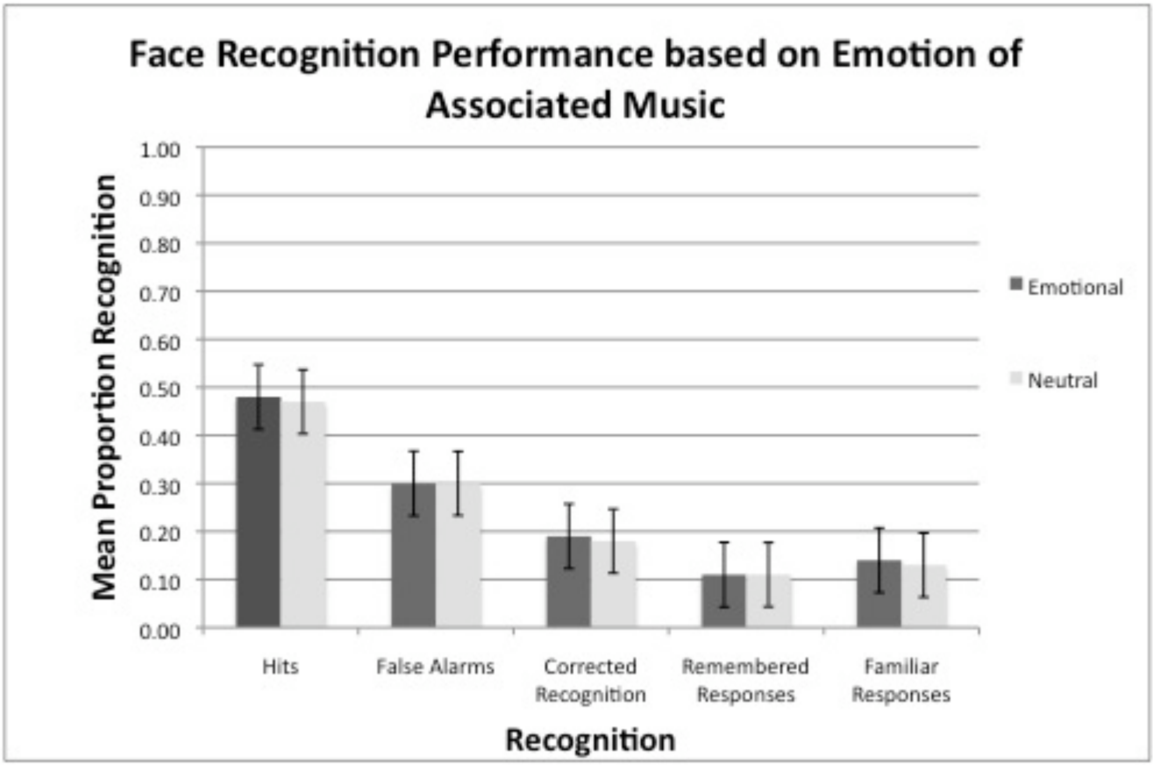


Figure 8. This figure shows proportion hit scores, false alarms, corrected recognition scores, and corrected recognition scores broken down by recollective experience for remember judgments and familiar judgments of faces. Emotion category was determined according to the music that the faces were paired with and categorized by subjective arousal ratings for the music. Error bars indicate the standard error of the mean.

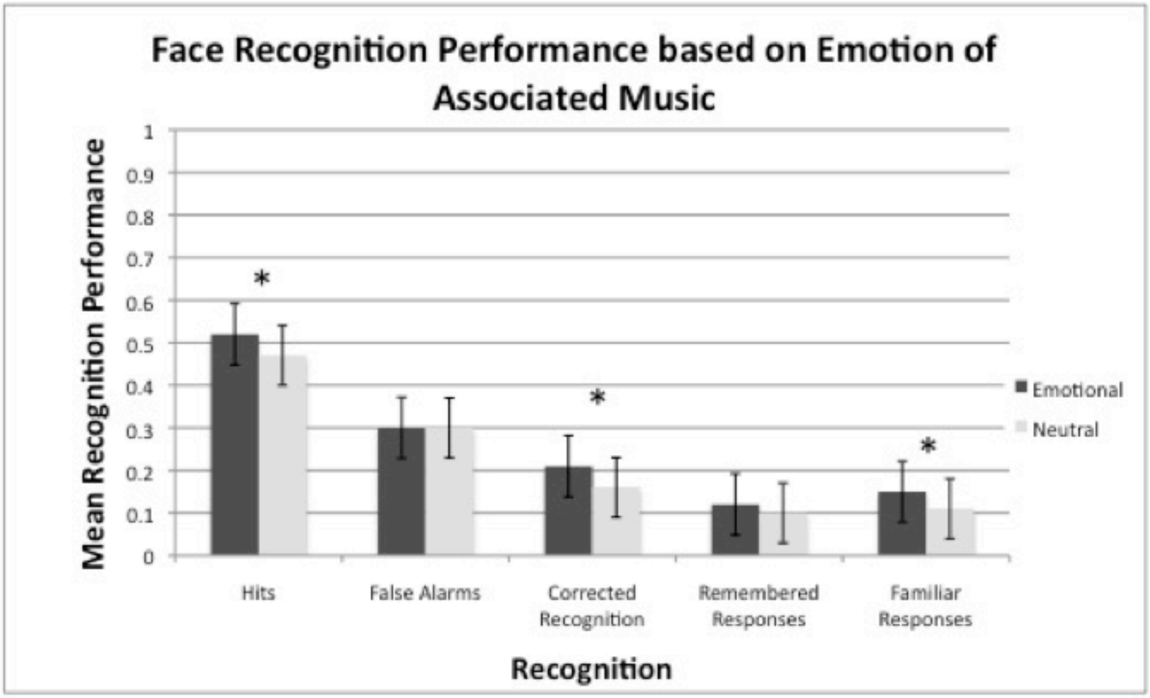


Figure 9. This figure shows proportion hit scores, false alarms, corrected recognition scores, and corrected recognition scores broken down by recollective experience for remember judgments and familiar judgments of faces. Emotion category was determined according to the music that the faces were paired with and categorized by averaged subjective arousal ratings for the music. Error bars indicate the standard error of the mean.

Note. * = $p \leq .05$

Appendix A

Music Questionnaire

Name:___________________________ Subject #:__________

MUSIC QUESTIONNAIRE

Age:_____

Sex: FEMALE MALE

Year in School:______

Where are you from? (country)

What was your first language (if not English): __________

What kind of music do you normally listen to? (Circle all that apply)

Classical	Alternative
Jazz	Pop
Rap	Rock
Heavy Metal	Electronica
Folk	Blues
Country	Hip Hop
Opera	Indie
Punk Rock	Soundtracks
Other: ____________	

On the above list, *star* the genre that you would say is your favorite.

Has any part of your culture had an influence on your musical preferences that you know of? (please describe below):

____

____

____

Circle the below statement that best describes YOU:

Music is my passion and one of the most important aspects of my life.
I participate in music activities, but I have many other passions.
I listen to music all the time, but have no "musical ability."
I sometimes listen to music, but not a lot.
I rarely listen to music, I have no need for it

Are you a music major/ minor? YES NO

Is anyone in your family a musician? YES NO

Who? ________
What do they play/ do? ________

Do you play an instrument? YES NO

Which one? _________
Are you self taught? YES NO

Have you ever taken music lessons? YES NO

If so, what instrument(s): ___________
For how long? _________

Have you ever sang in a music group? YES NO

High school singing group
College singing group:_______________

Would you say you are tone deaf or can you sing on pitch? (circle one)

Can you *harmonize* when you listen to music? (i.e. sing a harmony that goes along with the melody or main vocal part of the song)

YES NO

Have you taken any music classes during college? YES NO

Which ones? ___________________________

Do you notice the film score when watching a movie?

ALWAYS SOMETIMES NEVER

Can you read music? YES NO

Is music an important part of your life? YES NO

Do you ever get "chills" when listening to a song you love? YES NO

Would you consider yourself a movie person? YES NO
(i.e. you love movies and watch them regularly)

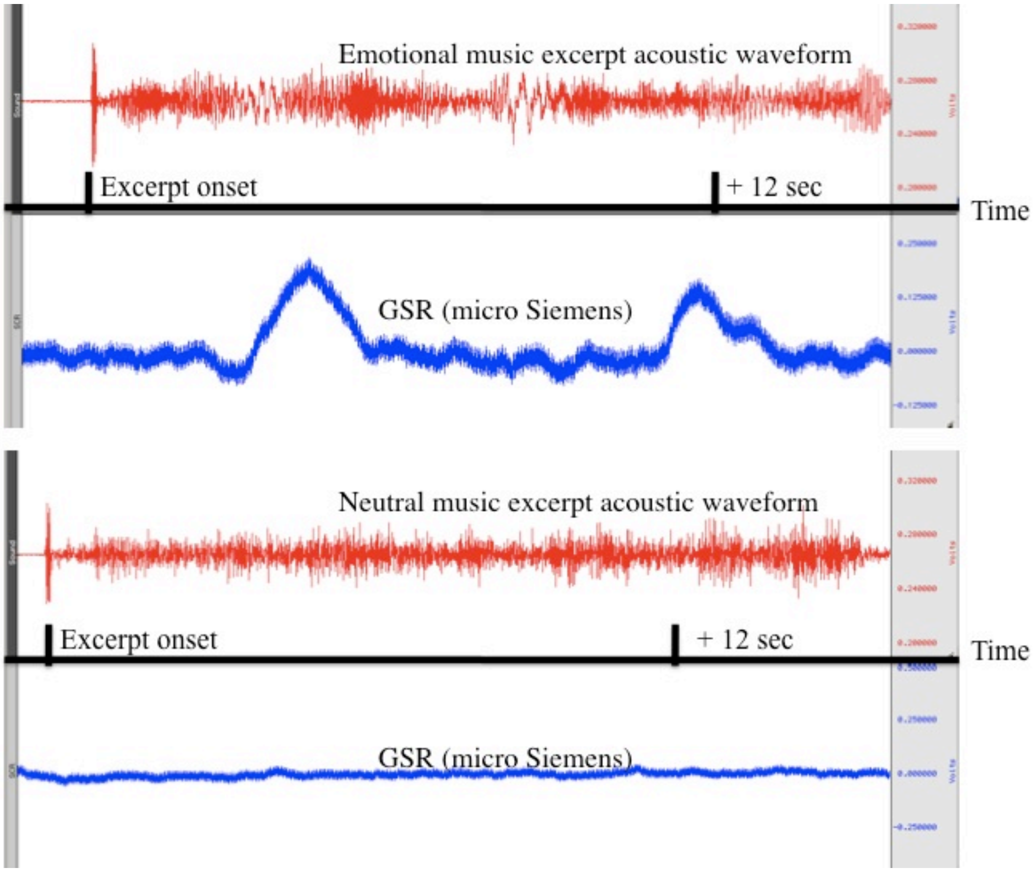
Do you listen to the WORDS when you hear a song or just listen to the MELODY or BOTH?

Are you a VISUAL learner, and AUDIO learner, or BOTH? (circle)

Have you ever taken Art History or Visual Arts? (list classes below if YES)

Appendix B

Skin Conductance Response



These images are from AcqKnowledge files recording the skin conductance response (SCR) of each participant. The top image is of an emotionally arousing musical excerpt while the bottom image is of an emotionally neutral music excerpt. SCR was obtained only during the first 12 seconds after the excerpt's onset.