USING MUSIC TO MODULATE EMOTIONAL MEMORY

A Dissertation
Presented to
The Academic Faculty

By

Sophia Kaltsouni Mehdizadeh

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in the
School of Music
Department of Music Technology

Georgia Institute of Technology

Dec 2021

USING MUSIC TO MODULATE EMOTIONAL MEMORY

Thesis committee:

Dr. Grace Leslie
Assistant Professor, Music Technology
Georgia Institute of Technology

Dr. Claire Arthur
Assistant Professor, Music Technology
Georgia Institute of Technology

Dr. Thackery Brown
Assistant Professor, Psychology and Neuroscience
Georgia Institute of Technology

Date approved: November 23, 2021

ACKNOWLEDGMENTS

I would first like to thank the members of my thesis committee for their help in preparation of this work. A special thank you to my faculty adviser, Grace Leslie, for her continued guidance and support over the past two years, and for helping me grow as a student and a researcher.

This work was a collaborative effort, and I would like to greatly acknowledge Yiren Ren and Thackery Brown for their ongoing and invaluable contributions and mentorship. I am so grateful to have the opportunity to work with both of you.

I would also like to thank my friends and colleagues who gave their time and feedback in the early stages of this work, and of course, our study participants. Last but not least, a big thank you to my friends and my family who were farther away, sending me their love and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANEW Affective Norms for English Words

ASM Attitudes towards Sad Music

CAM-WN Congruence-Association Model with Working Narrative

IAPS International Affective Picture System

LSMS Like Sad Music Scale

MDD Major Depressive Disorder

MEAMs Music-Evoked Autobiographical Memories

PTSD Post-Traumatic Stress Disorder

PUMS Previously-Used Musical Stimuli

STOMP-R revised Short Test of Musical Preferences

SUMMARY

Music is powerful in both affecting emotion and evoking memory. This thesis explores if music might be able to modulate, or change, aspects of our emotional episodic memories.

We present a behavioral, human-subjects experiment with a cognitive memory task targeting the reconsolidation mechanism. Memory reconsolidation allows for a previous experience to be relived and simultaneously reframed in memory. Moreover, reconsolidation of emotional, potentially maladaptive, autobiographical episodic memories has become a research focus in the development of new affective psychotherapy protocols. To this end, we propose that music may be a useful tool in driving and reshaping our memories and their associated emotions. This thesis additionally focuses on the roles that affect and preference may play in these memory processes.

Through this research, we provide evidence supporting music's ability to serve as a powerful context for emotional autobiographical episodic memories. Overall, our results suggest that affective characteristics of the music and the emotions induced in the listener significantly influence memory creation and retrieval, and that furthermore, the musical emotion may be equally as powerful as the musical structure in contextualizing and cueing memories. We also find support for individual differences and personal relevance of the musical context playing a determining role in these processes. This thesis establishes a foundation for subsequent neuroimaging work and future clinical research directions.

CHAPTER 1

INTRODUCTION

Music is a powerful, ubiquitous phenomenon that has been found to influence many aspects of our lives, from personality and how we perceive others [1], to our emotions, physiology, and attention [2]. I begin with an overview of three research areas at the intersection of the current work: music and emotion, memory, and preference and individual differences.

Music induces a variety of emotions in its listeners, through a number of different pathways, or psychological mechanisms. One example of these mechanisms is episodic memory: remembering events from the past as a result of listening to music. Research has found that it is quite common for music to evoke autobiographical memories in everyday life [3]. Interestingly, in these moments the music may additionally induce the emotions of the original memory as we relive this past event [4]. At the core of this work, we aim to explore this episodic memory mechanism of musically induced emotion and understand how it interacts with and may be able to manipulate other mechanisms of human memory.

Music's effects on memory performance have been studied in many capacities, leading to a number of relevant theories linking music, mood, preference, and memory. Past works have suggested that the emotions music may induce—not the music directly—are what subsequently influence cognitive processes, such as memory [5, 6]. Furthermore, the degree to which these musical emotions "fit," or don't, with other incoming information may affect how we encode and remember those events [7].

The role of subjective preference/enjoyment as an influence over memory cannot be overlooked. For one, our musical preferences often have strong ties to adolescence and defining moments in our young adult lives—thereby also tying them to episodic memory and nostalgia [8]. One's preference for music has also been found to modulate levels of musically induced emotion [9]. Additionally, listening to preferred music increases pleasurable and reward responses, also affecting mood and arousal levels [10].

1.1 Motivations and Aims

Given prior work supporting that music is able to affect emotion and evoke memory, this thesis aims to explore if music might be able to modulate, or change, aspects of our emotional episodic memories. How might music drive and reshape our memories and their associated emotions as we reexperience them over time? Would it be possible to use music to alter how we remember a negative past event?

To study this, we designed a behavioral, human-subjects experiment with a cognitive memory task targeting the reconsolidation mechanism. Reconsolidation happens when contextual cues drive partial reactivation of old memories while new memories are simultaneously acquired. This enables features of the new experience to distort or update the way we remember the old memory in the future [11]. Physical location is one example of a context that has been commonly used in studies of memory reconsolidation [12]. Our study aims to ask if music could similarly serve as a contextual trace, linking two episodic memories. If so, how do various characteristics of the music (specific timbral/melodic/temporal elements, induced emotion, and preference) impact the reconsolidation process and possible modulation of an older memory?

To the best of our knowledge, no studies of memory reconsolidation have incorporated music and explicitly explored effects on emotional memory. In the broader psychotherapy literature, the encoding of new memories through old contexts (via reconsolidation) is proposed as a mechanism by which emotional memories may be modulated for the treatment of mood-related disorders such as Major Depressive Disorder (MDD) [13, 14] and Post-Traumatic Stress Disorder (PTSD) [15]. Results of this behavioral study will provide much-needed insight into music's function as a mood regulation tool, and how music and emotional memory interact. To that end, outcomes of this ongoing work may eventually also aid those who experience memory impairment (Mild Cognitive Impairment and

Alzheimer's disease).

More immediate goals are for this work to inform future research directions in neuroimaging and understanding underlying neural mechanisms of these interactions. We believe our novel approach and experimental design, which incorporates music's inherent emotional qualities along with participant individual differences, will provide fundamental knowledge to the field and establish future clinical research directions for the development of new musical memory protocols.

1.2 Thesis Overview and Scope

The study described in this thesis is part of a larger project with the goal of providing behavioral *and neural* evidence that music can influence memory in the way described above. For this reason, it is important to note that we designed the experiment so that it may work as a neuroimaging paradigm in the future with minimal adjustments. However, this thesis contains the analysis and results of the *behavioral* pilot (N = 26) study for these methods.

Within this behavioral sample, the scope of my thesis is to address the two main foundational questions posed earlier:

1. Can music serve as a contextual trace linking two episodic memories?

2. If so, how do various characteristics of the music (specific timbral/melodic/temporal elements, induced emotion, and preference) impact the reconsolidation process and possible modulation of an older memory?

There are several additional analyses left to be performed of the data collected in the experimental paradigm described below for the purposes of our subsequent neuroimaging study aims. However, these do not fall into the scope of this thesis.

1.3 Research Summary

We hypothesized that music could serve as a contextual trace and memory cue. Furthermore, we predicted that the mood and feeling induced by the music would interact with the emotion of the memory, impacting memory encoding, updating, and retrieval, but that the specific musical/auditory elements themselves would be what participants mainly associated as the "context" to the memory, not the induced emotion. We also hypothesized that individual differences such as listener preference and connection to the music would be additional modulators of how subsequently "powerful" of a memory context the music was.

The data largely supported our hypotheses, while also pointing to some unexpected findings. Results support the claim that music acts as a contextual trace and memory cue, and that musically induced emotion significantly impacted both the creation and subsequent reactivation and reconsolidation of the memory—although not always in the ways we anticipated. Listener preference was also found to play a determining role in these memory processes. Results also suggest that participants relied on both specific musical/auditory elements and emotional qualities of the music to contextualize memories.

CHAPTER 2
BACKGROUND

2.1 Music and Emotion

Music is capable of both communicating and evoking emotions [16]. In this work I mainly focus on the latter. While perceiving the emotions that a piece of music may be trying to express mainly occurs by picking up on and understanding certain external, expressive or musical cues (scales, key, tempo, timings, dynamics, etc.) [17, 18, 19, 20], music can internally induce emotions in a number of different ways. Some of these proposed mechanisms are rhythmic entrainment, contagion, visual imagery, musical expectancy, and episodic memory (for a review, see BRECVEMA framework of musical emotions [21, 2]). Different pieces of music may activate different pathways of musical emotion, to varying degrees, in different people; this may be influenced by things like our past experiences [3], musical training [22], and other individual factors and differences in our lives (e.g., [23]).

This tendency for high levels of variability in how we respond to music can make selecting musical stimuli for controlled research purposes quite challenging. In these scenarios, it is important to consider all potential mechanisms of emotion induction. For example, is the musical stimulus popular and well-known to the extent that participants may have individual prior associations or experiences with it? Does the stimulus violate commonly accepted compositional rules and expectations to the point where some listeners might be caught off guard? Does the stimulus contain sung or spoken lyrics which might affect aesthetic judgement or visual imagery? If multiple mechanisms happen to be recruited simultaneously, the result may be mixed or conflicting emotional responses and subsequent data [21]. This section will further discuss contagion, which I will argue in Sections 2.4 and 4.1 is most relevant to selecting the musical stimuli in the present study. Details on how the musical stimuli were deliberately selected, being mindful of all of the potential mechanisms, are also discussed Chapter 4.

Emotional contagion describes the perception and internal mirroring of musically expressed emotions [21]. Evidence from behavioral studies has shown that people are able to distinguish and understand the differences between perception/recognition of emotion and what they themselves are feeling as a result (induced emotion), and that while these two may often closely align, this is not always the case [9, 19]. Unlike empathy, which is another closely-related mechanism found to be a mediator of this perceived-induced emotion relationship [9, 24], emotional contagion ("primitive empathy" [25]) is considered to be a more automatic process, where this distinction between our own emotions and other's expressed emotions is not as consciously emphasized [2]. It is hypothesized that humans may have neural circuitry similar to those mirror neuron systems found in other primates [26], which is activated by hearing speech, or even a stimulus resembling speech—such as instrumental music which is "voice-like" in its expression [17, 27]. These circuits are then responsible for activating pre-motor vocal areas in the brain in an attempt to mimic, or mirror, the perceived stimulus [28].

In addition to how music may evoke emotions in listeners, we need to be able to describe and quantify what these emotions are. Past music emotion studies have employed various emotion models for this. Russell's circumplex model of emotions contains two orthogonal dimensions of arousal (activation/deactivation) and valence (pleasant/unpleasant) [29]. Discrete emotions are represented by their characterizations on both of these axes—for example, "happy" or "energetic" (positive arousal and valence), "tender" or "calm" (negative arousal and positive valence), "sad" or "bored" (negative arousal and valence), and "angry" or "fearful" (positive arousal and negative valence). A variation of this model involving a third orthogonal dimension (dominance/submissiveness) also exists [30], and is used in standard affective measures such as the Self-Assessment Manikin [31, 32]. A related three-dimensional model has been used in music preference and personality research, in which the third dimension was classified as depth instead of dominance [33, 34, 1]. Lastly, another three-dimensional model of emotion has been proposed in which Russell's single arousal dimension is separated into energy arousal (energy/tiredness) and tension arousal (tension/calmness) [35]. These emotion models are not just used to describe music, but also emotional stimuli of other modalities, as will be exhibited in Chapter 4.

2.2 Musical Preference and Individual Differences

Music listening is a subjective activity, not just by the emotions we feel while listening, but also from our individual musical preferences. Our preferences for music are by no means static, with evidence finding that they may first form in adolescence [8] but continue to morph and change through adulthood [36, 37]. However, despite the fluctuating nature of this complex, individual characteristic, research using preferred music has been able to show some relatively consistent responses. No matter what one's "favorite" music might be at a given point in life, numerous studies have shown that individuals' preferred music may significantly affect behavior and cognitive processes. Pleasurable responses (such as chills, also known as "frisson"—for a review, see [38]) to one's favorite music are associated with reward regions in the brain, as well as increased physiological emotional arousal [10]. Ferreri and Rodriguez-Fornells (2017) found evidence that these individual reward experiences from music may drive recollection and improve episodic memory for music [39]. Furthermore, this arousal effect seemingly persists to some degree whether the selected favorite music is stimulative (greater effect) or sedative (lesser effect) in nature [40], pointing to some common, underlying psychophysiological effect of preference that is independent of the emotional properties of the music. Egermann and McAdams (2013) tested and found support for this in their music emotion model, in which they hypothesize preference for music drives an empathetic response, which in turn influences musically induced emotion [9].

Preference for musical stimuli is therefore a critical variable to consider in addition to and independently from the emotional qualities of music discussed previously. Preferred music has also found application in clinical settings (classified as a personally relevant stimulus) and shows particular promise as a therapeutic tool [41]. Studies of preferred music will often either use "favorite" music that is selected by the participant themselves, or music chosen by the researchers who then ask participants to record their preferences and liking of the music. Given the personal nature of musical preferences, participant-selected music will almost certainly evoke a strong response [10, 42]. On the other hand it is still possible to use researcher-selected stimuli, which may offer more control over aspects of the experimental design (e.g., [43]). However, it is important to note that using unfamiliar musical stimuli in general may present challenges, as familiarity is linked to both preference and intensity of emotional response [44].

The current study employs the latter approach described above (using researcher-selected music). Therefore, we need to be able to quantify participants' musical preferences and enjoyment of the chosen stimuli. Several models and measures of musical preference have been developed for this, the goals of which are to provide tools to classify preferences in a more consistent manner that is "genre-free" (for instance, the MUSIC model [45]). While genre labels (such as "Symphonic," "Electronic," "Metal," "Pop"...) are usually sufficient when discussing music in our everyday lives, their use in describing musical stimuli or participant preferences presents potential challenges in scientific studies, as these labels tend to be subjective, involve some degree of personal interpretation, and drift or evolve over time [46, 47].

Some of these models, or quantitative representations of preference, exist within a narrower scope than others, seeking to evaluate a very specific element of musical preference. Several such measures exist for the analysis of one's preference for sad music, as its counterintuitive enjoyment and underlying mechanisms is an ongoing research area [48, 49, 50]. The Attitudes towards Sad Music (ASM) [51] is a 25-item questionnaire which identifies and assesses sad music listening behavior and motives over six factors—or more broadly, as being preferential (approach/avoid behaviors) and/or contextual (dependent on individual circumstances/current situation). Another instrument, the Like Sad Music Scale (LSMS) [52], is a nine-item questionnaire based on a related measure for evaluating sadness experienced when watching sad films [53]. Whereas the ASM aims to provide a more comprehensive overview of why someone might enjoy sad music, the LSMS more broadly summarizes listeners' enjoyment/disliking of sad music in terms of adaptive or maladaptive strategies. We employ several of these measures in the current study, discussed in Chapter 4.

2.3 Music and Memory

Finally, music not only influences our emotions, driven by our subjective judgements and experiences, but many studies have also investigated the potential effects of music listening on cognitive performance. Perhaps one of the most well-known of these theories is the Mozart effect. This began as a finding that that students performed significantly better at spatial reasoning tasks after listening to 10 minutes of Mozart's sonata for two pianos in D major, compared to 10 minutes of guided relaxation or silence [54]. Various studies have since tried to expand or replicate this effect with different cognitive tasks, types of music used for priming, and/or populations, with mostly mixed results. Studies specifically using preferred music also appear to have mixed findings. Carr and Rickard (2016) found that priming with participant-selected highly enjoyed music improved image encoding and recall compared to silence [55]. Others found that preferred researcher-selected music had no effect on episodic memory (item or source memory) recognition when compared to silence or non-musical auditory conditions [56]. However, several studies have been able to demonstrate benefits of background music (concurrent cognition task and auditory stimulus, as opposed to only listening prior to the task) on episodic memory encoding [57, 58] and context/source retrieval [59] in tasks involving verbal memory.

One explanation that has been presented for these inconsistent observations on music and cognitive performance/memory is the arousal-and-mood hypothesis [5, 6]. The hypothesis draws from Russell's circumplex model of emotions (see [29]; also discussed in Section 2.1). Changes in activation (arousal) and valence (mood)—in all, an individual's emotional response—are what is thought to create positive/negative effects on cognitive functioning and performance—not the musical stimulus directly. In other words, subjective responses to music and individual differences in emotion induction via contagion (the underlying mechanism proposed responsible; discussed in Section 2.1) are theorized to be linked to our cognitive processes [60].

So how exactly might music and emotion influence memory? Several findings have come from studies of music's role in film. Researching emotional film music, Eschrich et al. (2008) found that very positive valence (felt/induced) stimuli were associated with better memory (recognition) of the music, compared to more neutral valence pieces [61]. On the other hand, musically induced arousal levels did not appear to effect music recognition performance in this study. However, an influence of arousal on memory has been seen for stimuli in other domains (e.g., images [62], words [63]), with high arousal positively impacting memory in both cases.

Furthermore, how well music aligns or pairs with the other stimuli presented alongside it (i.e., congruence) may additionally affect memory. A.J. Cohen's Congruence-Association Model with Working Narrative (CAM-WN), developed specifically to understand music's role and impact in the context of film, suggests that there exists a cross-modal pathway between our processing of visual and musical structures. This interaction (modulated by mood congruency between these two modalities) informs our conscious, real-time interpretation of the film (Working Narrative), while also guiding our attention and affecting how this information is encoded in memory [64, 7, 65]. The CAM-WN was also supported by Boltz (2004), who found that mood congruency between presented music and film clips promoted unified encoding of the two stimuli, leading to better memory for both, compared to mood-incongruent pairs [66]. For mood-incongruent music and film clips each stimulus appears to be encoded separately, with participants only remembering one or the other according to which they selectively attended.

The CAM-WN is particularly relevant in the context of this thesis, because it presents a framework for how two emotionally charged stimuli of different modalities may be processed in memory. Like the studies mentioned above, the study described in this thesis also seeks to examine how the emotional qualities of two stimuli interact in memory. The first, as in the CAM-WN studies, is of course music. The second, episodic memories (defined below in Section 2.4), has a similar narrative component to the prior works, but is based off of verbal instead of visual stimuli (film). More details are given below in the Experimental Methods (Chapter 4).

Specifically looking at studies of music and memory for words, some benefits have been demonstrated for learning novel words in a musical presentation (i.e. words to be learned are encoded as lyrics). Tamminen et al. (2017) compared spoken and musical (familiar and unfamiliar melodies) presentations of novel words. Between the three conditions, the words presented with familiar music seemed to most enhance lexical integration of the words, although no benefits for episodic memory were observed [67]. Others have also studied the spoken versus sung modalities for encoding verbal material: some have found disadvantages of singing on subsequent word recall [68], while other studies have shown that perhaps easily learned, repeated melodies might be key in facilitating recall [69]. Nguyen and Grahn (2017) compared levels of perceived valence and arousal in background music during a word memorization task. Low-arousal, negative-valence music resulted in the highest recognition accuracy, while high-arousal, positive-valence music resulted in the lowest. In terms of recall performance, only an effect of arousal was observed (with low-arousal music having the highest correct recall). The same authors also investigated the effects of listening to the same music during both encoding and testing (i.e., using music as a context to potentially enhance memory), however no effect was observed [70]. These works inform the design of the current study, which similarly investigates memory for words that are simultaneously presented with music.

However, the experimental paradigm developed here and described in the following chapters disguises and transforms a word memorization task into a cognitive memory task, by asking participants to craft and memorize fictitious autobiographical memories out of emotional word sets. Autobiographical episodic memories have been found to be another possible mechanism of musically induced emotion, with the music specifically inducing the emotions of the original memory itself as we relive this past event [21, 4]. Music-Evoked Autobiographical Memories (MEAMs) have been observed and studied in both naturalistic [3] and lab [71] environments, are vivid [72] and often retrieved involuntarily [73, 3], and are accompanied by various (mostly positive) emotions [3, 71]. It is not the goal of the present study to evoke participants' existing autobiographical memories using music, but rather to attempt to influence how participants encode and recall the fictitious stimulus episodes we provide using music. We are interested in the interactions between autobiographical episodic memory and emotional musical contexts, and how emotions associated with these memories may be transformed. The exact memory processes which we are targeting in this study are defined in the following section.

2.4 Memory Reconsolidation and Episodic Memory

Memory consolidation refers to the process that follows the encoding of new information, in which the new, active memory (short-term memory) enters a more inactive, stable state (long-term memory). Memory reconsolidation describes reactivation (re-expressing the pattern of neural activity representative of the memory) of a previously consolidated memory, usually by some cue or reminder trigger. This brings the memory back into a labile (active/sensitive) state, during which it may change subject to new information, before returning (potentially modified) back to its stable (consolidated) state [11, 74]. In other words, the reconsolidation mechanism allows for a previous memory to be modulated or updated. This dynamic memory process has been demonstrated in a number of human-subject studies for various types of memory (e.g., declarative memory [75], episodic memory [12], fear memory/conditioning [76], procedural memory [77]). Most human studies of reconsolidation use behavioral paradigms, some of which are discussed in the following chapter.

The present study focuses on reconsolidation of episodic memories (see [78] for a review). Episodic memory uniquely captures our past experiences, critically consisting of three components—the content, or "what," and the context, both "where" and "when"—and furthermore allows us to consciously re-experience these moments [79, 80]. Given evidence that music is able to provide some sort of context and subsequent reminder trigger for autobiographical (episodic) memories (discussed in Section 2.3), we wish to further explore if this auditory context is comparable to spatiotemporal contexts in its ability to reactivate and return the memory to a labile state (i.e. trigger the reconsolidation process). That is, can we use music to modulate episodic memories? Moreover, we uniquely investigate the roles of affect (Section 2.1) and preference (Section 2.2) in these memory processes.

CHAPTER 3

RESEARCH THEORY AND HYPOTHESES

3.1 Related Experimental Paradigms

This study supplements what are very few existing episodic memory reconsolidation studies involving music. Before introducing our experimental methods, I review paradigms from critical related works which were inspirations for our design.

In Hupbach et al.'s (2007) behavioral reconsolidation study, researchers employed a between-subjects, three-day object learning paradigm to demonstrate integration of new information into previously consolidated episodic memories via reactivation-induced reconsolidation ("updating" of a previous experience through memory reconsolidation). A summary of this paradigm is as follows: on Day 1, every participant was shown a series of items which they were asked to memorize. On Day 2, participants were randomly assigned to one of three groups. The "reminder" group were first taken to the same room, by the same experimenter from Day 1, and were encouraged to describe the prior activity (without recalling specific items). The "no-reminder" group were taken to a new room, by a new experimenter, without any reference made to the prior activity. The control group omitted the Day 2 task entirely. Participants in the first two groups were then shown a new series of items, which they were asked to memorize. On Day 3, the experimenter from the first day administered a free recall memory test to all participants. Participants listed as many items as they could remember from Day 1 only. Researchers found that participants from the "reminder" group mistakenly included significantly more items from Day 2 in their recall of Day 1, compared to the "no-reminder" group. These observed "intrusions" (falsely recalled items from Day 2) demonstrate that the reminder reactivated memory of Day 1, bringing it to a labile state where it could be modified. Furthermore, subsequent experiments showed that this effect is not immediate and the reconsolidation process is time-dependent—a delay of approximately 48 hours between Days 2 and 3 was used in this experiment [12].

The same researchers have since used this paradigm in a number of follow up studies on the reconsolidation process, showing the importance of same spatial context for new information to be integrated into old memories [81], and concluding that this effect could not be simply explained by source discrimination errors [82]. They additionally investigated effects of familiar spatial environments, finding that in highly familiar contexts being in the same space was not a sufficient reminder to reactivate the existing memory and that additional prompting was needed [83]. This prior work is crucial in the development of the current study because it both establishes a precedent for behavioral episodic memory reconsolidation paradigms and identifies some critical elements of the reconsolidation process (reminder cue, time dependency, spatial context, etc.).

Forcato et al. (2007) employed a different multi-day experimental design to study reconsolidation of declarative memory. In this paired-associate learning paradigm, participants also trained on two different lists over the course of 2-3 days (depending on the experimental condition) with behavioral memory errors measured during testing on the last day. Notably, this study used background music in conjunction with visual media to define the specific context in which memorization took place. This multimedia context was sufficient to trigger declarative memory reconsolidation, observed as new memories (formed closely after the reminder trigger) "intruding" on old memories priorly formed under that context [75].

Most recently, Tay (2018) modified the aforementioned object learning paradigm to explore if music alone could form a strong enough context and reminder cue for episodic memories [84]. In this study, five different groups of participants completed the object learning task (modified to images) under different musical conditions. Group 1 ("reminder" group) completed both Day 1 and Day 2 of the study in the presence of the same piece of classical music. Prior to beginning Day 2, they also heard part of the music again and were asked to describe the prior day's activity. Group 2 also completed both Day 1 and Day 2 of the study while listening to classical music, however Day 2 used a different piece of classical music. Group 3 completed Day 1 of the study with classical music and Day 2 of the study with a piece of jazz music. Group 4 only heard music during Day 1 of the study; classical music was used for Day 1. Group 5 completed both days of the study with no music at all. Only Group 1 received the additional verbal reminder, and for all groups participants went to a different room on Day 2 with the same experimenter from Day 1. Additionally, the object learning procedure differed between Days 1 and 2 for all groups, so that the task itself would not serve as a reminder (as in [12]).

Tay found no significant differences between the five groups in terms of the number of intrusions or recall of Day 1 items, concluding that re-exposure to the same piece of music (and maybe other parameters of the current study) was not sufficient to trigger the reconsolidation process, and suggesting this mechanism is perhaps not as reliable as previously thought [84]. However, from a music perception and cognition perspective, there are some elements of this study and experimental design that we believe must be further explored. For example, to our knowledge individual differences in participant musical preference were not accounted for. Moreover, all musical stimuli were researcher selected and appeared arbitrarily chosen; no analysis of piece familiarity, perceived/induced emotion, acoustic features, etc. is provided. Prior literature has shown that preference and enjoyment of music has implications for our physiological and emotional responses, as well as cognitive processes (reviewed in Chapter 2). Therefore, it is possible that interactions between individual differences in music preference, familiarity, other perceptual variables, and memory confounded the results. These could be explanations for why music appeared to be an insufficient context/reminder cue in this study.

These prior works provide a critical foundation for the current study. Together they establish precedent for a multi-day behavioral reconsolidation study. Promising results from Forcato et al. (2007) demonstrate substituting synthesized auditory and visual stimuli for the traditionally studied spatiotemporal context and provide additional evidence supporting the premise of this study [75]. Tay (2018) is the first study we have found to attempt to isolate music and study its role as a contextual memory cue within the reconsolidation process [84]. Their adaptation of the object learning paradigm greatly informs our methodology. It is also important to note that although the referenced works have all implemented between-subjects experimental groups (e.g., “reminder,” “no reminder”), we design our study to be within-subjects (see Section 1.2) and implement analogous experimental conditions (e.g., “control,” “reconsolidation”). These are further described in Section 4.4.2 below.

3.2 Research Hypotheses

From the results of the prior related works discussed previously in Chapter 2 and the mentioned research theories and paradigms (Section 3.1), we pose the following hypotheses regarding music’s ability to serve as a memory context, and properties of the music that may influence how “powerful” of a contextual trace it can be. “Powerful” here is used to describe the context’s ability to 1) be associated with specific events, 2) cue memory retrieval, and 3) promote memory integration and reactivation-induced reconsolidation.

Section 2.3 presents music’s known links to autobiographical episodic memories, which have been studied in both naturalistic and lab settings. If we are able to form connections between music and our own personal experiences, then music should act as a context and cue for fictitious autobiographical episodic memories. If this is the case, we predict to see significant recall of episodes that have been paired with music, as well as hindered recall of episodes which were reactivated and underwent the reconsolidation process (H1).

The arousal-and-mood hypothesis (Section 2.3) postulates that internal emotional state is what ultimately influences cognition. Section 2.1 presents an overview of evidence supporting that music is capable of modulating our felt emotions through mechanisms such as contagion. Furthermore, the CAM-WN (discussed in Section 2.3) proposes that mood congruency between two different stimuli promotes unified encoding of the two stimuli in memory, whereas mood incongruent pairs are encoded separately and inconsistently. If our musical contexts are able to induce the targeted emotional effects in listeners, then we should see measurable differences in memory performance according to music-episode stimulus congruence (H2).

Preferred music has also been found in some studies to improve memory recall (Section 2.3). Section 2.2 links individual differences such as preference, empathy, and familiarity to musically induced emotion. Given evidence for these theoretical models of how preference and empathy modulate felt emotion, we predict that listener individual differences will be additional modulators of context power, with greater recall exhibited for episodes paired with preferred or personally relevant music contexts (H3).

This study attempts to substitute music for the traditionally studied spatiotemporal contexts of episodic memory (Sections 2.4 and 3.1). Like physical contexts, music also has unique (auditory) features (melody, rhythmic patterns, instrumentation, etc.) that distinguish one piece from another. To this end, we predict that these unique elements will be what participants use to contextualize the given episodes, as opposed to the more general emotional context (H4).

Our four main hypotheses are summarized below:

H1. Music will be able to act as a memory context and cue significant recall of paired episodic memories. Subsequently, an implicit musical reminder should be able to reactivate a previously paired episode and trigger the reconsolidation process. We predict that memory for these original episodes will be measurably altered compared to episodes which do not undergo this process.

H2. Feelings induced by the music and how well these are perceived to “fit” with the episode content (mood congruence) will affect the power of the music context. We predict that emotionally congruent musical contexts will be more powerful than emotionally incongruent contexts.

H3. How powerful the musical context is will be additionally modulated by participants' preference for and felt connection to the musical context. We predict that musical contexts which participants prefer and feel connected to will be more powerful than those which they do not prefer/feel connected to.

H4. The more general emotional context offered by music will not be powerful as the specific context offered by the musical structure, or auditory elements of a given piece.

CHAPTER 4
EXPERIMENTAL METHODS

Below, I detail our methodology for a behavioral, human-subjects experiment with a cognitive memory task targeting the reconsolidation mechanism. The task we developed consists of a three-day story-making paradigm, drawing from previous memory reconsolidation studies (Chapter 3) as well as research on autobiographical episodic memories evoked by music in our everyday lives (Chapter 2). In summary, participants memorize fictional autobiographical episodes that they create using emotion-laden words paired with music. We use a distributed selection of emotional film music (Section 4.1) and emotional words (Section 4.2). Some pairings are designed to be emotionally congruent, while others are designed to be incongruent (Figure 4.6).

On Day 1, participants create and memorize 24 episode-music context pairings. On Day 2, participants listen to a subset of the music contexts from Day 1 while creating and memorizing new episodes. On Day 3, we test participants' memory for the Day 1 episodes only, acquiring established behavioral measures for memory strength and degree to which memory reconsolidation occurred (Chapter 3). This procedure is detailed in Section 4.4; an overview is represented graphically in Figure 4.1 below.

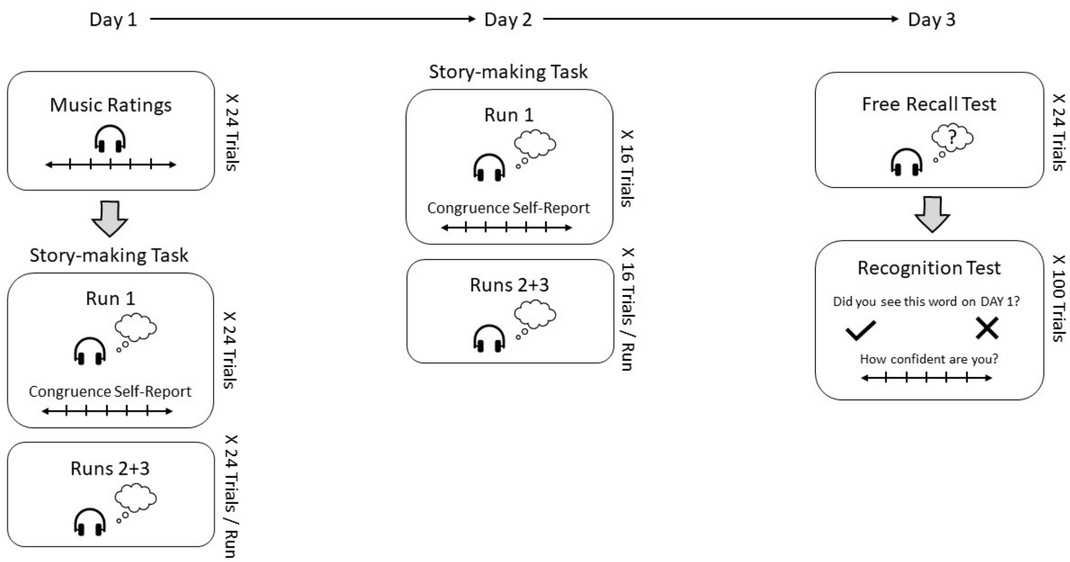


Figure 4.1: Progression of the study over three consecutive days (total duration is approximately four hours).

4.1 Musical Stimuli

Since this study involves musically induced emotion, it is critical that all possible mechanisms underlying emotional response to music are accounted for. Specifically, we are interested in isolating emotion induction through contagion (the mechanism implicated in the arousal-and-mood hypothesis) and then analyzing how these emotions become associated and interact with the paired episodic memories during the experiment. Therefore, it is essential for the musical stimuli to be instrumental, researcher-selected, and unfamiliar to the participants, as any preexisting associated memories/contexts, lyrics, or conditioning could become confounding elements. Additionally, using a highly familiar context may not cause the memory updating effects if the reminder is solely presenting the context itself [83].

To create emotional congruency conditions with the word stimuli (Section 4.2), we use positive and negative valence music. The publicly-available database of Previously-Used Musical Stimuli (PUMS) [85] serves as the starting point for finding appropriate musical stimuli. Listed stimuli are filtered to include those previously used in emotion induction studies and those that have been pilot tested to ensure they elicit the intended emotion. Additionally, it is critical that the stimuli be instrumental only (no lyrics), as mentioned above, and ideally at least 15 seconds long so that they can be looped effectively. We also consider the subject population of the original study, and if the stimuli were found to be mainly unfamiliar to those participants, as unfamiliarity is also a criterion of our study.

Several studies in the PUMS database meet these criteria. These consist of stimuli from a variety of genres, including Western Classical, Jazz, modern Pop, and movie soundtracks. In an effort to increase ecological validity and reduce biases of only using Western music, we select excerpts from movie soundtracks from the publicly available "Film Soundtracks" dataset [86]. Fitting our criteria, this dataset was created to provide a large, unfamiliar, validated, and naturalistic collection of musical stimuli for the study of perceived [86] and induced [50] emotions, similar to existing widely used datasets for the visual domain.

Movie soundtracks appear to be the optimal choice in terms of the style of musical stimuli for this study for several reasons. First, music in film has been substantially researched with regards to both musically induced emotion and memory (Section 2.3). Soundtracks are intentionally composed to contain strong emotional cues and provide a musical backdrop to a story [64, 86]—in contrast to other styles where this is not the primary "function" of the music. This is particularly fitting for our study on episodic memory, as we ask participants to memorize stories ("episodes") while actively listening to the musical stimulus. The unfamiliar movie soundtrack excerpt can be thought of as the soundtrack to the participant's given episode, providing an emotional backdrop. Additionally, movie soundtracks tend to have a less rigid genre definition or set instrumentation, which suggests they may be more neutral in terms of people's genre-level musical preferences [86]. This is also desirable for the current study, as we want to reduce genre biases in our results.

Our experimental design requires 12 positive and 12 negative valence musical stimuli (for a total of 24 pieces). These are selected from Set 2 of the "Film Soundtracks" dataset and from Vuoskoski, Thompson, McIlwain, and Eerola (2012), an induced emotion study that used longer, (approximately) one-minute excerpts of pieces from Set 2 of the "Film Soundtracks" dataset [50]. All stimuli were validated by the original researchers, with affective ratings on a scale from 1-9 provided for five discrete emotions as well as valence, energy, and tension (following the three-dimensional emotion model by Schimmack and Grob [35]).

From the dataset, we carefully choose the subset of 24 pieces such that each is as musically (in terms of style, instrumentation, etc.) distinct as possible from the others. In this study of episodic memory involving multiple within-subjects conditions, it is critical that each "memory" context (music) is unique and that there is minimal risk of contexts being indistinguishable. Distinctness of the selected musical stimuli was additionally validated through a pilot study. We also take care to maintain a valence, energy, and tension balance across all stimuli (Table 4.1), as well as choose stimuli with more extreme and definitive emotion ratings (avoiding stimuli that appear to convey mixed emotions). All excerpts are normalized in terms of loudness and are of equal duration (either truncated or looped to 41 seconds) with a 1-second fade out. This is done using the audio editing software Audacity version 2.1.3 [87]. All stimuli from the "Film Soundtracks" dataset are acquired online from the Open Science Framework (osf.io/p6vkg). Track names, affective ratings, and other meta data for the musical stimuli are provided in Appendix A.

Table 4.1: Mean and standard deviation for valence, energy, and tension ratings of our selected 24 musical stimuli from the "Film Soundtracks" dataset. Ratings are part of the data collected by the original researchers.

Target emotion	Number of stimuli	Mean valence (SD)	Mean energy (SD)	Mean tension (SD)
Anger/Fear	6	2.39 (0.17)	6.66 (1.20)	8.21 (0.26)
Happiness	6	7.39 (0.66)	7.32 (1.17)	4.67 (0.62)
Tenderness	6	6.62 (0.54)	4.20 (0.48)	3.58 (0.97)
Sadness	6	4.76 (0.57)	3.63 (0.87)	5.02 (1.3)

4.2 Word Stimuli

The original proposed methods for this study involved using both words from the Affective Norms for English Words (ANEW) [88] and images from the International Affective Picture System (IAPS) [89] to create the item sets that would be shown to participants. However, upon review of the images in the IAPS database we decided that they would not be suitable for use in this study; we were concerned that the negative valence images were overall more graphic than the positive valence images, which might skew participants' memory/attention. The item sets therefore consist only of words from ANEW, which is a substantial dataset of English word stimuli with ratings of valence, arousal, and dominance on scales from 1-9.

The experimental design requires 24 sets of negative valence words and 16 sets of positive valence words, with a set consisting of seven words. The number of sets/trials as well as the number of words per set were piloted to ensure reasonable difficulty for the task, and also align with prior literature on short term and working memory [90, 91], and prior use of the ANEW dataset in neuroimaging studies [63, 92, 93]. All of the words are unique and semantically distinct. This is in attempt to avoid memory illusions where participants falsely recall related words that were not included in any set [94], as well as retroactive interference that might occur from shared or repeated words between sets [95]. All sets consist of a mixture of nouns, verbs, and adjectives, to facilitate forming a cohesive "episode" using all seven words in just a couple sentences. We also attempt to balance all sets in terms of arousal (mean, 5.44; SD, 0.97) and dominance (mean, 4.69; SD, 1.15). Negative word sets have a mean valence rating of 2.71 (SD, 0.57) and positive word sets have a mean valence rating of 7.29 (SD, 0.61). All word sets with affective ratings are listed in Appendix B.

4.3 Participants

Participants for this study are N = 26 Georgia Tech undergraduate students recruited through the School of Psychology subject pool (Sona System). Eligible participants must be between 18-40 years old and have normal or corrected-to-normal hearing and vision. Additionally, because English words are used as stimuli in this study, all participants must be native English speakers. Participants are informed the study will take up to four hours over the course of three consecutive days and are compensated with four course credits for their participation. Before participating, all volunteers sign an informed consent form per the Georgia Tech Institutional Review Board.

4.4 Procedures

This study takes place over any three consecutive days, to ensure memories of the day's task are consolidated during overnight sleep [96]. Multiple versions of instructions and task flow were piloted prior to the start of the study, testing for clarity, engagement, and ease-of-use. All tasks are coded using PsychoPy version 2021.1.4 [97]. The study is conducted at the Georgia Tech School of Psychology (J.S. Coon Building) in a multi-room lab space. Participants are provided with a desktop computer, QWERTY keyboard, mouse, and Sony MDR 7506 over-ear headphones.

4.4.1 Story-making Task

To explore emotional episodic memory and reconsolidation in the context of music as mentioned in previous chapters, we devise the following core task to mimic the naturalistic, autobiographical episodic memories evoked by music in our everyday lives.

Participants are presented with a "cover story," designed to personalize and engage them in the upcoming task (full version and written instructions can be found in Appendix C):

> "You have just discovered that you are the main character of a novel. Events in your life are being written and communicated to you by some unknown 'author;' you are living out the plot as the author narrates it. With each new event, you will hear its 'soundtrack:' a piece of music that reflects the emotions of the event you are about to 'experience.' [...] You will also see 7 words on the screen. These words are all part of the description of the event written by your author."

Each musical stimulus is presented alongside one of the word sets. The pairing of word sets to musical stimuli is pseudorandomized; participants receive one of three possible versions of word sets randomly paired with musical stimuli. This is due to limitations in working with the software and coding the experiment. Words are presented in randomized locations on the screen (Figure 4.2). Participants have the entire duration of the musical stimulus (41 seconds) to "reconstruct the description of the upcoming event" in 1-3 sentences using as many of the shown words as possible. During the verbal overview of this task, the experimenter encourages the participant to try their best to use all seven of the words in their description, or to try and squeeze as many words in as possible. This is to ensure everyone is at least attempting to complete the task at the same level of difficulty. Our aim is to have the event/description act as a fictional autobiographical memory that we have paired with a specific musical stimulus.

To this end, participants are instructed that their descriptions must be in the first person and that they should avoid using words that are not shown on the screen, unless needed for sentence structure. Participants are not able to write down or record each description in any way, because we wanted to design the task to be fMRI friendly. Instead, participants are instructed to click on each word they use as they mentally form their descriptions (selected words turn green, as in Figure 4.2). Furthermore, after each trial participants report how well they believe the event matched the music on a scale from 1-5 ("not at all" to "perfectly").

Figure 4.2: Example of one word set that is shown to participants alongside one of the musical stimuli. Words are presented in randomized locations on the screen. Participants have 41 seconds to mentally synthesize a description of an event using the shown words, clicking on each word as it is incorporated.

Participants view each trial/event a total of three times, with different goals for each repetition. Once participants go through all of the trials/events for the first time, *creating* their descriptions, they are given the opportunity to take a short, two-minute break before continuing. Next, they are informed that they will see the same events repeated again (word sets paired with music), and that this time around they are to recall the descriptions they have already made (clicking on the words as they go along) and focus on *memorizing* them and further familiarizing themselves with the music. At the end of this second repetition, participants are able to take another short break. They are then informed that they will see the same events repeated one more time, and that with each trial they should again recall the descriptions they have already made (while clicking on the words used). However, this time their goal is to focus on the cover story, *imagining* that these events are actually happening to them, and to focus on connecting the event to the musical context. Piloting this task revealed that breaking the instructions up progressively into three stages (create, memorize, imagine) was the least overwhelming and most engaging for participants.

4.4.2 Day-by-Day

4.4.2.1 Day 1

When participants arrive on the first day, they are provided the consent form to review and sign, as well as forms collecting demographic information. They are then introduced to the study, given the opportunity to use the restroom, and informed that there would be opportunities for breaks throughout the study. Participants are encouraged to leave cell phones and belongings in a separate room away from their desk in the experiment space, so as to minimize distractions during the task. They are then given a verbal overview of the instructions for the first part of the task: providing induced emotion, familiarity, and preference ratings for each of the 24 musical stimuli. At this time, the experimenter ensures the participant understands the definitions of induced emotion, familiarity, preference, and depth of connection. Participants are then shown to their desk, where the same instructions are presented again on the screen, and they are given the chance to practice reporting their ratings with a test piece of music. Instruction text for this affective ratings portion of the task can be found in Appendix C.

Participants provide their ratings for each of the 24 musical stimuli one at a time, presented in a random order. Before each piece is presented, a seven-second break screen prompts them to "Relax, and pay attention to your breathing," and "Return to a neutral emotional state." This is to help participants "reset" and rate each piece of music independently of what they heard before. Participants must then press a key to proceed. The full musical stimulus (41 seconds) is presented along with a blank screen with a fixation cross at the center. At the end of the excerpt participants are presented with two sliders (nine-point scale), one for valence (ranging from "unpleasant" to "pleasant") and one for arousal (ranging from "calming" to "arousing") [29] and are asked to report their felt emotion (Figure 4.3).

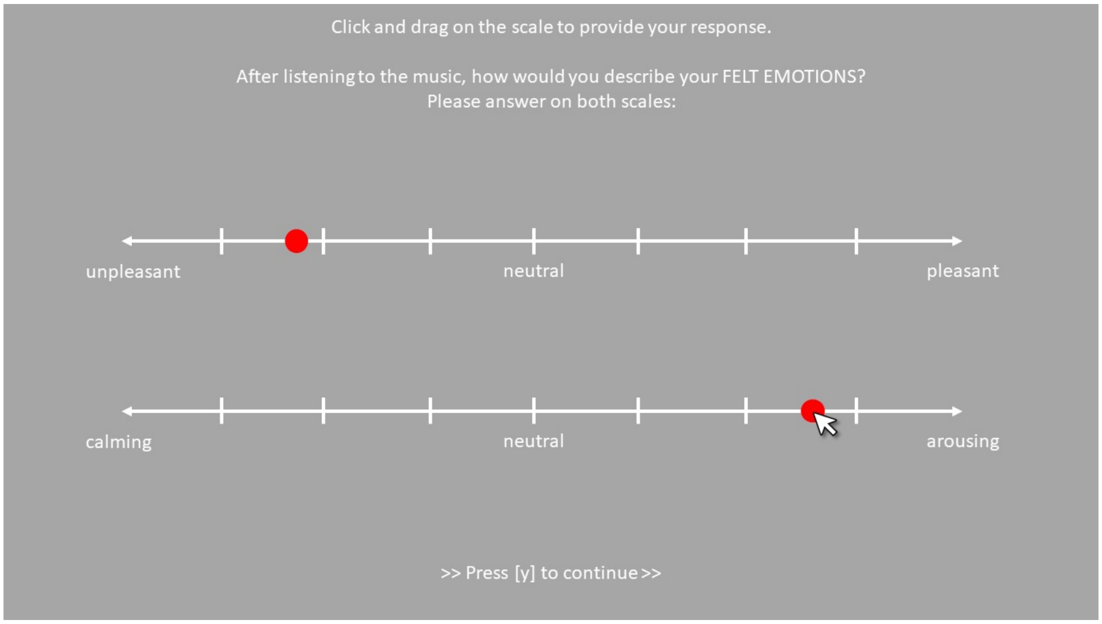


Figure 4.3: After listening to each song, participants report their felt arousal and valence levels on two nine-point scales.

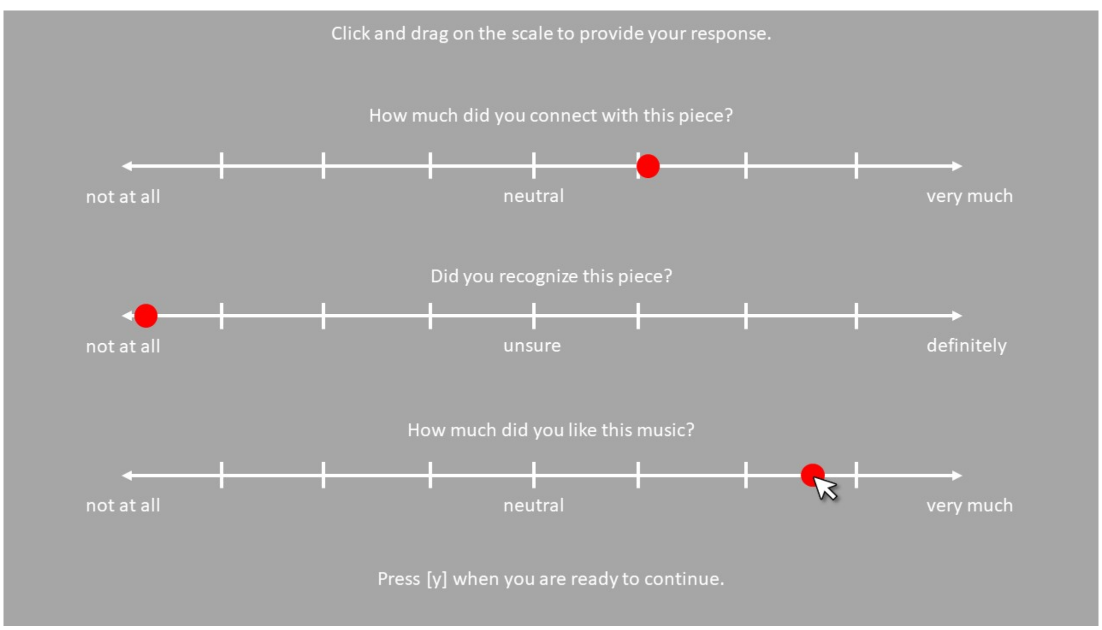


Figure 4.4: After rating their levels of felt emotion, participants additionally answer three more questions regarding their individual responses to each piece.

We elected to have participants provide affective ratings for the music according to Russell's circumplex model [29], even though ratings in the dataset are originally provided in terms of the Schimmack and Grob valence-energy-tension model [35]. This was done so that we may more easily relate the music affective ratings to the word affective ratings in the ANEW dataset (rated using a nine-point valence-arousal-dominance model). All rating questions in this study maintain the nine-point scale also used in the "Film Soundtracks" and ANEW datasets for continuity.

On the next page participants are presented with three additional sliders (nine-point scale) and are asked to report their prior familiarity with the music ("Did you recognize this piece?" with possible responses ranging from "not at all" to "definitely"), their enjoyment of the music ("How much did you like this music? With possible responses ranging from "not at all" to "very much"), and their depth of connection with the piece ("How much did you connect with this piece?" with possible responses ranging from "not at all" to "very much") (Figure 4.4). Depth of connection was defined to participants as "the extent to which you are able to feel or take part in the emotions of the music; the degree to which you feel that this music resonates with you." These prompts were inspired by Egermann and McAdams (2013), as we wished to ask both a vague preference question as well as a more specific preference question that incorporated elements of empathic response [9]. Two seconds after the sliders are presented, the same musical excerpt begins playing again, offering a reminder or extra time to listen as participants provide their ratings (they do not need to listen to the entire stimulus again, nor did any participant choose to do so). Participants are free to proceed through these trials at their own pace.

Once participants have rated and familiarized themselves with all 24 pieces of music (the musical "contexts" for their upcoming episodes), they are given a chance to take a short one-to-two-minute break and are then presented with the instructions for the story-making task (reviewed in Section 4.4.1 above). After reading the first set of instructions, participants are able to practice creating a short description out of presented words in a similar format to the upcoming task (Figure 4.5). At this point, the experimenter would check in with the participant, ensure they understand the task, and ask to hear the practice description they just made. Participants then get feedback on their description before beginning the story-making task for all 24 pieces of music they just listened to.

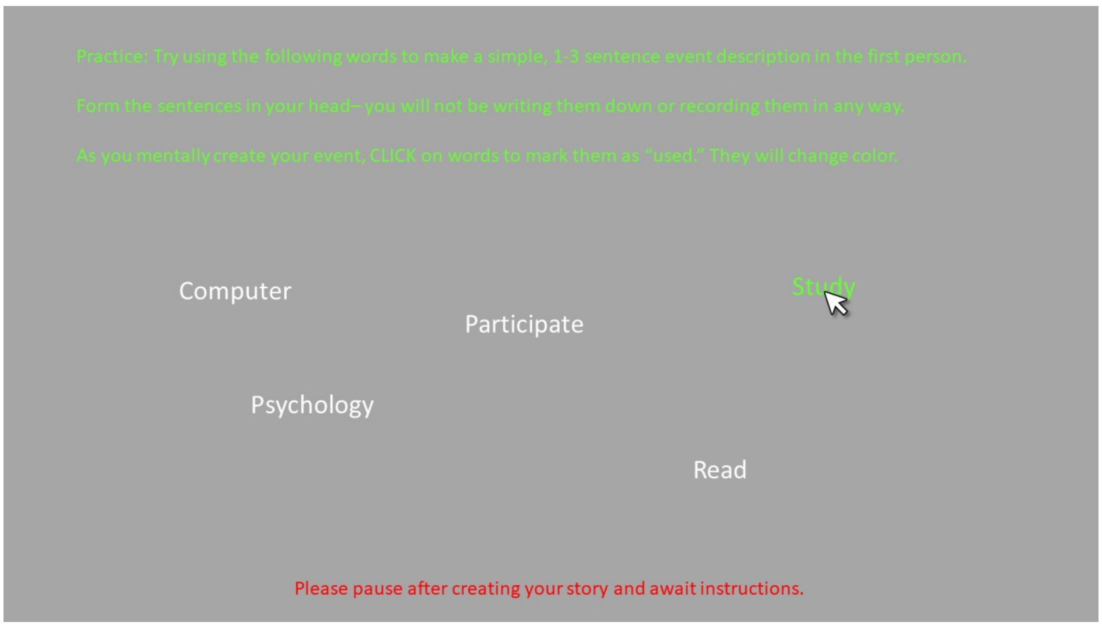


Figure 4.5: Before beginning the story-making task, participants have an opportunity to practice making these fictional autobiographical episodes on a small set of five words (no music). When they are finished, they recite the description to the researcher so that their understanding of the task can be evaluated. The researcher provides verbal feedback before allowing participants to move on to the real story-making task.

4.4.2.2 Day 2

When participants arrive on the second day, they are given a short supplemental demographics form to complete (sleep information, and how much they had thought about the task while they were away). They are then reintroduced to the study, given the opportunity to use the restroom, and informed that there would be opportunities for breaks throughout. Participants are encouraged to leave cell phones and belongings in a separate room away from their desk in the experiment space, so as to minimize distractions during the task. They are then given a verbal overview of the task and informed that it would be a similar activity to what they completed yesterday. Participants are then shown to their desk (same as Day 1), where they are presented with the story-making task (Section 4.4.1) in a similar manner as on Day 1.

No practice session takes place this time, as participants are now sufficiently familiar with the structure of the task from the previous day. All words used for the story-making task today are new (Figure 4.6, right). Additionally, the story-making task is only completed for 16 out of the 24 pieces of music from Day 1; two music excerpts from each quadrant of the circumplex model are randomly excluded from this task. Together, these eight pieces serve as control trials (Figure 4.6, bottom). Their stories from Day 1 will still be assessed on Day 3 to determine memory performance when no additional Day 2 content is presented over these contexts.

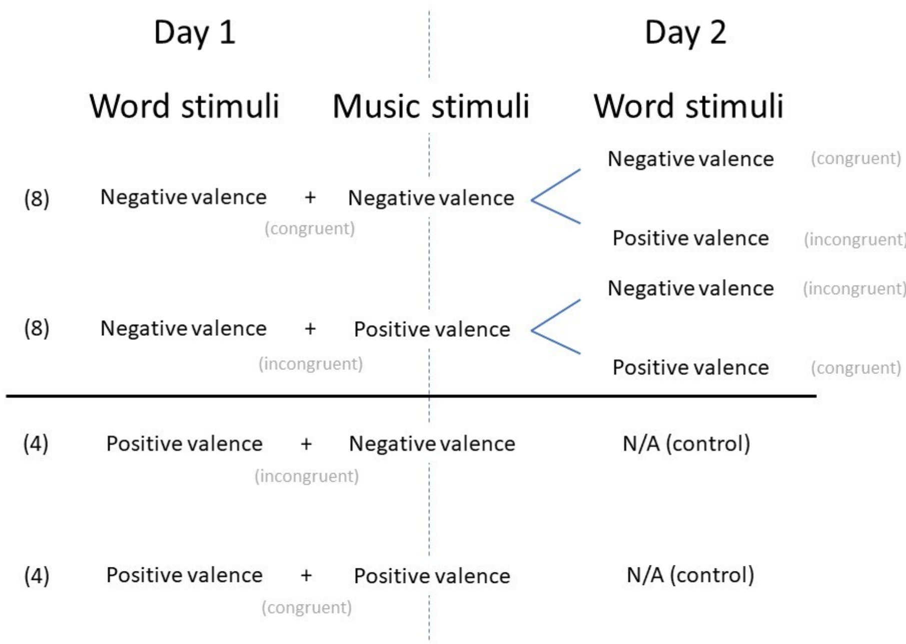


Figure 4.6: Within-subjects experimental conditions created between Days 1 and 2 of the study. Musical stimuli are shared between the two days, with new word sets being presented on Day 2. Eight pieces of music are not repeated on the second day; these serve as "control" trials, as the original Day 1 memory is not being disturbed on Day 2. Within the remaining 16 trials, four emotional congruency conditions are created.

4.4.2.3 Day 3

When participants arrive on the third and final day, they are given a short supplemental demographics form to complete (sleep information, and how much they had thought about the task while they were away). They are then reintroduced to the study and given the opportunity to use the restroom before beginning the day's activity. Participants are encouraged to leave cell phones and belongings in a separate room away from their desk in the experiment space, so as to minimize distractions during the task. They are then given a verbal overview of the task and informed that today will consist of two types of memory test for the music and words shown to them on Day 1 only. At this time, the experimenter ensures the participant understands the format for completing the memory tests, and that they are to answer all questions with regards to Day 1 words only. Participants are then shown to their desk (same as Days 1 and 2), where the same instructions are presented again on the screen. Instruction text for Day 3 tasks can be found in Appendix C.

The first memory test consists of a free-recall task [12]. One by one, in random order, participants hear one of the 24 musical contexts presented to them on the previous days. They are reminded to "Recall your description from DAY 1 and type the INDIVIDUAL WORDS FROM THE SET you were shown in context of this piece of music." Participants have an additional 20 seconds (for a total of about 1 minute) after the end of the 41-second musical stimulus to continue to recall and type words belonging to this context on Day 1. In the case that a participant believes they have typed out all seven words correctly before time is up, they may press the "submit" button on the screen to proceed to the next trial (otherwise, responses are automatically submitted when time is up). However, participants are told verbally by the experimenter to not use the "submit" button to prematurely skip a trial where they feel as though they cannot recall any words; they are encouraged to at least allow the full musical excerpt to play before giving up on a trial. Between each trial there is a three-second (minimum) rest period—participants must press a key to proceed to the next trial.

The second memory test is a recognition task [82], consisting of both "used" (seen on either Day 1 or Day 2) and "unused" (novel) words from the ANEW dataset. The 280 total words shown between Days 1 and 2 are pooled together, out of which 80 are randomly chosen for the recognition task. Additionally, we create a pool of 40 novel words (20 positive valence, 20 negative valence), out of which 20 are randomly chosen for the test. The 100 words (80 "used" and 20 "unused") are presented one at a time, in random order, to the participant, who is asked "Did the above word appear on DAY 1?" After answering, they are furthermore asked to rate how confident they are of the answer they just gave on a scale from 1-5 (from "not sure" to "absolutely sure"). No music is used during the recognition test. Between each trial, there is a three-second (minimum) rest period—participants must press a key to proceed to the next trial.

4.5 Measures of Individual Differences

Upon finishing both memory tests on Day 3 participants complete a questionnaire, consisting of musical background/training, the revised Short Test of Musical Preferences [45], and the Like Sad Music Scale [52]. They additionally complete the Eysenck's Personality Inventory [98], accessed online at GoGovernment.org (results are screen-captured and stored as images on Georgia Tech Dropbox for analysis).

The revised revised Short Test of Musical Preferences (STOMP-R) is a tool providing a way to translate preferences in terms of genre labels (which may be ill-defined or subjective) into other high-level attributes that are genre-free. Participants complete the test by rating their general preference for several different genres of music on a scale from 1 ("Dislike strongly") to 7 ("Like strongly"). In scoring, responses are grouped into five categories and averaged, corresponding to the five high-level attributes. These attributes, or factors, are Mellow, Unpretentious, Sophisticated, Intense, and Contemporary (MUSIC), with each participant receiving a score in each one of these dimensions that altogether describes their musical preferences. The MUSIC five-factor model and STOMP-R have been used and validated extensively in the field. Furthermore, in past work we used the STOMP-R and successfully showed a link between levels of physiological arousal and the Mellow and Intense factors. We will again focus on these factors in this analysis, in an attempt to measure participants' general preference for high or low arousal music. The questions presented to participants are included in Appendix D.

The LSMS is a nine-item questionnaire broadly summarizing listeners' enjoyment or disliking of sad music. Participants rate their level of agreement with nine statements about sad music listening from 1-5. We decide to use the LSMS over the ASM [51] for its succinctness and our interest in general affinity for sad music, as opposed to motives for listening. Whereas our purpose for using the STOMP-R is to measure preference in the arousal dimension, we use the LSMS to measure participants' general preference in the valence direction. This element of musical preference has been studied with regards to empathy [48] as well as autobiographical memories [99, 49], however not the reconsolidation mechanism in particular. The questions presented to participants are included in Appendix E.

CHAPTER 5

RESULTS

As discussed in the prior section, two memory tests are given to participants on Day 3 of the study: a free recall test, and a forced-choice recognition test. These tests are designed to serve as behavioral measures of Day 1 memory strength and memory reconsolidation on Day 2. For the scope of this work, only the free recall data is thoroughly analyzed and discussed here. All processing and analyses are done using Python3. Our four main hypotheses are restated below, for reference:

H1. Music will be able to act as a memory context and cue significant recall of paired episodic memories. Subsequently, an implicit musical reminder should be able to reactivate a previously paired episode and trigger the reconsolidation process. We predict that memory for these original episodes will be measurably altered compared to episodes which do not undergo this process.

H2. Feelings induced by the music and how well these are perceived to "fit" with the episode content (mood congruence) will affect the power of the music context. We predict that emotionally congruent musical contexts will be more powerful than emotionally incongruent contexts.

H3. How powerful the musical context is will be additionally modulated by participants' preference for and felt connection to the musical context. We predict that musical contexts which participants prefer and feel connected to will be more powerful than those which they do not prefer/feel connected to.

H4. The more general emotional context offered by music will not be powerful as the specific context offered by the musical structure, or auditory elements of a given piece.

5.1 Validation of Musical Stimuli

First, we wanted to validate our musical stimuli and confirm that our participants' affective ratings and prior familiarity aligned with our assumptions and information from the "Film Soundtracks" dataset. Familiarity was rated on a nine-point scale, with participants responding to the question "Did you recognize this piece?" with possible responses ranging from "not at all" to "definitely." Songs were found to be mostly unfamiliar (average by song: M = 2.5, SD = 0.45) with only three responses out of 624 where a participant reported that they definitely recognized the song. As this did not significantly impact our results, we did not exclude any trials.

Figure 5.1: Valence and arousal distribution of 24 musical stimuli based on collected (Green) and reference (Purple) ratings. For the purposes of visualization of reference ratings, arousal was plotted as the average of energy and tension. Collected ratings closely agree with reference ratings and maintain the same distributions as prior induced emotion studies with this dataset [50].

Participants also rated levels of felt valence and arousal for each song, also on nine-point scales. The difference between the valence values for each song from the dataset and our participants' reported felt valence was not found to be significant [$t(23) = 0.97$, $p = 0.341$]. For reasons previously discussed in Chapter 4, we could not directly compare participants' reported felt arousal with the values in the dataset. However, analysis of our participants' reported felt arousal ratings revealed two even groups of songs: 12 which were rated as inducing an arousal less than 5 ($M = 3.6$, $SD = 0.7$) and 12 which were rated as inducing an arousal greater than or equal to 5 ($M = 6.5$, $SD = 0.7$), confirming our assumptions. A visual summary of the felt valence and arousal distributions of our 24 musical stimuli are shown in Figure 5.1.

5.2 Preprocessing and Scoring of Recall Data

The raw data output of the free recall test consists of a string of recalled/typed words (undetermined length) for each of 24 trials per participant (one per musical context). These strings are parsed to extract a list of the individual words typed for that trial. Words are then spell-checked and corrected, and any duplicate words entered within a single trial are removed. Words (responses) are finally compared against the cumulative list of word stimuli used in this experiment, by searching for the "root" (and "compound," if applicable) of each stimulus word (see Appendix B) within the word responses.

5.3 Music as a Context for Episodic Memories

We first want to test whether music might act as a context and furthermore serve as a cue for episodic memories. To do this, we extract the first main dependent variable from our preprocessed recall data: number of Day 1 words correctly recalled for each trial. This is split into two conditions for each participant, control trials (8) and reconsolidation trials (16). As discussed in Section 4.4.2, control trials consist of musical contexts that are only presented with an episode/word set on Day 1; these musical stimuli are not presented for the participant again on Day 2, meaning the reconsolidation process is not triggered for these trials. By contrast, reconsolidation trials consist of musical contexts that are also re-presented on Day 2 with a new episode/word set, thus creating an opportunity for reconsolidation of these trials/memories to occur.

We hypothesized that the musical stimuli would in fact be associated as a context for the paired emotional episodes and that furthermore, participants would exhibit greater memory recall of control trials compared to reconsolidation trials. This would suggest that music can serve as a contextual cue, because a hindered ability to recall the original memory may suggest (according to reconsolidation theory) that re-presenting a musical context reactivated and returned the memory to a labile state, where it was affected by the new (Day 2) episode. If the average number of words correctly recalled for both conditions was not statistically different from zero, it would suggest that the music was not effectively encoded and associated as the context to the episodes. Additionally, if there were no significant differences between the control and reconsolidation conditions, that would suggest that the cue provided by the music on Day 2 was not effective in triggering the reconsolidation mechanism.

Trials are averaged within control and reconsolidation conditions for each participant. A graphical comparison is shown in Figure 5.2 below. A one-sample t-Test revealed that the means of both conditions (control: $M = 0.92$, $SD = 0.99$; reconsolidation: $M = 0.21$, $SD = 0.29$) are significantly different from zero [control: $t(25) = 4.6$, $p < 0.001$; reconsolidation: $t(25) = 3.6$, $p = 0.001$]. This suggests that the musical stimuli were in fact able to serve as memory contexts for participant's episodes. Additionally, a paired-sample t-Test showed a statistically significant difference between the average number of words recalled correctly for control trials and reconsolidation trials [$t(25) = 4.1$, $p < 0.001$]. This is consistent with reactivation and reconsolidation of the Day 1 memory occurring on Day 2, through the use of music as the contextual link.

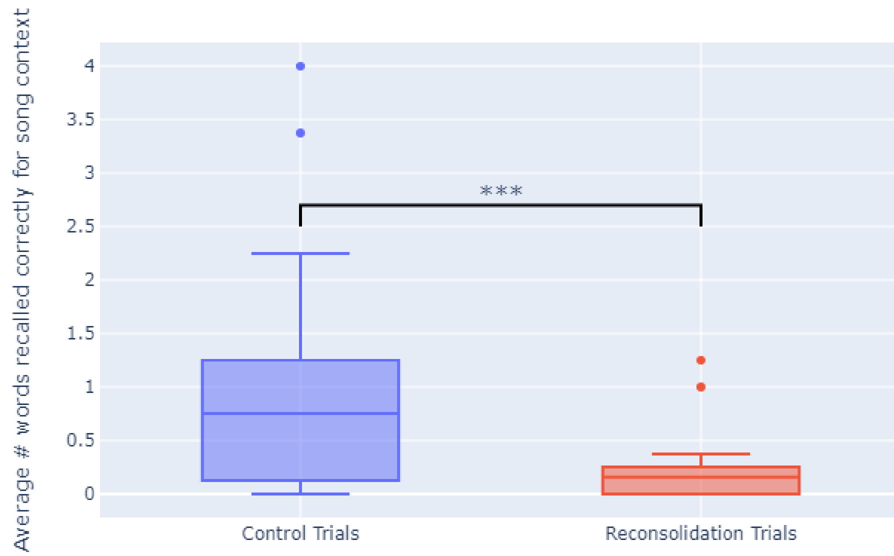


Figure 5.2: Recall performance for trials under control condition versus reconsolidation condition. The data shown is the average number of words recalled correctly within each of the two conditions, for each participant. The means are statistically different [$t(25) = 4.1$, $p < 0.001$]. As hypothesized, retrieval of the original memory was significantly hindered for reconsolidation trials.

5.4 Effects of Congruency on Day 1 Memory Recall

Secondly, we wanted to test affective (in)congruency between the musical contexts and episode content (word stimuli) and determine the effect this might have on Day 1 memory. To do this, we split the two conditions analyzed in the previous section (control and reconsolidation) into the following sub-conditions, as discussed in Chapter 4 and shown in Figure 4.6 above. Out of the 8 control trials per participant on Day 1:

- 4 are negative-valence music with positive-valence words (incongruent)
- 4 are positive-valence music with positive-valence words (congruent)

Out of the 16 reconsolidation trials per participant:

- 4 are negative-valence music with negative-valence words on both Days 1 and 2 (D1-congruent and D2-congruent)
- 4 are positive-valence music with negative valence-words on Day 1, but positive-valence words on Day 2 (D1-incongruent and D2-congruent)
- 4 are negative-valence music with negative-valence words on Day 1, but positive-valence words on Day 2 (D1-congruent and D2-incongruent)
- 4 are positive-valence music with negative-valence words on both Days 1 and 2 (D1-incongruent and D2-incongruent)

We chose to sub-divide the reconsolidation trials in this way to attempt to detangle any possible underlying interactions of the different Day 2 memories and reconsolidation process that were introduced for these trials. We first compare congruency conditions using the same dependent variable as before—number of Day 1 words correctly recalled for each trial.

We hypothesized that participants would show stronger memory recall of emotionally congruent episodes compared to incongruent episodes. This means that participants would have more easily memorized as well as retained memory for trials in which the music context "fit" with the episode content and would point to an influence of affect over episodic memory encoding and consolidation. If there were no significant differences between congruency conditions, this would suggest that the affect of the music neither helped nor hindered creation of the memory in a significant way.

Trials were averaged within the listed conditions for each participant. For the control trials we found that, compared to incongruent episodes ($M = 0.51$, $SD = 0.88$), congruent episodes ($M = 1.33$, $SD = 1.42$) did have significantly greater word recall rates [$t(25) = 3.2$, $p = 0.004$]. This suggests that in situations where there is no disturbance of the original memory, affective congruence provided by the music aided in encoding a stronger Day 1 memory. A graphical comparison is shown in Figure 5.3 below.

To analyze the four reconsolidation conditions, we ran a two-way repeated measures ANOVA to determine if Day 1 and Day 2 music-word congruency had significant effects on Day 1 memory recall, and if there were any interaction effects between congruency on the two days. The ANOVA revealed that only Day 1 congruency had a significant effect on correct Day 1 word recall [F(1,25) = 4.78, p = 0.038]. Surprisingly, this effect is in the opposite direction than we hypothesized (Figure 5.4). For reconsolidation trials we found that Day-1 congruent episodes had lower word recall rates (M = 0.15, SD = 0.25) compared to Day-1 incongruent episodes (M = 0.26, SD = 0.37). Possible explanations will be discussed in Section 6.3.

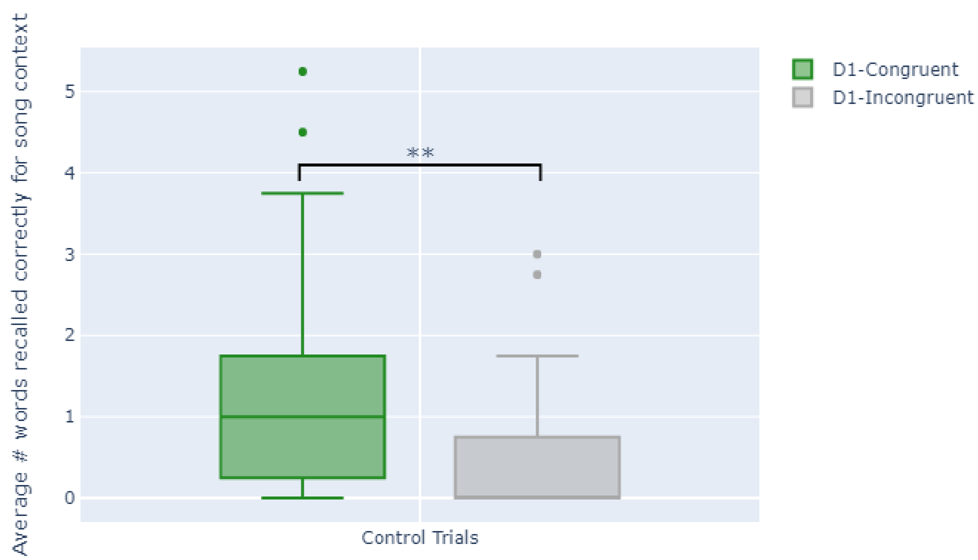


Figure 5.3: Effect of emotional congruency between musical contexts and episode content (words) on Day 1 memory. The data shown is the average number of words recalled correctly within congruent and incongruent control trials, respectively, for each participant. A paired-sample t-Test revealed a statistically significant difference [t(25) = 3.2, p = 0.004], suggesting that when there is no disturbance of the original memory, affective congruence provided by the music aided in encoding a stronger Day 1 memory.

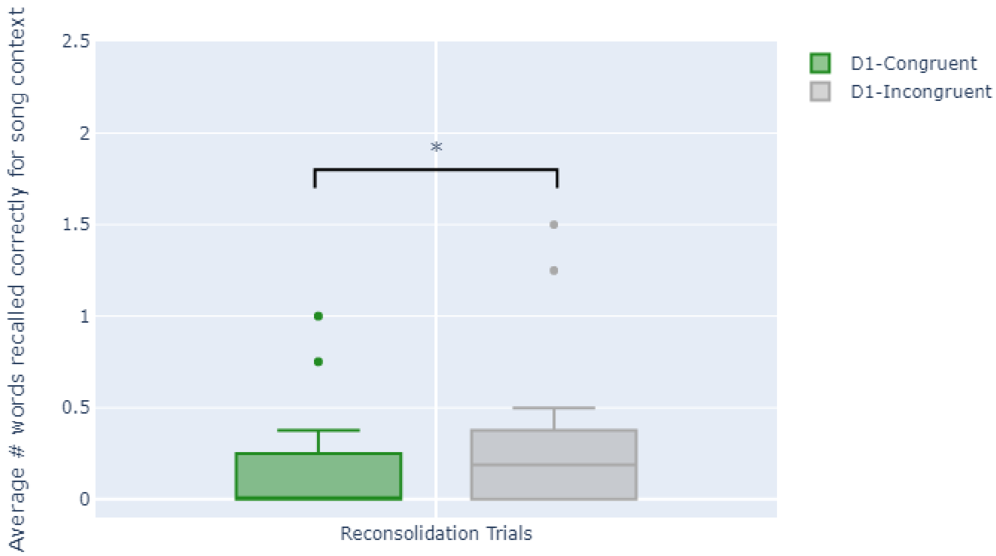


Figure 5.4: Effect of emotional congruency between musical contexts and episode content (words) on Day 1 memory. The data shown is the average number of words recalled correctly within Day-1 congruent and Day-1 incongruent reconsolidation trials, respectively, for each participant. A two-way repeated measures ANOVA revealed only a significant effect of Day 1 congruency on recall. Surprisingly, Day-1 incongruent trials showed higher recall rates than Day-1 congruent trials, which is opposite the relationship demonstrated by the control trials in Figure 5.3.

5.5 Effects of Congruency on Day 2 Intrusions

To additionally evaluate affective (in)congruency between the musical contexts and episode content (word stimuli) on Day 1 memory, we analyze a second dependent variable: number of Day 2 words accidentally recalled for each of the reconsolidation trials. This metric will also be referred to as number of "intrusions," following other memory reconsolidation studies. Number of intrusions has been used in prior works as a behavioral measure of the degree to which memory reconsolidation and new information integration took place (Chapter 3). We analyze this dependent variable and compare the four congruency conditions for the reconsolidation trials discussed above in the previous analysis.

We hypothesized that participants would have a greater number of Day 2 intrusions in their recall of Day 1 episodes for emotionally congruent trials on Day 2, compared to emotionally incongruent trials on Day 2. In other words, if the music context "fit" with the new episode introduced on Day 2, we predicted more of this new information would be integrated into the old memory. This would suggest that affect influences memory reconsolidation and integration of new material. If there were no significant differences between congruency conditions, this would suggest that, while we found evidence of affect influencing the memory encoding/consolidation and reactivation processes in the previous analyses, the affect of the music does not influence memory reconsolidation and integration in a similar way.

Trials were averaged within the listed conditions for each participant. We ran a two-way repeated measures ANOVA to determine if Day 1 and Day 2 music-word congruency had significant effects on the number of Day 2 intrusions (Figure 5.5), and if there were any interaction effects between congruency on the two days. No significant effects were found, suggesting that the affect of the music neither helped nor hindered integration of the new episodes on Day 2.

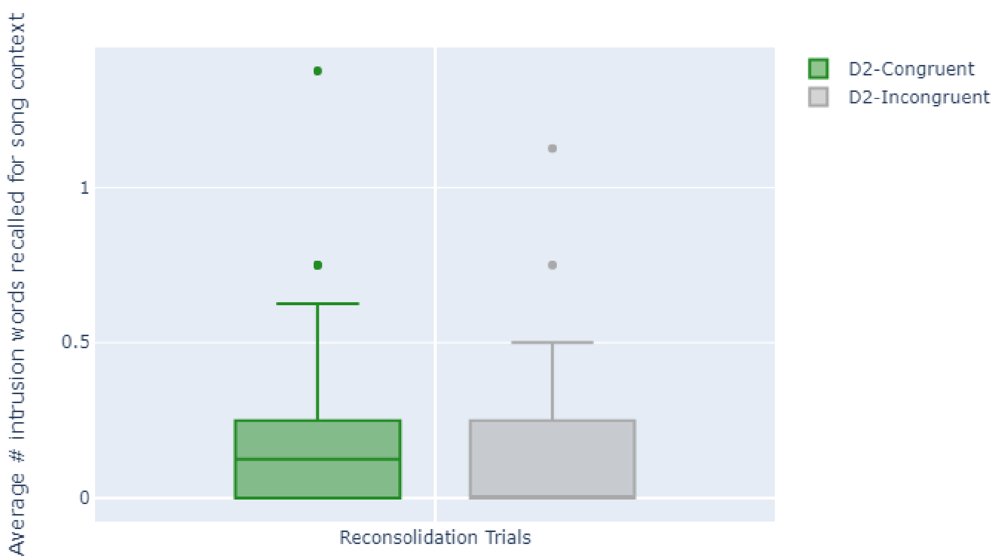


Figure 5.5: Effect of emotional congruency between musical contexts and episode content (words) on number of Day 2 intrusions. The data shown is the average number of intrusion words accidentally recalled within Day-2 congruent and Day-2 incongruent reconsolidation trials, respectively, for each participant. A two-way repeated measures ANOVA found no significant effects or interactions of congruency.

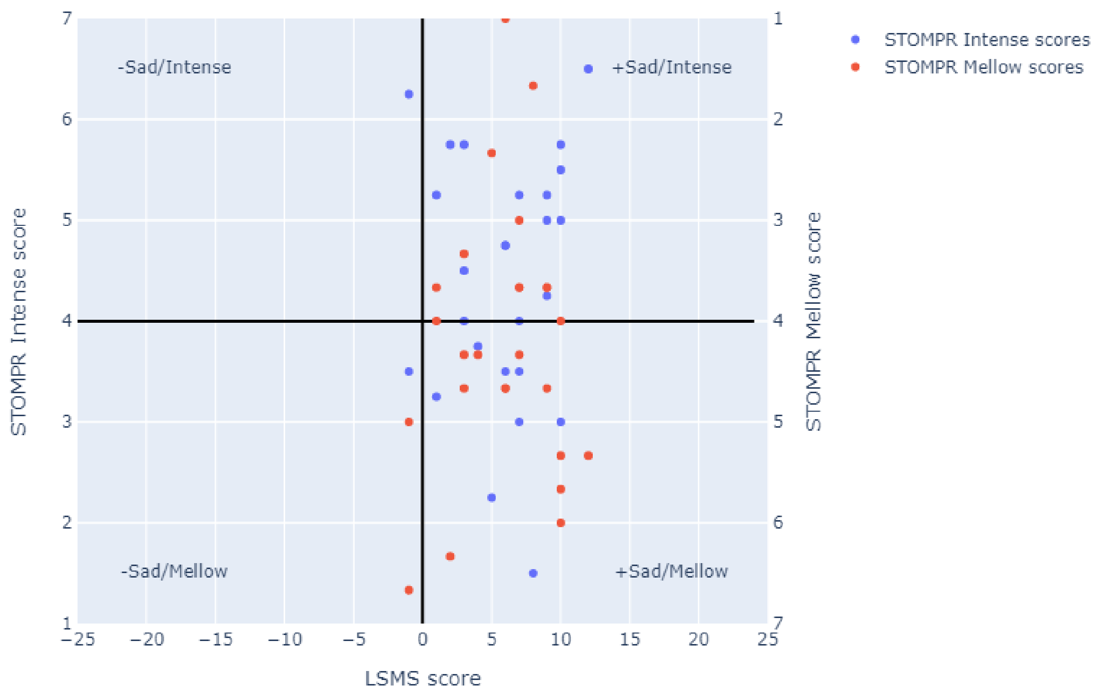


Figure 5.6: Participant (N = 26) scores on the LSMS versus STOMP-R. Preference for sad music (LSMS score) is plotted on the X-Axis. Preference for intense and mellow music (STOMP-R Mellow and Intense scores) are both plotted on the Y-Axis, as both of these factors can be related to levels of arousal. None of the participants reported severely disliking sad music.

5.6 Effects of Music Preference and Connection on Day 1 Memory

Additionally, we wanted to test what roles listener individual differences may play in these memory processes. As mentioned in Section 4.5, we collected several measures of participant preferences both during the Day 1 task as well as in the post-study questionnaire (STOMP-R and LSMS). Results from the scoring of these two post-study measures are shown overlayed in Figure 5.6. While participants were normally distributed about the middle of the STOMP-R "Mellow" and "Intense" factor scales, the same could not be said about the LSMS results. Because of this, we do not analyze these measures and instead proceed with the participant responses during the initial music listening and rating task on Day 1. The ones that we will analyze here are:

1. The preference question: “How much did you like this music? Responses were on a nine-point scale for each musical stimulus ranging from “not at all” to “very much.”

2. The depth-of-connection question: “How much did you connect with this piece?” Responses were on a nine-point scale for each musical stimulus ranging from “not at all” to “very much.”

From each set of responses, we extract two independent variables for our analysis:

1. ”High” and ”Low” preference

2. ”High” and ”Low” connection

The threshold between “High” and “Low” is individualized per participant [100] by using their median rating value. This ensures there is an equal number of trials (12) under each condition. We chose to transform the nine-point rating data into these binary classifications for the analysis for two main reasons. First, this would account for biases in how each participant used the rating scale. Second, this would help with interpretability of our results given the overall low performance by participants on the recall task.

Given that preference for music has been found to drive stronger affective responses [9], we hypothesized that participants would form stronger memories under musical contexts which they prefer and feel more connected to. In other words, participants would have more easily memorized as well as retained memory for Day 1 episodes in which the music context more closely aligned with their own personal preferences and empathetic responses. This would suggest that personal relevance plays an important role in how memories are created and reactivated. No significant differences due to preference or connection would point to these listener judgments acting independently of the memory processes underway.

We analyzed both number of Day 1 words correctly recalled for each trial and number of Day 2 intrusion words recalled for each trial as our dependent variables. These data were each averaged within the binary “High”/”Low” preference and connection conditions described above for each participant. Paired-sample t-Tests within each binary pair revealed that average number of Day 1 words correctly recalled was significantly greater [t(25) = -2.1, p = 0.044] for high preference contexts (M = 0.57, SD = 0.67) compared to low preference contexts (M = 0.33, SD = 0.4). No other significant differences between conditions were found. This is shown graphically in Figure 5.7 below. This suggests that songs that participants liked also helped them encode and subsequently recall the associated Day 1 memory. As there is no difference in the number of Day 2 intrusions, this suggests that this is an effect that only appeared during initial encoding and consolidation on Day 1 and not during the reactivation and integration of the new memory on Day 2. Additionally, as no differences between levels of connection were observed, this suggests that listener's felt connection to the music is not as strong of a response or an influence on memory as their liking, or enjoyment of the music.

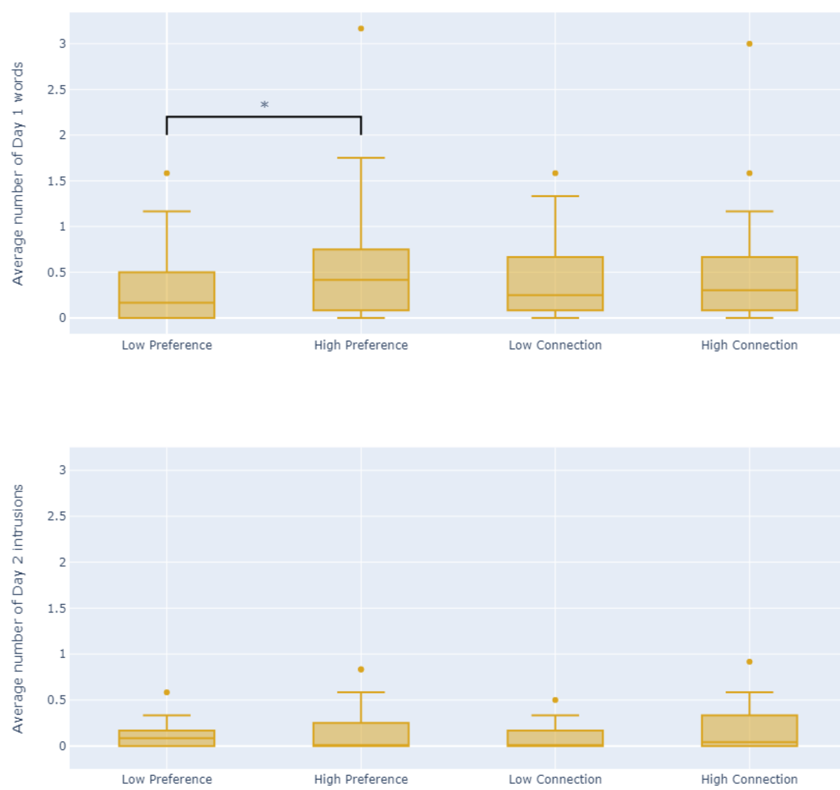


Figure 5.7: Effects of high and low preference (left) and depth of connection (right) for musical stimuli on correct Day 1 recall (top) and number of Day 2 intrusions (bottom). Only a significant effect of high or low preference on correct Day 1 recall rate was found (top left), suggesting a stronger effect of preference on memory processes compared to felt connection, and specifically a stronger effect on encoding and recall.

This is further confirmed by looking at the relationship between participant's preference and depth of connection ratings per song. A simple mixed effects model for depth of connection ratings included a fixed effect of preference ($p < 0.001$) and random effect of participant ($p = 1.0$). Estimation of parameters using Restricted Maximum Likelihood (REML) revealed the preference coefficient to be 0.691. In other words, the relationship between connection and preference as indicated by the model suggests that depth of connection, while closely related to one's preference for the song, is a less-potent response.

5.7 Comparing Musical Context with Emotional Context

In previous analyses, we found evidence that pieces of music could act as contexts for episodic memories and that, furthermore, affect of the music does have some influence over memory processes. Lastly, we wanted to test if the more general emotional context provided by music, as opposed to each piece's unique musical structure, could be just as powerful of a context for episodic memories. To do this, we extract several new dependent variables and conditions from our recall data:

1. Number of Day 1 words recalled per trial for *same* song.
2. Number of Day 1 words recalled per trial for *other* songs of similar valence *and* arousal.
3. Number of Day 1 words recalled per trial for *other* songs of similar valence *only*.
4. Number of Day 1 words recalled per trial for *other* songs of similar arousal *only*.

The goal was to test whether participants tended to recall more words for the Day 1 episode belonging to the same song shown to them in each trial, or if they were recalling equally as many words for Day 1 episodes belonging to songs which possessed similar emotional qualities to the song they were being prompted with.

We hypothesized that the emotional context provided by the music would not be as powerful as the context provided by the unique musical structure of each song. This would mean that participants would more readily recall the episode associated with each musical stimulus as opposed to an episode from an emotionally similar musical stimulus. This would also mean that participants tended to specifically use each piece of music as the context for the episodes they were encoding, as opposed to the emotion induced in them by the music. If no significant difference were found between context conditions, that might suggest that emotions induced by the music are just as influential in how participants associated and encoded the episodes.

A repeated measures ANOVA test demonstrated a significant effect of context condition on correct Day 1 word recall [$F(3,75) = 4.78$, $p = 0.003$]. Post hoc t-Tests showed there was a statistically significant difference [$t(25) = 2.1$, $p = 0.045$] between the same song condition ($M = 0.45$, $SD = 0.47$) and the same valence condition ($M = 0.23$, $SD = 0.21$), as well as between the same arousal condition ($M = 0.16$, $SD = 0.13$) and the same song condition [$t(25) = 3.0$, $p = 0.006$] (Figure 5.8). No significant difference was found between the same song condition and the same emotion quadrant (valence and arousal) condition ($M = 0.29$, $SD = 0.22$). In other words, the songs that participants were prompted with during the recall test acted as strong cues not just for episodes that were presented with that same song on Day 1, but also for other episodes that were presented with songs of similar valence and arousal on Day 1. This suggests that while participants were able to strongly associate each episode with the specific musical context, they were also creating associations among other emotionally similar contexts.

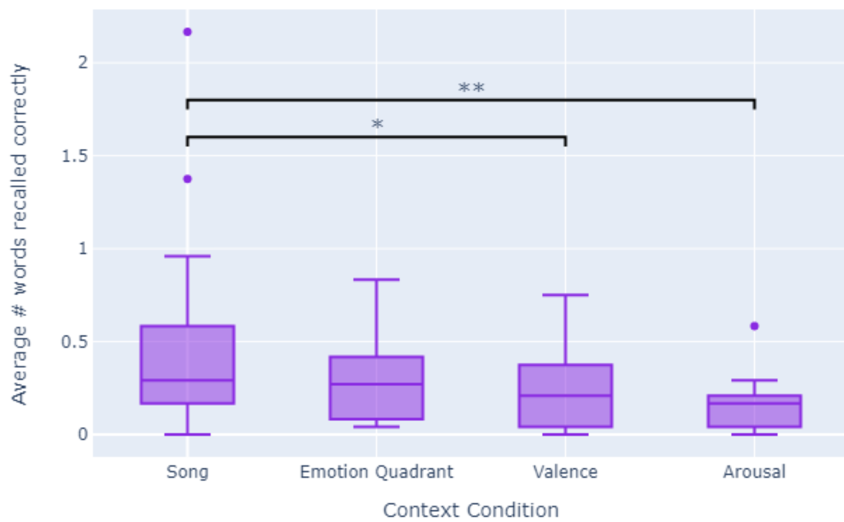


Figure 5.8: Comparisons of recall performance when looking at different possible memory contexts. The data shown is the average number of words recalled correctly for various context conditions, per participant. Results suggest that while participants most strongly associated episodes with the specific musical context being presented during the trial, the musically induced emotion also provided a memory context. However, it seems that similar valence and arousal characteristics both had to be present for this effect to occur.

Continuing this analysis, we compare number of Day 2 intrusion words recalled per trial between musical context and emotional context conditions discussed above. Following our original hypothesis, we expect that participants will exhibit more intrusions from Day 2 episodes associated with each musical stimulus as opposed to an episode from an emotionally similar musical stimulus. This would suggest that when participants heard a musical context again on Day 2, it cued and reactivated the specific episode associated with that same context on Day 1, as opposed to cueing and reactivating other "old" (consolidated) episodes that had similar emotional contexts, and that furthermore the new information was integrated and reconsolidated with that song's Day 1 episode. In other words, the musical structure would be the strongest memory cue, not the emotion induced by the music. If no significant difference were found between context conditions, that would suggest that aspects of the musically induced emotion were just as powerful memory cues as the specific musical elements themselves.

A repeated measures ANOVA test found no significant effect of context condition on number of Day 2 intrusions [$F(3,75) = 2.39$, $p = 0.076$]. This means that a new episode a participant memorized for a song on Day 2 was not necessarily integrated with the Day 1 memory corresponding to the same song but was also associated with other prior episodes from emotionally similar songs. Together with the previous analysis, these results suggest that the emotions induced by a piece of music might be just as powerful of a memory context as the specific musical elements themselves.

CHAPTER 6
DISCUSSION

6.1 Research Overview

We designed a three-day story-making paradigm, drawing from previous memory reconsolidation studies (Chapter 3), to provide behavioral evidence that music can be used to contextualize and subsequently modulate emotional episodic memories. Our results suggest that music can act as a contextual trace and memory cue (Section 5.3), and that furthermore the feeling induced by the music (Sections 5.4 and 5.7) as well as individual listener preference (Section 5.6) play determining roles in how the memory is encoded, retained, and recalled.

Our four main hypotheses were:

H1. Music will be able to act as a memory context and cue significant recall of paired episodic memories. Subsequently, an implicit musical reminder should be able to reactivate a previously paired episode and trigger the reconsolidation process. We predict that memory for these original episodes will be measurably altered compared to episodes which do not undergo this process.

H2. Feelings induced by the music and how well these are perceived to "fit" with the episode content (mood congruence) will affect the power of the music context. We predict that emotionally congruent musical contexts will be more powerful than emotionally incongruent contexts.

H3. How powerful the musical context is will be additionally modulated by participants' preference for and felt connection to the musical context. We predict that musical contexts which participants prefer and feel connected to will be more powerful than those which they do not prefer/feel connected to.

H4. The more general emotional context offered by music will not be powerful as the specific context offered by the musical structure, or auditory elements of a given piece.

6.2 H1: Music as a Memory Context

Given prior work supporting that music is able to influence and evoke memory (Section 2.3), we wanted to first establish if our experimental paradigm allowed for participants to create these contextual associations between music and our fictional episodic memories. As suggested by the literature, we predicted that the music would provide a memory context and cue for the paired memories (H1).

We measured this using participants' free recall test results. We calculated participants' average number of Day 1 words correctly recalled under "control" and "reconsolidation" conditions (Section 5.3). Participants exhibited significant recall of Day 1 episodes under both conditions, suggesting that they were able to associate the musical contexts with the paired fictional episodes they were creating.

Furthermore, there was a significant difference in the average number of Day 1 words correctly recalled between control and reconsolidation conditions. Participants recalled more words for musical contexts which were only presented on Day 1 (control trials). This means that re-presenting a previously used musical context with a new episode significantly hindered recall of the original memory. While some previous episodic memory reconsolidation studies showed that reactivation and reconsolidation does not affect the original memory [12], other works specifically exploring emotional autobiographical memory reconsolidation have presented evidence that reactivation along with integration of new information can degrade the original memory [101]. Our results additionally support this, which may be evidence that reactivation and reconsolidation of the Day 1 memory did in fact occur on Day 2, through the use of music as the contextual link. This would support our hypothesis that music is able to provide a context and serve as a contextual cue for episodic memories. Our results suggest that the music was able to be associated with specific events, cue memory retrieval, and promote memory reactivation.

These results are strongly supported by prior literature. It is common for music to be associated with various personal events in one's life, with the music subsequently acting as a cue evoking that memory and its emotions along with it [21, 4]. However, these MEAMs have typically been studied with regards to participants' real-life, personal memories and associations with music [72, 3], even those studies done in lab environments [71]. In the current study, we were able to show that participants were able to form connections between pieces of music and fictional autobiographical memories that they synthesized using emotional word stimuli.

Although the current study was designed to share key similarities (e.g., multi-day paradigm) to other episodic memory reconsolidation studies [75, 12, 84], the effects generally observed here may be open to alternative mechanistic explanations other than reactivation-induced reconsolidation. For instance, "response competition" [102, 103] (also related to retroactive inhibition [95]), which describes impaired memory performance for the desired response (in this study, the Day 1 episode) when there are other, competing, responses (Day 2 episode) which have also been associated with the same stimulus (common music context).

Furthermore, it is important to also note the relatively low values for the dependent variable. Even though control trials were found statistically to be recalled better than reconsolidation trials, the mean between participants for average number of Day 1 words correctly recalled for control trials is less than one word (for reference, seven words were presented per trial). Participants left between 7-8 trials out of 24 completely blank during the recall test, on average. This may be an indication that the task is overly difficult (floor effects), or that participants were not able to create associations for all musical contexts; it may also be an indication of some other memory interference effects (such as those described above). Together, these point to some key experimental design iterations necessary in future work.

6.3 H2: Effects of Mood (In)Congruency

Continuing on from our previous result that the music in this study was acting as a context for the paired episodic memories, we wanted to determine how Day 1 memory was affected by the musically induced emotion and affective (in)congruency between the music and the episode content (word set). We hypothesized that music congruent with the episode content would be a more powerful memory context, compared to music incongruent with the episode content (H2).

We measured this using participants' free recall test results and calculating two complementary behavioral measures of memory encoding and reconsolidation: average number of Day 1 words correctly recalled, and average number of Day 2 "intrusion" words accidentally recalled. From previous behavioral memory reconsolidation studies, number of "intrusions" is taken as a measure of the degree to which memory reconsolidation and integration occurred [75, 12].

First, we analyzed participants' average number of Day 1 words correctly recalled under various control and reconsolidation congruency conditions (Figure 4.6). We found that in situations where there was no disturbance of the original memory (control trials), participants showed significantly stronger memory recall of emotionally congruent episodes compared to incongruent episodes, suggesting that affective congruence provided by the music aided in encoding and recalling a stronger Day 1 memory. This is in support of our hypothesis and in agreement with A.J. Cohen's CAM-WN, which posits that mood congruency between two different stimuli promotes stronger, unified encoding of both stimuli in memory [7].

However, in situations where there was subsequent disturbance (reactivation and reconsolidation) of the original memory (reconsolidation trials), participants surprisingly exhibited significantly weaker memory recall of emotionally congruent episodes compared to incongruent episodes. This was unexpected; we anticipated observing the same effect as the control trials above.

One possible explanation is an underlying effect of positive valence music [61]. Both conditions which had the strongest memory recall—congruent control trials and incongruent reconsolidation trials—involved positive valence music as a context (see Figure 4.6). Therefore, it is possible that the significant effects seen in the data are explained more accurately overall by affective characteristics of the music alone. This cannot be definitively determined with the current data, based on limitations with the experimental design. As can be seen from Figure 4.6, the experimental conditions are not completely symmetrical (e.g., There is no congruent control condition with negative words and negative music). This was done in an attempt to keep the task within a feasible time duration while doing it as a within-subjects study. However, future work and amendments to the experimental design should clarify the effects seen in the current results.

Another possible explanation comes from the broader mood and memory literature. Enhanced memory for emotion-laden items that are incongruent with one's induced mood is referred to as mood-incongruent learning [104, 105, 106], seen in the reconsolidation results above. While there are many models which explain mood-congruent learning (seen in the control results above), mood-incongruent learning—while also commonly demonstrated in experimental findings—is less easily explained by these same models. Rinck et al. (1992) propose and provide evidence for a two-component processing model which explains both congruency effects. According to their model, how easily one can determine the valence of a presented item ("valence determination"), along with the associative connections one makes based on the item and their current mood ("additional elaboration"), both play a role in predicting either mood-congruent or mood-incongruent learning. Very emotional items (easy valence determination) congruent with mood tend to be memorized more efficiently due to additional elaboration and associations easily made, compared to very emotional incongruent items (less elaboration). However, weakly emotional items (mixed additional elaboration) incongruent with mood tend to also be memorized more due to the higher cognitive effort invested in the valence determination, compared to weakly emotional congruent items (easier valence determination).

In our study, we selected all stimuli to be strongly emotional based on the validated ratings from the source datasets. This would then suggest mood-congruent learning, as we hypothesized (H2). However, we only observed mood-congruent learning for the control trials (positive words with positive music); congruent reconsolidation trials (negative words with negative music) were not similarly recalled. According to the two-component processing model, this would suggest that perhaps these stimuli were not as emotionally potent or perceived just as drastically congruent or incongruent as the control trials, leading to the observed mood-incongruent effect. As can be observed from Figure 5.1, there is a valence skew in the musical stimuli stemming from the source dataset; there are a limited number of very low-valence, low-arousal excerpts, with the ratings tending more towards "neutral" compared to the other four quadrants of the circumplex model. Further analysis into participant affective ratings of the music, as well as episode congruence responses, might reveal if these results can be explained by way of the two-component processing model.

Finally, we also analyzed participants' average number of Day 2 "intrusion" words accidentally recalled under the same reconsolidation conditions as above. However, we found no significant differences between the congruency conditions, suggesting that the affect of the music neither helped nor hindered integration of the new episodes on Day 2. This was also a surprising result, as we had hypothesized that participants would have a greater number of intrusions for new episodes that were introduced with congruent music contexts on Day 2.

Once again, we note the very low values for the dependent variable here as well. One possibility is that floor effects also observed in the earlier analyses did not allow for any relation to be observed. Future adjustments to the task difficulty would be needed in order to determine if this is the case or if, alternatively, only a reconsolidation blockade occurred (Section 6.2) and not integration of the new material [101].

6.4 H3: Effects of Preference and Connection

Numerous prior works have demonstrated the importance of individual musical preference and its ability to influence emotional responses as well as memory (Sections 2.2 and 2.3). We wanted to measure how participant preference for the musical contexts affected Day 1 memory encoding as well as Day 2 memory integration. Given Egermann and McAdams' (2013) model linking preference and empathy [9], we additionally measured participants' "depth of connection" to each musical context; this was inspired by and adapted from the original study which asked about participants' level of empathy with the heard musician. We hypothesized that music which participants preferred and felt more personally connected to would be a more powerful memory context (H3).

We again measured this using participants' free recall test results and calculating average number of Day 1 words correctly recalled, and average number of Day 2 "intrusion" words accidentally recalled. Preference and connection ratings were each split into "High" and "Low" binary conditions using an individualized threshold for each participant (Section 5.6).

In support of our hypothesis, we found that participants showed significantly greater Day 1 memory recall for musical contexts which they preferred, compared to contexts which they did not prefer. This implies that songs that participants liked also helped them encode and subsequently recall the associated Day 1 memory. This observation is supported by several studies in prior literature which have also found that reward responses elicited from preferred music aid in encoding and recollection of memory [55, 39]. Together, this points to personal relevance playing an important role in how memories are created and retrieved.

However, contrary to our hypothesis, no similar significant difference between "Low" and "High"-connection contexts was observed. This suggests that perhaps listeners' felt connection to the music was not as strong of a response as their liking, or enjoyment of the music. This is supported by Egermann and McAdams' (2013) music emotion model, which posits that it is preference for music which then drives the empathetic response. In their study, Egermann and McAdams were able to use a linear mixed model to show a significant relationship between empathy and preference responses [9]. We were able to reproduce a similar relationship between preference and empathy ("connection") responses using a simple mixed effects model. The model fit further confirmed that depth of connection, while closely related to one's preference for the song, was recorded as a less-potent response.

No significant differences were found in participants' average number of Day 2 intrusions between their "High" and "Low" preference or connection contexts. Again, it is possible that floor effects obstructed the results, or that only a reconsolidation blockade occurred (hindering of the original memory) in this study and not integration of new material. Alternatively, it may possibly suggest that the reward responses elicited by preferred music only play a determining role in the initial encoding and recollection of the memory, and not in the integration of new information. To our knowledge, previous works have primarily studied preferred music only in terms of memory encoding and recall; we believe this is the first study investigating musical preference in the context of memory reconsolidation and integration new memories. Future adjustments to the current task are necessary to determine the role of individual preference more accurately in these memory processes.

6.5 H4: Musical and Emotional Contexts

As a memory context, music does share some similarities to the traditionally studied spatiotemporal contexts of episodic memory. For example, both contain a time-domain representation, or temporal sequence. However, a musical composition on its own (ignoring contributions of playback medium) does not have a spatial setting. Unlike spatiotemporal contexts, which just consist of these “when” are “where” elements, music consists of unique time-dependent auditory features like melody, instrumentation, rhythm, tempo, etc. in addition to emotional expression.

Since prior works have shown that music is able to cue episodic memories (see MEAMs, Section 2.3) similar to spatial settings, we wanted to determine which aspect of music (auditory features/musical structure or emotional expression) was most critical in its role as a context for episodic memories. Since this prior work often implicates specific songs as memory cues, we hypothesized that the unique musical structure of each song would be a more powerful context than the emotion conveyed and induced by the music. In other words, we thought that participants would more readily recall the episode paired with each musical context as opposed to an episode from an emotionally similar musical context.

We again measured this using participants’ free recall test results and calculating average number of Day 1 words correctly recalled and average number of Day 2 “intrusion” words accidentally recalled per trial for the same song context, as well as for other songs which provided similar emotional contexts. Surprisingly, we found that given a musical memory cue, participants tended to equally recall the episode paired with that cue and episodes paired with other contexts of similar valence and arousal. In other words, the songs that participants were prompted with during the recall test acted as strong cues not just for episodes that were presented with that same song on Day 1, but also for other episodes that were presented with songs of similar valence and arousal on Day 1 (the same could not be said for songs only of similar valence or arousal). Similarly, we found that participants had just as many Day 2 intrusions from the paired musical context as they did from emotionally similar musical contexts.

This result is surprising because it potentially implies that while participants were able to strongly associate each episode with the specific musical context, they were also creating associations among other emotionally similar contexts. However, this is a possibility that would be supported by several prior works. Our results suggest that the musical emotion may be equally as powerful as the musical structure in contextualizing and cueing memories. The arousal-and-mood hypothesis also implicates emotional expressions of the music over the specific musical structure or features in influencing cognitive processes such as memory [5, 6]. Furthermore, Rinck et al.'s (1992) two-component processing model suggests that we tend to "elaborate," or form associative connections with other mood-congruent memories [106]. Other works and theories have also found emotional memory cues to subsequently cause retrieval of emotionally-similar memories [107, 108], as we observed in our results.

CHAPTER 7
CONCLUSIONS AND FUTURE WORK

7.1 Core Contribution

We present a three-day story-making paradigm to study encoding, reactivation, and reconsolidation of emotional autobiographical episodic memories with music as the contextual link. Through this research we demonstrate music's ability to serve as a context for these memories.

We found that music was able to cue significant recall of the paired fictional autobiographical episodes used in the experiment. Moreover, we found evidence that re-presenting the musical contexts alongside new material gave an implicit reminder and succeeded in reactivating the previously paired episode. Memory for the original episode was significantly impaired, which is consistent with prior accounts of emotional episodic memory reconsolidation. However, it is unclear if the current design facilitates new memory integration or only a reconsolidation "blockade," disrupting the original memory.

In general, we found that affective characteristics of the music and the emotions subsequently induced in the listener significantly influence memory creation and retrieval. Furthermore, our results suggest that the musical emotion may be equally as powerful as the musical structure in contextualizing and cueing memories. Evidence supports that individual differences and personal relevance of the musical context play a determining role in these processes as well. In showing this, we also reproduced a previous finding that preference for music is linked to empathy [9].

7.2 Impact

The reactivation-induced reconsolidation mechanism allows for a previous experience to be relived and simultaneously reframed in memory. To this end, memory reconsolidation has become a research focus in the development of new affective psychotherapy protocols [109, 15]. Reconsolidation of emotional, potentially maladaptive, autobiographical episodic memories in a safe setting is a proposed clinical tool for mood regulation-based therapies and could potentially aid in the treatment of many mood-related disorders, such as MDD [13, 14] and trauma-related disorders (PTSD, complex PTSD, adverse childhood experiences, etc.) [15].

This work establishes promising future research directions for new music technologies and interventions designed for this clinical population. To our knowledge, we contribute the first behavioral study of emotional memory reconsolidation using music. While definitively implicating reconsolidation (over other memory interference effects, for instance) as the "overwriting" mechanism in human memory remains largely controversial in such studies, the music-driven effects demonstrated in this work nevertheless show promise for how we may be able to attenuate the prolonged effects of negative past experiences. Our novel approach, which addresses musically induced emotion along with participant individual differences, furthers prior related works—very few of which explore music as a memory context. More specifically, this analysis establishes a foundation for our future neuroimaging work and necessary design iterations.

7.3 Future Work and Improvements to Experimental Design

Before proceeding to the neuroimaging stage of this project, several subsequent analyses and design iterations will be necessary. As noted throughout the analyses above (Chapter 6), our data is suggestive of floor effects. Further pilot testing of task iterations using fewer words per set and/or fewer sets (trials) overall may reveal if the current task is in fact overly difficult, obstructing results, or if music is not being associated with memory as anticipated. Since we were still able to observe some significant trends in our data, despite the relatively low quantitative measures, we predict that decreasing the task difficulty will amplify and extend our current results.

Our results pose another important question: is it the affect of the music alone, or the affective interaction (congruence) between the music and the episode that influences memory the most? As discussed in Section 6.3, our results could be potentially explained by an underlying effect of positive music alone, or by mood-incongruent learning models. In the case of the latter explanation, literature suggests that a subsequent analysis of our data and participants' affective responses would reveal that the negative valence stimuli used in this study were not perceived to be as potent as the positive valence stimuli. If this is not found to be the case, further pilot testing using a symmetrical experimental design may provide more insights into the current results.

Following the necessary improvements to the experimental design, we intend to conduct a neuroimaging study using this protocol. The aim of this next stage of the project will be to gain a mechanistic window into these behavioral results and to begin to collect an anatomical explanation of how music modulates emotional memory in the brain. This will be a critical next step in establishing future clinical research directions.

Appendices

APPENDIX A

MUSICAL STIMULI

The following list contains information on the 24 musical stimuli used in this experiment. All stimuli were taken from “Set 2” of the “Film Soundtracks” dataset [86] and acquired online from the Open Science Framework (osf.io/p6vkg).

The first column, “Filename,” is the identifier we used for each stimulus in our study. A file name which includes the `"_L"` tag signifies that this audio was looped to a final duration of 41-seconds. Stimuli without the `"_L"` tag were taken from the extended 1-minute-long excerpts of select “Set 2” stimuli also available through the link above, and truncated to 41-seconds. The second column, “Stim no.” is the identifier of the stimulus within the “Set 2” dataset. “Duration” refers to the duration of the original clip in the dataset; the final duration of all stimuli in the experiment was 41-seconds. Emotion ratings are from the original dataset.

Table A.1: Complete list of selected musical stimuli (all values are from original dataset [86])

Filename	Stim no.	Source film	Track no.	Duration	Valence	Energy	Tension	Anger	Fear	Happy	Sad	Tender	Beauty	Liking
01_L.wav	1	Lethal Weapon 3	8	0:14	2.56	7.73	8.38	6.39	4.4	1.21	1.75	1.01	4.71	4.97
02.wav	11	Batman Returns	5	0:46	2.38	6.38	8.33	2.79	7.42	1.09	1.6	1.07	3.58	4.37
03_L.wav	68	Road to Perdition	6	0:15	2.51	6.03	8.01	3.13	6.7	1	1.79	1.04	4.02	4.67
04_L.wav	2	The Rainmaker	7	0:15	2.5	8.21	8.56	5.76	5.93	1.09	1.6	1.1	4.57	4.79
05_L.wav	69	Hellraiser	5	0:15	2.36	7.09	8.24	6.38	5.34	1	1.83	1.02	4.22	5.19
06_L.wav	70	Grizzle Man	16	0:27	2.04	4.54	7.76	2.17	6.17	1.04	1.68	1.06	2.94	3.3
07_L.wav	77	Lethal Weapon 3	4	0:20	6.27	6.34	5.42	1.04	1.26	4.53	1.55	1.83	4.66	5.6
08_L.wav	26	The Omen	9	0:15	6.9	5.25	4.21	1.04	1.52	4.66	2.16	4.34	6.19	5.83
09.wav	71	The Untouchables	6	1:07	7.45	7.64	4.27	1.02	1.02	6.89	1.11	1.79	5.7	5.69
10_L.wav	21	The Rainmaker	3	0:18	8	7.77	4.02	1	1.09	6.63	1.12	2.19	5.79	5.92
11_L.wav	23	Shallow Grave	6	0:15	8.27	8.54	4.46	1.04	1.03	8.21	1.1	1.45	4.35	4.85
12_L.wav	72	Man of Galilee CD1	2	0:16	7.45	8.39	5.61	1.19	1.17	7.34	1.09	1.11	4.54	4.65
13_L.wav	99	Dracula	5	0:16	4.16	5.22	6.84	2.55	2.81	1.11	4.89	1.83	5.41	4.99
14.wav	33	The Portrait of a Lady	9	0:45	4.38	2.48	3.27	1.07	1.78	1.12	7.18	3.03	6.73	5.83
15.wav	86	Running Scared	15	0:55	4.28	3.88	5.84	1.96	3.13	1.02	5.94	1.57	5.67	5.21
16_L.wav	50	Oliver Twist	2	0:15	5.77	3.27	3.69	1.01	1.63	1.64	5.28	3.69	6.35	5.88
17_L.wav	84	Blanc	18	0:16	5.19	2.99	4.43	1.04	2.02	1.04	6.17	3.02	6.47	5.9
18_L.wav	63	Batman	9	0:19	4.76	3.96	6.04	1.23	3.83	1.19	3.91	2.32	5.72	5.42
19_L.wav	103	The Fifth Element	12	0:15	5.87	4.54	4.73	1.17	1.36	2.06	3.64	2.74	5.46	5.69
20.wav	41	Shine	10	0:59	7.27	3.85	2.48	1.01	1.15	3.72	3.01	6.66	6.73	5.94
21_L.wav	76	Juha	2	0:11	6.61	4.93	4	1	1.04	3.45	2.26	2.49	4.51	4.71
22_L.wav	83	Big Fish	11	0:11	6.4	4.49	4.6	1	1.23	2.43	3.96	4.26	6.24	5.81
23_L.wav	106	Lethal Weapon 3	10	0:18	7.37	3.73	2.21	1	1	3.13	2.45	6.57	6.3	5.93
24_L.wav	104	Crouching Tiger Hidden Dragon	11	0:18	6.19	3.63	3.48	1.09	1.3	1.32	5.6	3.79	6.55	6.26

APPENDIX B
WORD STIMULI

The following list contains information on the word stimuli used in this experiment. All stimuli were taken from the ANEW dataset [88].

As mentioned in the text above, the experiment was pseudo-randomized, with participants randomly receiving one of three possible versions of the study (V1, V2, V3). "1" signifies that the given word was presented on Day 1 for that version. "2" signifies that the given word was presented on Day 2 for that version. "0" signifies that the word was not used on Day 1 nor Day 2 but was rather presented only during the recognition test on Day 3 as a novel word ("noise" trial). Emotion ratings are from the original dataset.

"Root," "Compound," and "RootTotal" parameters are not from the original dataset, but rather parameters we manually assigned to each stimulus to be used during detection and scoring of the free recall test.

B.1 Cumulative List

Table B.1: Complete list of word stimuli

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Lame	1	2	1	3.66	3.69	4.83	Lame		1
Hell	1	1	2	2.24	5.38	3.24	Hell		1
Cranky	1	1	1	2.9	5.36	4.39	Crank		0
Gallery	1	2	2	6.03	4.07	4.73	Galler		0
Starvation	1	1	2	1.82	6.46	3.11	Starv		0
Trophy	1	2	2	7.78	5.39	6.44	Troph		0
Stain	1	1	1	3.42	4.54	4.74	Stain		1
End	1	2	1	3.44	4.44	4.41	End		1
Idol	1	2	2	6.12	4.95	5.37	Idol		1

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Slap	1	1	1	2.95	6.46	4.21	Slap		1
Moon	1	2	1	6.74	4.6	4.8	Moon		1
Infest	1	1	1	2.85	5.19	3.62	Infest		1
Expel	1	1	2	2.77	5.9	3.29	Expel		1
Talk	1	1	1	6.41	5.25	5.7	Talk		1
Cut	1	1	2	3.64	5	4.7	Cut		1
Sting	1	2	1	2.48	6.78	3.67	Sting		1
Addicted	1	1	1	2.51	4.81	3.46	Addict		0
Warmth	1	2	2	7.41	3.73	5.61	Warm		0
Guaranteed	1	1	1	7.14	4.93	6.39	Guarant		0
Depressed	1	1	1	1.83	4.72	2.74	Depress		0
Pain	1	2	1	2.13	6.5	3.71	Pain		1
Disaster	1	2	2	1.73	6.33	3.52	Disaster		1
Glaze	1	1	1	6.8	5.1	5.3	Glaz		0
Betray	1	2	1	1.68	7.24	4.92	Betray		1
Terrible	1	2	1	1.93	6.27	3.58	Terrible		1
Perish	1	1	2	2.9	5.3	3.2	Perish		1
Worry	1	1	1	2.31	6	2.96	Worr		0
Poet	1	2	2	6.46	4.67	4.81	Poet		1
Widow	1	1	2	2.42	3.64	3.73	Widow		1
Wink	1	2	2	6.93	5.44	5.7	Wink		1
Hurt	1	1	1	1.9	5.85	3.33	Hurt		1
Abandon	1	2	1	2.36	4.66	3.45	Abandon		1
Wishful	1	2	2	7.5	5.57	5.27	Wish		0
Intruder	1	1	1	2.77	6.86	4	Intrud		0
Relax	1	2	1	7.87	2.47	6.37	Relax		1
Furious	1	1	1	1.96	7.64	5.32	Fur		0
Cockroach	1	1	2	2.81	6.11	4.74	Cock	Roach	0
Airplane	1	1	1	6.43	6.77	3.73	Air	Plane	0
Divorce	1	1	2	2.22	6.33	3.26	Divorc		0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Sad	1	2	1	1.61	4.13	3.45	Sad		1
Despair	1	1	1	2.99	4.49	4.3	Despair		1
Spa	1	2	2	7.86	4.82	5.46	Spa		1
Eager	1	1	1	7.32	6.57	5.14	Eager		1
War	1	1	1	2.08	7.49	4.5	War		1
Crucify	1	2	1	2.23	6.47	3.74	Crucif		0
Pollute	1	2	2	1.85	6.08	4.92	Pollut		0
Football	1	1	1	7.64	6.54	6.21	Foot	Ball	0
Trash	1	2	1	2.67	4.16	5.24	Trash		1
Accident	1	2	1	2.05	6.26	3.76	Accident		1
Bored	1	1	2	2.95	2.83	4.11	Bor		0
Denial	1	1	1	3.28	6.03	4.06	Den		0
Friendly	1	2	2	8.43	5.11	5.92	Friend		0
Cocaine	1	1	2	3.37	4.93	4.7	Cocaine		1
Puppy	1	2	2	7.56	5.85	5.51	Pup		0
Neglect	1	1	1	2.63	4.83	3.85	Neglect		1
Chore	1	2	1	2.74	3.52	3.26	Chor		0
Pillow	1	2	2	7.92	2.97	4.56	Pillow		1
Sin	1	1	1	2.8	5.78	3.62	Sin		1
Parrot	1	2	1	6.94	5.37	4.53	Parrot		1
Owe	1	1	1	3.25	5.68	3.07	Owe		1
Assassin	1	1	2	3.09	6.28	4.33	Assassin		1
Rainbow	1	1	1	8.14	4.64	4.72	Rainbow		1
Hostility	1	1	2	3.19	5.04	5.29	Hostil		0
Worse	1	2	1	2.59	4.56	4.1	Wors		0
Severe	1	1	1	3.2	5.26	3.83	Sever		0
Tasty	1	2	2	7.64	5.87	5.63	Tast		0
Health	1	1	1	6.81	5.13	5.83	Health		1
Seasick	1	1	1	2.05	5.8	3.41	Sea	Sick	0
Exam	1	2	1	2.76	7.03	3.34	Exam		1

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Rush	1	2	2	3.97	6.38	3.88	Rush		1
Interest	1	1	1	6.97	5.66	5.89	Interest		1
Butcher	1	2	1	3.89	4.38	5.47	Butcher		1
Skunk	1	2	1	3.14	4.91	4.48	Skunk		1
Upset	1	1	2	2	5.86	4.08	Upset		1
Argue	1	1	1	2.83	6.07	4.7	Argu		0
Brownies	1	2	2	7.96	6.42	6.04	Brown		0
Flu	1	1	2	2.52	4.83	2.67	Flu		1
Vote	1	2	2	6.63	5.3	6.93	Vot		0
Pale	1	1	1	3.17	3.5	4.32	Pal		0
Fail	1	2	1	1.79	6.31	3.31	Fail		1
Lust	1	2	2	7.12	6.88	5.49	Lust		1
Detain	1	1	1	3.03	5.52	3.58	Detain		1
Laugh	1	2	1	8.36	7.39	6.64	Laugh		1
Penalty	1	1	1	2.83	5.1	3.95	Penalt		0
Misfortune	1	1	2	2.53	4.31	3.79	Misfortun		0
Green	1	1	1	6.18	4.28	4.82	Green		1
Allergy	1	1	2	3.07	4.64	3.21	Allerg		0
Anguished	1	2	1	2.12	5.33	3.45	Anguish		0
Crime	1	1	1	2.89	5.41	4.12	Crim		0
Profit	1	2	2	7.63	6.68	5.85	Profit		1
Cheery	1	1	1	7.55	5.99	5.6	Cheer		0
Accuse	1	1	1	2.54	6.57	4.07	Accus		0
Shun	1	2	1	2.97	5.24	3.66	Shun		1
Cigarette	1	2	2	2.46	5.35	4.54	Cigar		0
Colorful	1	1	1	7.31	5.6	5.98	Color		0
Weep	1	2	1	1.8	5.07	3	Weep		1
Despise	1	2	1	2.03	6.28	4.72	Despis		0
Hopeless	1	1	2	2.27	4.28	2.96	Hopeles		0
Blister	1	1	1	2.88	4.1	3.98	Blister		1

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Satisfied	1	2	2	7.94	4.94	6.14	Satisf		0
Dump	1	1	2	3.21	4.12	3.83	Dump		1
Thankful	1	2	2	6.89	4.34	5.32	Thank		0
Tense	1	1	1	3.56	6.53	5.22	Tens		0
Bald	1	2	1	3.78	4.26	4.44	Bald		1
Fantasy	1	2	2	7.41	5.14	6.43	Fantas		0
Disrespect	1	1	1	2.47	5.02	4.82	Disrespect		1
Cute	1	2	1	7.62	5.53	4.86	Cute		1
Lie	1	1	1	2.79	5.96	3.3	Lie		1
Grief	1	1	2	1.69	4.78	3.5	Grie		0
Free	1	1	1	8.26	5.15	6.35	Free		1
Lose	1	1	2	2.81	4.93	3.33	Los		0
Hostage	1	2	1	2.2	6.76	2.83	Hostag		0
Struggle	1	1	1	2.82	4.98	3.85	Struggl		0
Wealth	1	2	2	7.7	5.9	6.7	Wealth		1
Delight	1	1	1	7.48	6.68	5.68	Delight		1
Insane	1	1	1	2.85	5.83	4.12	Insan		0
Gloom	1	2	1	1.88	3.83	3.55	Gloom		1
Traffic	1	2	2	2.27	5.8	2.57	Traffic		1
Forest	1	1	1	6.39	4.86	5.11	Forest		1
Refuse	1	2	1	3.69	4.44	5.81	Refus		0
Wasteful	1	2	1	2.69	4.23	5.08	Wast		0
Avoid	1	1	2	3.62	5.04	4.26	Avoid		1
Drugs	1	1	1	3.76	6	4.75	Drug		0
Volunteered	1	2	2	7.14	5.34	6.04	Volunt		0
Dead	1	1	2	1.94	5.73	2.84	Dead		1
Rescue	1	2	2	7.7	6.53	6.45	Rescu		0
Tarnish	1	1	1	3.31	3.77	5.18	Tarnish		1
Irritated	1	2	1	2.23	6.13	4.37	Irritat		0
Grin	1	2	2	7.4	5.27	6	Grin		1

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Weak	1	1	1	2.64	3.78	3.44	Weak		1
Marvel	1	2	1	7.06	5.2	4.93	Marvel		1
Resign	1	1	1	3.47	4.21	4.57	Resign		1
Bleed	1	1	2	2.97	5.64	3.93	Bleed		1
Surprise	1	1	1	7.73	7.07	3.87	Surpris		0
Bothered	1	1	2	3	6.17	4.17	Bother		0
Broken	1	2	1	3.05	5.43	4.14	Brok		0
Insecure	1	1	1	2.36	5.56	2.33	Insecur		0
Cook	1	2	2	6.16	4.44	5.14	Cook		1
Imagination	1	1	1	6.98	5.83	5.84	Imagin		0
Crude	1	1	1	3.12	5.07	4.27	Crud		0
Puke	1	2	1	2.09	5.26	3.51	Puk		0
Frown	1	2	2	1.87	4.27	3.7	Frown		1
Kiss	1	1	1	8.26	7.32	6.93	Kiss		1
Heartless	1	2	1	2.66	4.71	4.74	Heartles		0
Ban	1	2	1	3.48	5.62	3.9	Ban		1
Dandruff	1	1	2	2.95	3.33	4.3	Dand		0
Jealous	1	1	1	2.86	6.48	3.72	Jealous		1
Heir	1	2	2	6.57	5.22	5.78	Heir		1
Math	1	1	2	3.81	4.63	4.44	Math		1
Savior	1	2	2	7.73	5.8	6.64	Sav		0
Mope	1	1	1	2.85	3.25	4.51	Mop		0
Trauma	1	2	1	2.1	6.33	2.84	Trauma		1
Entertain	1	2	2	7.1	5.9	5.73	Entertain		1
Rumor	1	1	1	3.76	4.93	4.58	Rumor		1
Soft	1	2	1	7.12	4.63	6	Soft		1
Poison	1	1	1	1.98	6.05	3.1	Poison		1
Ignorance	1	1	2	3.07	4.39	4.41	Ignor		0
Sister	1	1	1	7.46	5.43	4.93	Sister		1
Remorse	1	1	2	2.48	5.66	3.31	Remors		0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Mistake	1	2	1	2.86	5.18	3.86	Mistak		0
Insult	1	1	1	2.29	6	3.62	Insult		1
Elated	1	2	2	7.45	6.21	5.53	Elat		0
Jewel	1	1	1	7	5.38	5.59	Jewel		1
Choke	1	1	1	2.38	6.34	2.91	Chok		0
Beg	1	2	1	2.75	5	3.3	Beg		1
Stinky	1	2	2	2.74	4.55	4.48	Stink		0
Elegant	1	1	1	7.43	4.53	5.95	Elegant		1
Parasite	1	2	1	2.29	5.34	3.45	Parasit		0
Cancer	2	1	2	1.5	6.42	3.42	Cancer		1
Humor	2	2	2	8.56	5.5	6.08	Humor		1
Leave	2	2	2	3.83	4.36	4.36	Leav		0
Wedding	2	1	1	7.82	5.97	6.68	Wed		0
Alarm	2	1	1	2.86	7.36	3.75	Alarm		1
Delayed	2	1	1	3.07	5.62	3.64	Delay		0
Legendary	2	1	1	7.25	6.08	6.25	Legend		0
Lake	2	1	1	6.82	3.95	4.9	Lake		1
Stolen	2	2	1	2.69	6.03	3.41	Stol		0
Surfer	2	2	2	6.55	5.45	5.45	Surf		0
Sailboat	2	1	1	7.25	4.88	5.86	Sail	Boat	0
Brutal	2	1	1	2.8	6.6	4.59	Brut		0
Fighting	2	1	1	3.53	5.88	5.52	Fight		0
Sofa	2	1	2	6.53	3.1	6.17	Sofa		1
Sabotage	2	1	2	2.86	4.82	5.28	Sabotag		0
Complete	2	2	2	8.17	5.75	7.36	Complet		0
Selfish	2	1	2	2.42	5.5	4.64	Selfish		1
Cottage	2	2	2	6.45	3.39	5.39	Cottag		0
Disgusting	2	2	2	2.96	5.18	3.64	Disgust		0
Strong	2	1	1	7.11	5.92	6.92	Strong		1
Homeless	2	1	1	2.06	4.59	3.31	Homeles		0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Repulsed	2	1	1	2.48	5.93	4.1	Repuls		0
Hobby	2	1	1	7.24	5.36	7.24	Hobb		0
Glow	2	1	1	7.07	5.28	5.48	Glow		1
Embarrass	2	2	1	2.5	6.14	2.78	Embarras		0
Passion	2	2	2	8.03	7.26	6.13	Passion		1
Refreshment	2	1	1	7.44	4.45	5	Refresh		0
Wreck	2	1	1	3	5.77	4.17	Wreck		1
Enraged	2	1	1	2.46	7.97	6.33	Enrag	Rage	0
Sleep	2	1	2	7.2	2.8	5.41	Sle		0
Braces	2	1	2	3.17	5.24	3.9	Brac		0
Proud	2	2	2	8.03	5.56	6.74	Proud		1
Affair	2	1	2	3.12	6.21	3.71	Affair		1
Festival	2	2	2	7.41	6.18	5.53	Fest		0
Agony	2	2	2	2.43	6.06	4.02	Agon		0
Gift	2	1	1	7.77	6.14	5.52	Gift		1
Freeze	2	1	1	3.81	4.65	4.59	Freez		0
Disability	2	1	1	2.52	4.46	2.43	Disab		0
Decorate	2	1	1	6.93	5.14	6.05	Decor		0
Dance	2	1	1	7.38	6.71	6.04	Danc		0
Sewage	2	2	1	2.61	4.57	4.47	Sew		0
Daisy	2	2	2	7.48	3.96	5.33	Dais		0
Lovable	2	1	1	7.78	6.07	5.83	Lov		0
Injury	2	1	1	2.49	5.69	3.57	Injur		0
Surgery	2	1	1	2.86	6.35	2.75	Surg		0
Improve	2	1	2	7.65	5.69	6.08	Improv		0
Torture	2	1	2	1.56	6.1	3.33	Tortur		0
Church	2	2	2	6.28	4.34	5	Church		1
Paranoid	2	1	2	2.83	6.04	3.29	Paran		0
Singing	2	2	2	6.98	5.48	5.49	Sing		0
Pervert	2	2	2	2.79	6.26	4.72	Perv		0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Picnic	2	1	1	7.07	5.18	5.93	Picnic		1
Scam	2	1	1	2.52	4.54	4.34	Scam		1
Burdened	2	1	1	2.5	5.63	5.03	Burden		0
Game	2	1	1	6.98	5.89	5.7	Gam		0
Innocence	2	1	1	6.54	4.79	5.75	Innocen		0
Blackmail	2	2	1	2.95	6.03	3.54	Black	Mail	0
Ocean	2	2	2	7.12	4.95	5.53	Ocean		1
Play	2	1	1	8.1	6.93	6.97	Play		1
Abortion	2	1	1	3.5	5.39	4.59	Abort		0
Morbid	2	1	1	2.87	5.06	4.34	Morbid		1
Life	2	1	2	7.27	6.02	5.72	Lif		0
Difficult	2	1	2	2.93	5.96	4.19	Difficult		1
Balloons	2	2	2	6.97	4.9	5.53	Balloon		0
Pessimism	2	1	2	3.1	4.74	4.48	Pessim		0
Applaud	2	2	2	6.98	5.78	5.93	Applau		0
Creepy	2	2	2	2.71	5.49	3.95	Creep		0
Memories	2	1	1	7.48	6.1	5.88	Memor		0
Arson	2	1	1	2.6	6.58	3.46	Arson		1
Brat	2	1	1	3.13	4.65	5.17	Brat		1
Honey	2	1	1	6.73	4.51	5.44	Honey		1
Explore	2	1	1	7.08	6.36	5.99	Explor		0
Scorn	2	2	1	2.84	5.48	3.93	Scorn		1
Female	2	2	2	7.83	5.83	5.57	Female		1
Admired	2	1	1	7.74	6.11	7.53	Admir		0
Fever	2	1	1	2.76	4.29	3.52	Fever		1
Bitter	2	1	1	3.31	4.4	5.17	Bitter		1
Truthful	2	1	2	7.18	5.03	6.06	Tru		0
Ugly	2	1	2	2.43	5.38	4.26	Ugl		0
Graduate	2	2	2	8.19	7.25	6.94	Grad		0
Bastard	2	1	2	3.36	6.07	4.17	Bastard		1

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Energy	2	2	2	7.23	6.9	6.93	Energ		0
Urine	2	2	2	3.25	4.2	5.24	Urin		0
Lucky	2	1	1	8.17	6.53	6.05	Luck		0
Tornado	2	1	1	2.55	6.83	4.3	Tornado		1
Nightmare	2	1	1	1.91	7.59	3.68	Night		0
Compliment	2	1	1	7.03	5.64	5.88	Complim		0
Mountain	2	1	1	6.59	5.49	5.46	Mount		0
Crash	2	2	1	2.31	6.95	3.44	Crash		1
Fabulous	2	2	2	7.7	6.17	6.05	Fabu		0
Gentleman	2	1	1	6.52	5.2	5.81	Gent	Man	0
Bankrupt	2	1	1	2	6.21	3.27	Bank		0
Clot	2	1	1	3.13	4.7	3.66	Clot		1
Photographer	2	1	2	6.5	5.09	5.59	Photo		0
Gossip	2	1	2	3.48	5.74	3.57	Gossip		1
Coach	2	2	2	6.21	5.59	4.83	Coach		1
Isolation	2	1	2	2.17	4.7	2.6	Isolat		0
Car	2	2	2	7.73	6.24	6.98	Car		1
Harass	2	2	2	2.48	5.64	3.93	Haras		0
Mansion	2	1	1	7.24	6.03	5.86	Mansion		1
Dreary	2	1	1	3.05	2.98	3.81	Drear		0
Fake	2	1	1	3.1	5.26	4.58	Fak		0
Fame	2	1	1	7.93	6.55	6.85	Fam		0
Fashion	2	1	1	7.04	6	6	Fashion		1
Dictator	2	2	1	2.15	5.5	3.58	Dictat		0
Appreciate	2	2	2	7.4	5.18	5.92	Apprec		0
Guitar	2	1	1	6.86	5.82	5.29	Guitar		1
Stress	2	1	1	2.09	7.45	3.93	Stres		0
Suffer	2	1	1	1.72	6.13	2.54	Suffer		1
Joke	2	1	2	8.1	6.74	6.15	Jok		0
Hysteria	2	1	2	3.67	5.69	4.11	Hyster		0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Care	2	2	2	7.53	6.03	6.37	Care		1
Brain	0	0	0	6.7	5.53	5.93	Brain		1
Rollercoaster	0	0	0	8.02	8.06	5.1	Roller	Coaster	0
Gorgeous	0	0	0	7.59	6.44	5.37	Gorg		0
Luscious	0	0	0	7.5	5.34	5.68	Lusc		0
Oxygen	0	0	0	6.44	4.38	5.38	Oxyg		0
Triumphant	0	0	0	8.82	6.78	6.95	Triumph		0
Lick	0	0	0	6.27	5.7	5.9	Lick		1
Sprinkle	0	0	0	6.13	4.5	5.22	Sprink		0
Noon	0	0	0	6.3	3.65	5.08	Noon		1
Donate	0	0	0	6.89	4.48	6.7	Donat		0
Suffocate	0	0	0	1.56	6.03	3.44	Suffoc		0
Dust	0	0	0	3.9	4.1	4.5	Dust		1
Rusty	0	0	0	3.86	3.77	4.53	Rust		0
Defecate	0	0	0	3.33	5.14	4.77	Defec		0
Communism	0	0	0	2.8	5.55	3.07	Commun		0
Flabby	0	0	0	2.66	4.82	3.31	Flab		0
Bitch	0	0	0	3	6.36	4.36	Bitch		1
Hooker	0	0	0	3.34	4.93	4.73	Hook		0
Nameless	0	0	0	3.79	3.97	4.35	Name		0
Growl	0	0	0	4.11	5.93	5.52	Growl		1
Pus	0	0	0	2.86	4.82	4.35	Pus		1
Prejudice	0	0	0	2.98	5.17	4.85	Prejud		0
Bruise	0	0	0	3.38	5.93	4.52	Bruis		0
Alienation	0	0	0	2.75	4.45	3.25	Alien		0
Violation	0	0	0	3.02	5.55	4.44	Viol		0
Suicide	0	0	0	1.25	5.73	3.58	Suic		0
Missiles	0	0	0	3.17	6.69	3.14	Missil		0
Binge	0	0	0	3.25	4.94	4.28	Bing		0
Lawsuit	0	0	0	3.37	4.93	3.92	Law	Suit	0

Table B.1 (continued)

Word	V1	V2	V3	ValMn	AroMn	DomMn	Root	Compound	RootTotal
Ambulance	0	0	0	2.47	7.33	3.22	Ambu		0
High	0	0	0	6.63	5.56	5.38	High		1
Infinite	0	0	0	6.14	5.21	4.31	Infin		0
Inspire	0	0	0	6.97	5	6.34	Inspir		0
Open	0	0	0	6.13	4.4	5.77	Open		1
Favorite	0	0	0	7.06	5.75	6.02	Favor		0
Kind	0	0	0	7.59	4.46	5.95	Kind		1
Safe	0	0	0	7.07	3.86	5.81	Safe		1
Capable	0	0	0	7.16	5.08	6.47	Capab		0
People	0	0	0	7.33	5.94	6.14	Peopl		0
Know	0	0	0	6.93	5.77	6.9	Know		1

B.2 Word Sets by Version

Table B.2: Complete list of word sets

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
01_L.wav	{Accident, Terrible, Skunk, Ban, Despise, Wasteful Lame}	{Paranoid, Selfish, Bastard, Affair, Isolation, Cancer, Pessimism}	{Poison, Owe, Furious, Infest, Resign, Penalty, Lie}	{Crucify, Puke, Exam, Beg, Shun, Pain, Gloom}	{Accident, Terrible, Skunk, Ban, Despise, Wasteful, Lame}	{Coach, Proud, Complete, Graduate, Balloons, Care, Church}
02.wav	{Bored, Hopeless, Perish, Hell, Upset, Avoid, Dandruff}	{Singing, Energy, Applaud, Cottage, Humor, Festival, Car}	{Life, Sofa, Joke, Sleep, Photographer, Improve, Truthful}	NA	{Anguished, Sting, Mistake, Sad, Worse, Hostage, Broken}	{Assassin, Expel, Ignorance, Misfortune, Bleed, Grief, Cockroach}

Table B.2 (continued)

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
03_L.wav	{Blister, Denial, Argue, Worry, Jealous, Cranky, Drugs}	{Creepy, Disgusting, Agony, Leave, Urine, Pervert, Harass}	{Cut, Allergy, Bothered, Hostility, Lose, Divorce, Remorse}	{Cook, Wealth, Warmth, Spa, Tasty, Elated, Profit}	{Complement, Fame, Decorate, Hobby, Game, Legendary, Honey}	NA
04_L.wav	{Poet, Satisfied, Heir, Volunteered, Brownies, Gallery, Friendly}	NA	{Bored, Hopeless, Perish, Hell, Upset, Avoid, Dandruff}	{Appreciate, Female, Daisy, Fabulous, Passion, Surfer, Ocean}	{Football, Glaze, Interest, Colorful, Kiss, Elegant, Forest}	NA
05_L.wav	{Math, Cocaine, Starvation, Flu, Dead, Dump, Widow}	{Wedding, Gift, Memories, Strong, Picnic, Mansion, Lucky}	{Bitter, Suffer, Morbid, Clot, Enraged, Surgery, Fighting}	{Anguished, Sting, Mistake, Sad, Worse, Hostage, Broken}	{Blister, Denial, Argue, Worry, Jealous, Cranky, Drugs}	{Entertain, Idol, Grin, Lust, Fantasy, Pillow, Wishful}
06_L.wav	{Thankful, Puppy, Wink, Rescue, Vote, Savior, Trophy}	NA	{Admired, Sailboat, Guitar, Lovable, Play, Gentleman, Refreshment}	NA	{Arson, Freeze, Scam, Homeless, Tornado, Dreary, Alarm}	{Creepy, Disgusting, Agony, Leave, Urine, Pervert, Harass}
07_L.wav	{Neglect, Tense, Tarnish, Stain, Hurt, Pale, Mope}	{Arson, Freeze, Scam, Homeless, Tornado, Dreary, Alarm}	{Injury, Abortion, Stress, Fever, Bankrupt, Wreck, Brutal}	{Thankful, Puppy, Wink, Rescue, Vote, Savior, Trophy}	{Insecure, Addicted, Insult, Severe, Despair, Struggle, Crime}	{Appreciate, Female, Daisy, Fabulous, Passion, Surfer, Ocean}

Table B.2 (continued)

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
08_L.wav	{Irritated, Abandon, End, Bald, Chore, Trauma, Fail}	{Delayed, Repulsed, Fake, Nightmare, Burdened, Disability, Brat}	{Delayed, Repulsed, Fake, Nightmare, Burdened, Disability, Brat}	{Sewage, Blackmail, Crash, Embarrass, Dictator, Scorn, Stolen}	{Free, Talk, Surprise, Airplane, Sister, Green, Rainbow}	NA
09.wav	{Entertain, Idol, Grin, Lust, Fantasy, Pillow, Wishful}	NA	{Wedding, Gift, Memories, Strong, Picnic, Mansion, Lucky}	NA	{Neglect, Tense, Tarnish, Stain, Hurt, Pale, Mope}	{Sabotage, Braces, Torture, Gossip, Ugly, Difficult, Hysteria}
10_L.wav	{Detain, Sin, Weak, Rumor, Slap, Intruder, Disrespect}	{Compliment, Fame, Decorate, Hobby, Game, Legendary, Honey}	{Free, Talk, Surprise, Airplane, Sister, Green, Rainbow}	NA	{Accuse, War, Depressed, Crude, Seasick, Choke, Insane}	{Math, Cocaine, Starvation, Flu, Dead, Dump, Widow}
11_L.wav	{Moon, Marvel, Laugh, Cute, Parrot, Relax, Soft}	NA	{Math, Cocaine, Starvation, Flu, Dead, Dump, Widow}	{Creepy, Disgusting, Agony, Leave, Urine, Pervert, Harass}	{Poison, Owe, Furious, Infest, Resign, Penalty, Lie}	{Cook, Wealth, Warmth, Spa, Tasty, Elated, Profit}
12_L.wav	{Poison, Owe, Furious, Infest, Resign, Penalty, Lie}	{Mountain, Innocence, Glow, Lake, Fashion, Dance, Explore}	{Blister, Denial, Argue, Worry, Jealous, Cranky, Drugs}	{Singing, Energy, Applaud, Cottage, Humor, Festival, Car}	{Moon, Marvel, Laugh, Cute, Parrot, Relax, Soft}	NA

Table B.2 (continued)

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
13_L.wav	{Assassin, Expel, Ignorance, Misfortune, Bleed, Grief, Cockroach}	{Sewage, Blackmail, Crash, Embarrass, Dictator, Scorn, Stolen}	{Neglect, Tense, Tarnish, Stain, Hurt, Pale, Mope}	{Moon, Marvel, Laugh, Cute, Parrot, Relax, Soft}	{Irritated, Abandon, End, Bald, Chore, Trauma, Fail}	{Cut, Allergy, Bothered, Hostility, Lose, Divorce, Remorse}
14.wav	{Free, Talk, Surprise, Airplane, Sister, Green, Rainbow}	NA	{Accuse, War, Depressed, Crude, Seasick, Choke, Insane}	{Disaster, Traffic, Stinky, Frown, Pollute, Cigarette, Rush}	{Admired, Sailboat, Guitar, Lovable, Play, Gentleman, Refreshment}	NA
15.wav	{Cut, Allergy, Bothered, Hostility, Lose, Divorce, Remorse}	{Appreciate, Female, Daisy, Fabulous, Passion, Surfer, Ocean}	{Assassin, Expel, Ignorance, Misfortune, Bleed, Grief, Cockroach}	{Entertain, Idol, Grin, Lust, Fantasy, Pillow, Wishful}	{Wedding, Gift, Memories, Strong, Picnic, Mansion, Lucky}	NA
16_L.wav	{Anguished, Sting, Mistake, Sad, Worse, Hostage, Broken}	{Admired, Sailboat, Guitar, Lovable, Play, Gentleman, Refreshment}	{Paranoid, Selfish, Bastard, Affair, Isolation, Cancer, Pessimism}	{Irritated, Abandon, End, Bald, Chore, Trauma, Fail}	{Betray, Weep, Butcher, Trash, Parasite, Heartless, Refuse}	{Life, Sofa, Joke, Sleep, Photographer, Improve, Truthful}
17_L.wav	{Insecure, Addicted, Insult, Severe, Despair, Struggle, Crime}	{Injury, Abortion, Stress, Fever, Bankrupt, Wreck, Brutal}	{Complement, Fame, Decorate, Hobby, Game, Legendary, Honey}	NA	{Sewage, Blackmail, Crash, Embarrass, Dictator, Scorn, Stolen}	{Poet Satisfied, Heir, Volunteered, Brownies, Gallery, Friendly}

Table B.2 (continued)

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
18_L.wav	{Cook, Wealth, Warmth, Spa, Tasty, Elated, Profit}	NA	{Football, Glaze, Interest, Colorful, Kiss, Elegant, Forest}	NA	{Injury, Abortion, Stress, Fever, Bankrupt, Wreck, Brutal}	{Bored, Hopeless, Perish, Hell, Upset, Avoid, Dandruff}
19_L.wav	{Cheery, Jewel, Imagination, Health, Guaranteed, Delight, Eager}	NA	{Arson, Freeze, Scam, Homeless, Tornado, Dreary, Alarm}	{Coach, Proud, Complete, Graduate, Balloons, Care, Church}	{Cheery, Jewel, Imagination, Health, Guaranteed, Delight, Eager}	NA
20.wav	{Accuse, War, Depressed, Crude, Seasick, Choke, Insane}	{Bitter, Suffer, Morbid, Clot, Enraged, Surgery, Fighting}	{Detain, Sin, Weak, Rumor, Slap, Intruder, Disrespect}	{Betray, Weep, Butcher, Trash, Parasite, Heartless, Refuse}	{Bitter, Suffer, Morbid, Clot, Enraged, Surgery, Fighting}	{Singing, Energy, Applaud, Cottage, Humor, Festival Car}
21_L.wav	{Crucify, Puke, Exam, Beg, Shun, Pain, Gloom}	{Life, Sofa, Joke, Sleep, Photographer, Improve, Truthful}	{Cheery, Jewel, Imagination, Health, Guaranteed, Delight, Eager}	NA	{Detain, Sin, Weak, Rumor, Slap, Intruder, Disrespect}	{Disaster, Traffic, Stinky, Frown, Pollute, Cigarette, Rush}
22_L.wav	{Disaster, Traffic, Stinky, Frown, Pollute, Cigarette, Rush}	{Sabotage, Braces, Torture, Gossip, Ugly, Difficult, Hysteria}	{Sabotage, Braces, Torture, Gossip, Ugly, Difficult, Hysteria}	{Poet, Satisfied, Heir, Volunteered, Brownies, Gallery, Friendly}	{Mountain, Innocence Glow, Lake, Fashion, Dance, Explore	NA

Table B.2 (continued)

Context	V1_Day1	V1_Day2	V2_Day1	V2_Day2	V3_Day1	V3_Day2
23_L.wav	{Football, Glaze, Interest, Colorful, Kiss, Elegant, Forest}	NA	{Mountain, Innocence, Glow, Lake, Fashion, Dance, Explore}	NA	{Crucify, Puke, Exam, Beg, Shun, Pain, Gloom}	{Paranoid, Selfish, Bastard, Affair, Isolation, Cancer, Pessimism}
24_L.wav	{Betray, Weep, Butcher, Trash, Parasite, Heartless, Refuse}	{Coach, Proud, Complete, Graduate, Balloons, Care, Church}	{Insecure, Addicted, Insult, Severe, Despair, Struggle, Crime}	{Accident, Terrible, Skunk, Ban, Despise, Wasteful, Lame}	{Delayed, Repulsed, Fake, Nightmare, Burdened, Disability, Brat}	{Thankful, Puppy, Wink, Rescue, Vote, Savior, Trophy}

APPENDIX C
PARTICIPANT INSTRUCTIONS

The following instructions were given to each participant. Instructions were first given verbally and presented on the screen before each task.

C.1 Instructions for Affective Ratings Task (Day 1)

As part of the task, we will ask you to describe the emotions that are EVOKED by the different pieces of music that you hear. For instance, the first piece of music might be happy and lively—how do you feel in response? You might feel equally happy and energized yourself. Or you may find that the music has little to no effect on how you are feeling. For each piece, please pay attention and reflect on what YOU ARE FEELING. For instance, do you notice a shift in your emotions when the music starts playing? Do you notice any lingering effects or emotions after the piece is over? How does your body feel after listening to the piece?

Practice: Press [space] to listen to a piece of music. Pay attention to the emotions evoked in you by the music.

We will also ask you about the depth of connection you felt for the music. CONNECTION refers to the extent to which you are able to feel the emotions of the music. Think about your response on the last page—did you find yourself sharing or partaking in the emotions of the music? Or did you maybe find it difficult to relate to the music in this way?

You will also be asked to answer questions regarding your familiarity and liking for the piece of music.

You will hear several pieces of music. Just as before, pay attention to YOUR emotions as you listen to each piece. Additionally, try and FAMILIARIZE yourself with each piece of music, so that you may recognize it later.

C.2 Instructions for Story-Making Task (Day 1)

C.2.1 Run 1

You have just discovered that you are the main character of a novel. Events in your life are being written and communicated to you by some unknown “author;” you are living out the plot as the author narrates it. With each new event, you will hear its “soundtrack:” a piece of music that reflects the emotions of the event you are about to “experience.” You are already familiar with these soundtracks and have practiced this in the previous task. You will also see 7 words on the screen. These words are all part of the description of the event written by your author.

In just 1-3 sentences, use AS MANY of the SHOWN words AS POSSIBLE to reconstruct the description of this upcoming event. This should be in the FIRST PERSON. Keep the descriptions SIMPLE and AVOID including words that are NOT ON THE SCREEN (words like ”I,” ”am,” ”have,” ”like,” etc. that are needed for sentence structure are fine).

Practice: Try using the following words to make a simple, 1-3 sentence event description in the first person. Form the sentences in your head—you will not be writing them down or recording them in any way. As you mentally create your event, CLICK on words to mark them as ”used.” They will change color. Please pause after creating your story and await instructions.

Good job! Again, make sure your description...

- Is in the FIRST PERSON.
- Is SIMPLE and AVOIDS words NOT ON THE SCREEN.
- Uses AS MANY SHOWN WORDS AS POSSIBLE. It’s ok if you cannot easily use every word. PRIORITIZE having a simple and cohesive event description.

As before, make sure you CLICK on each word as you incorporate it into your story. Remember that you will also be hearing each event’s ”soundtrack.” The music reflects the emotions of the event you are trying to reconstruct, so make sure to consider that as you form your descriptions. Again, you CANNOT write down or record your event descriptions but try to REMEMBER IT as we will ask you to repeat it later.

You will be asked to do this several times with different "events" (words and music). Each event should be INDEPENDENT of the others.

C.2.2 Run 2

You will now hear the same soundtrack and see the same words repeated again. Think of the event descriptions you have already made with those words and music. As you do this, FOCUS ON MEMORIZING your description and FAMILIARIZING yourself with the music. Again, CLICK on the words you have incorporated into your description.

Feel free to take a short 1-2 minute break if needed.

C.2.3 Run 3

You will now hear the same soundtrack and see the same words repeated one more time. Think of the event descriptions you have already made with those words and music. Remember that you are a main character of a novel, and that you are living out these events written by your "author." Imagine each event ACTUALLY HAPPENING TO YOU. Additionally focus on BUILDING A CONNECTION between each event and its soundtrack. Again, CLICK on the words you have incorporated into your description.

Feel free to take a short 1-2 minute break if needed.

C.3 Instructions for Story-Making Task (Day 2)

C.3.1 Run 1

Yet again, you have discovered you are the main character of a novel. Events in your life are being written and communicated to you by a DIFFERENT unknown "author;" you are living out the plot as the author narrates it. With each new event, you will hear its "soundtrack:" a piece of music that reflects the emotions of the event you are about to "experience." You may recognize these from yesterday's activity. However, the events you will be presented with today are UNRELATED. You will also see 7 words on the screen. These words are all part of the description of the event written by your new author.

In just 1-3 sentences, use the words shown to reconstruct the description of this upcoming event. This should be in the FIRST PERSON; imagine this event actually happening to you. Use as many of the SHOWN words as possible. Keep the descriptions SIMPLE and AVOID including words that are NOT ON THE SCREEN (words like "I," "am," "have," "like," etc. that are needed for sentence structure are fine). Do NOT write it down or record it but try to remember it as we will ask you to repeat it later. You will be asked to do this several times with different "events" (words and music). Each event should be INDEPENDENT of the others, but each time imagine yourself as the main character of a story written by this "author."

C.3.2 Run 2

You will now hear the same soundtrack and see the same words repeated again. Think of the event descriptions you have already made with those words and music. As you do this, FOCUS ON MEMORIZING your description and FAMILIARIZING yourself with the music. Again, CLICK on the words you have incorporated into your description.

Feel free to take a short 1-2 minute break if needed.

C.3.3 Run 3

You will now hear the same soundtrack and see the same words repeated one more time. Think of the event descriptions you have already made with those words and music. Remember that you are a main character of a novel, and that you are living out these events written by your "author." Imagine each event ACTUALLY HAPPENING TO YOU. Additionally focus on BUILDING A CONNECTION between each event and its soundtrack.

Again, CLICK on the words you have incorporated into your description.

Feel free to take a short 1-2 minute break if needed.

C.4 Instructions for Free Recall Test (Day 3)

Today's goal is to test your memory of the word sets you saw on DAY 1. In the following task, for each trial, you will hear a piece of music you have heard on previous days. On previous days, you used each piece of music to make up stories using word sets. Your task today is to try to recall as many words as you can that were paired with each piece of music on DAY 1. You will hear the music and be provided with a textbox. Type INDIVIDUAL WORDS SEPARATED BY SPACES that you remember from this set on DAY 1 ONLY. Do not worry about spelling mistakes.

You will have 1 minute for each trial. Your response will be automatically submitted when time is up. If you finish early, you may click the ”submit” button above the text box.

C.5 Instructions for Forced-Choice Recognition Test (Day 3)

Good Job! You finished the first task of DAY 3.

Next, we are going to test you on your memory of DAY 1 words in another format. In each trial, you will see a word. Please indicate if the word appeared on DAY 1: press [y] for yes and [n] for no. Then from 1 -5, rate how confident you are about your answer.

APPENDIX D

REVISED SHORT TEST OF MUSICAL PREFERENCES

Please indicate your basic preference for each of the following genres using the scale provided.

	Dislike strongly	Dislike moderately	Dislike a little	Neither like nor dislike	Like a little	Like moderately	Like strongly
Alternative	○	○	○	○	○	○	○
Bluegrass	○	○	○	○	○	○	○
Blues	○	○	○	○	○	○	○
Classical	○	○	○	○	○	○	○
Country	○	○	○	○	○	○	○
Dance/Electronica	○	○	○	○	○	○	○
Folk	○	○	○	○	○	○	○
Funk	○	○	○	○	○	○	○
Gospel	○	○	○	○	○	○	○
Heavy Metal	○	○	○	○	○	○	○
World	○	○	○	○	○	○	○
Jazz	○	○	○	○	○	○	○

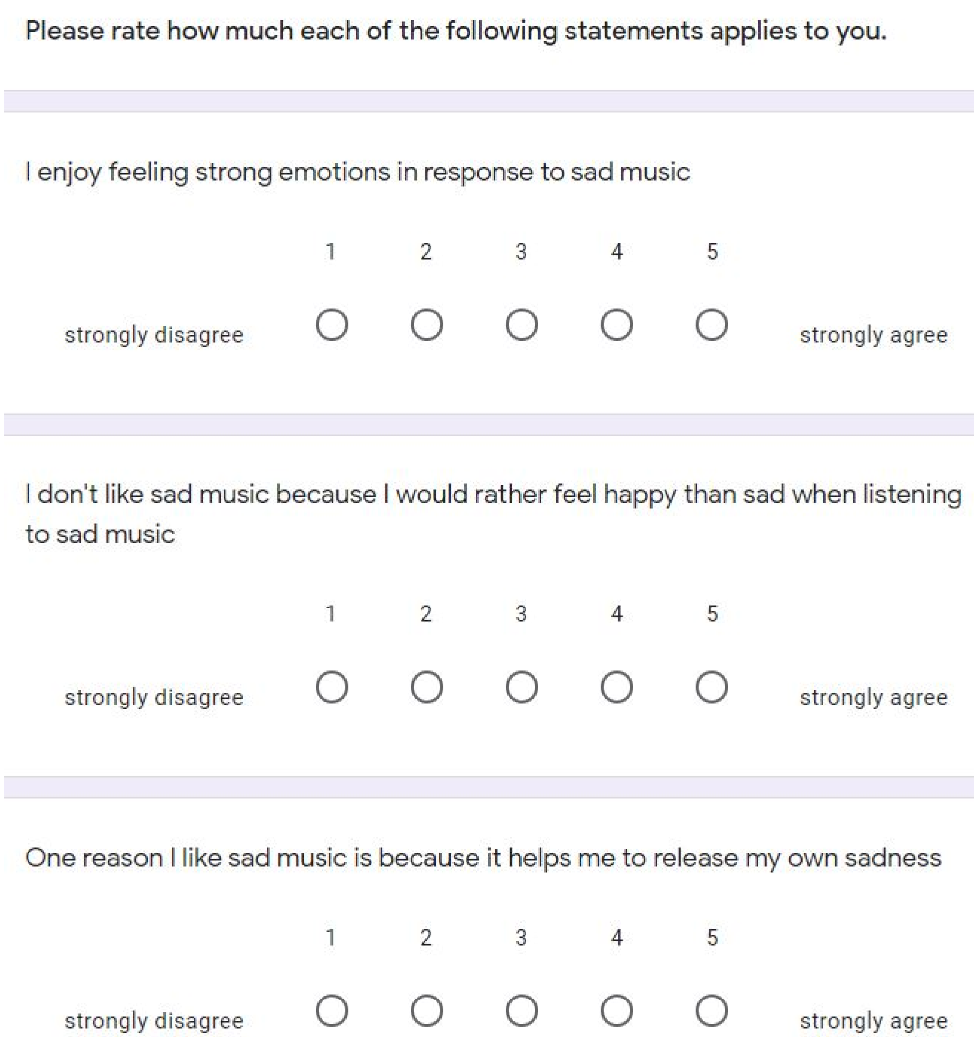
Figure D.1: Questions from the STOMP-R as presented to participants in the post-task questionnaire.

New Age							
Oldies							
Opera							
Pop							
Punk							
Rap/Hip-hop							
Reggae							
Religious							
Rock							
Soul/R&B							
Soundtracks/Theme songs							

Figure D.1 (continued)

APPENDIX E

LIKE SAD MUSIC SCALE


Please rate how much each of the following statements applies to you.

I enjoy feeling strong emotions in response to sad music

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

I don't like sad music because I would rather feel happy than sad when listening to sad music

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

One reason I like sad music is because it helps me to release my own sadness

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Figure E.1: Quetions from the LSMS as presented to participants in the post-task questionnaire.

Sad music is too depressing for me to enjoy

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

I like listening to sad music because I can relate to the feelings and emotions being expressed

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

I don't enjoy sad music because I like to be entertained or uplifted when I listen to music

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Figure E.1 (continued)

I often find myself grieving as a result of listening to sad music

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

I only like to listen to sad music if it resolves happily

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

I enjoy feelings of sadness or grief when listening to music

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Figure E.1 (continued)

REFERENCES

[1] D. M. Greenberg, M. Kosinski, D. J. Stillwell, B. L. Monteiro, D. J. Levitin, and P. J. Rentfrow, "The Song Is You: Preferences for Musical Attribute Dimensions Reflect Personality," *Social Psychological and Personality Science*, vol. 7, no. 6, pp. 597–605, Aug. 2016.

[2] P. N. Juslin and D. Västfjäll, "Emotional responses to music: The need to consider underlying mechanisms," *Behavioral and Brain Sciences*, vol. 31, no. 5, pp. 559–575, Oct. 2008.

[3] K. Jakubowski and A. Ghosh, "Music-evoked autobiographical memories in everyday life," *Psychology of Music*, vol. 49, no. 3, pp. 649–666, May 2021.

[4] J. A. Sloboda and S. A. O'Neill, "Emotions in everyday listening to music," in *Music and emotion: Theory and research*, P. N. Juslin and J. A. Sloboda, Eds., New York, NY, US: Oxford University Press, 2001, pp. 415–429.

[5] G. Husain, W. F. Thompson, and E. G. Schellenberg, "Effects of Musical Tempo and Mode on Arousal, Mood, and Spatial Abilities," *Music Perception*, vol. 20, no. 2, pp. 151–171, 2002.

[6] W. F. Thompson, E. G. Schellenberg, and G. Husain, "Arousal, mood, and the Mozart effect," *Psychological Science*, vol. 12, no. 3, pp. 248–251, May 2001.

[7] A. J. Cohen, "Congruence-Association Model and Experiments in Film Music: Toward Interdisciplinary Collaboration," *Music and the Moving Image*, vol. 8, no. 2, pp. 5–24, 2015.

[8] M. B. Holbrook and R. M. Schindler, "Some exploratory findings on the development of musical tastes," *Journal of Consumer Research*, vol. 16, no. 1, pp. 119–124, Jun. 1989.

[9] H. Egermann and S. McAdams, "Empathy and Emotional Contagion as a Link Between Recognized and Felt Emotions in Music Listening," *Music Perception*, vol. 31, no. 2, pp. 139–156, 2013.

[10] A. J. Blood and R. J. Zatorre, "Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion," *Proceedings of the National Academy of Sciences*, vol. 98, no. 20, pp. 11 818–11 823, Sep. 2001.

[11] D. Lewis, "Psychobiology of active and inactive memory," *Psychology Bulletin*, vol. 86, no. 5, pp. 1054–1083, 1979.

[12] A. Hupbach, R. Gomez, O. Hardt, and L. Nadel, “Reconsolidation of episodic memories: A subtle reminder triggers integration of new information,” *Learning & Memory (Cold Spring Habor, N.Y.)*, vol. 14, no. 1-2, pp. 47–53, 2007.

[13] G. Högberg and T. Hällström, “Mood Regulation Focused CBT Based on Memory Reconsolidation, Reduced Suicidal Ideation and Depression in Youth in a Randomised Controlled Study,” *International Journal of Environmental Research and Public Health*, vol. 15, no. 5, p. 921, May 2018.

[14] R. D. Lane, L. Ryan, L. Nadel, and L. Greenberg, “Memory reconsolidation, emotional arousal, and the process of change in psychotherapy: New insights from brain science,” *Behavioral and Brain Sciences*, vol. 38, E1, 2015.

[15] G. Högberg, D. Nardo, T. Hällström, and M. Pagani, “Affective psychotherapy in post-traumatic reactions guided by affective neuroscience: Memory reconsolidation and play,” *Psychology research and behavior management*, vol. 4, pp. 87–96, Jul. 2011.

[16] P. N. Juslin and J. A. Sloboda, Eds., *Music and emotion: Theory and research*. New York, NY, US: Oxford University Press, 2001.

[17] P. N. Juslin, “Communicating emotion in music performance: A review and a theoretical framework,” in *Music and emotion: Theory and research*, P. N. Juslin and J. A. Sloboda, Eds., New York, NY, US: Oxford University Press, 2001, pp. 309–337.

[18] P. N. Juslin and G. Madison, “The Role of Timing Patterns in Recognition of Emotional Expression from Musical Performance,” *Music Perception*, vol. 17, no. 2, pp. 197–221, 1999.

[19] K. Kallinen and N. Ravaja, “Emotion perceived and emotion felt: Same and different,” *Musicae Scientiae*, vol. 10, no. 2, pp. 191–213, Sep. 2006.

[20] J. M. Valla, J. A. Alappatt, A. Mathur, and N. C. Singh, “Music and Emotion—A Case for North Indian Classical Music,” *Frontiers in Psychology*, vol. 8, p. 2115, 2017.

[21] P. N. Juslin, “From everyday emotions to aesthetic emotions: Towards a unified theory of musical emotions,” *Physics of Life Reviews*, vol. 10, no. 3, pp. 235–266, Sep. 2013.

[22] N. Steinbeis, S. Koelsch, and J. A. Sloboda, “The Role of Harmonic Expectancy Violations in Musical Emotions: Evidence from Subjective, Physiological, and Neural Responses,” *Journal of Cognitive Neuroscience*, vol. 18, no. 8, pp. 1380–1393, Aug. 2006.

[23] A. Bolders, G. Band, and P. J. Stallen, “Evaluative Conditioning Induces Changes in Sound Valence,” *Frontiers in Psychology*, vol. 3, p. 106, 2012.

[24] T. Lipps, “Einfühling, innere Nachahmung und Organempfindung.,” in *Archiv für Gesamte Psychologie*, 1903, 1: 465–519.

[25] E. Hatfield, R. L. Rapson, and Y.-C. L. Le, “Emotional contagion and empathy,” in *The Social Neuroscience of Empathy*, J. Decety and W. Ickes, Eds., Cambridge, MA: MIT Press, 2009.

[26] G. Rizzolatti and L. Craighero, “The mirror-neuron system,” *Annual Review of Neuroscience*, vol. 27, pp. 169–192, 2004.

[27] P. N. Juslin and P. Laukka, “Communication of emotions in vocal expression and music performance: Different channels, same code?” *Psychological Bulletin*, vol. 129, no. 5, pp. 770–814, Sep. 2003.

[28] S. Koelsch, T. Fritz, D. Y. v. Cramon, K. Müller, and A. D. Friederici, “Investigating emotion with music: An fMRI study,” *Human Brain Mapping*, vol. 27, pp. 239–250, Mar. 2006.

[29] J. A. Russell, “A circumplex model of affect,” *Journal of Personality and Social Psychology*, vol. 39, no. 6, pp. 1161–1178, 1980.

[30] J. A. Russell and A. Mehrabian, “Evidence for a three-factor theory of emotions,” *Journal of Research in Personality*, vol. 11, no. 3, pp. 273–294, Sep. 1977.

[31] R. L. Hodes, E. W. I. Cook, and P. J. Lang, “Individual differences in autonomic response: Conditioned association or conditioned fear?” *Psychophysiology*, vol. 22, no. 5, pp. 545–560, 1985.

[32] P. J. Lang, “Behavioral treatment and bio-behavioral assessment: Computer applications,” in *Technology in mental health care delivery systems*, J. B. Sidowski, J. H. Johnson, and T. A. Williams, Eds., Norwood, NJ: Ablex Publishing, 1980, pp. 119–137.

[33] K. R. Fricke, D. M. Greenberg, P. J. Rentfrow, and P. Y. Herzberg, “Measuring musical preferences from listening behavior: Data from one million people and 200,000 songs,” *Psychology of Music*, vol. 49, no. 3, pp. 371–381, May 2021.

[34] D. M. Greenberg, S. Baron-Cohen, D. J. Stillwell, M. Kosinski, and P. J. Rentfrow, “Musical Preferences are Linked to Cognitive Styles,” *PLOS ONE*, vol. 10, no. 7, pp. 1–22, Jul. 2015.

[35] U. Schimmack and A. Grob, "Dimensional models of core affect: A quantitative comparison by means of structural equation modeling," *European Journal of Personality*, vol. 14, no. 4, pp. 325–345, 2000.

[36] A. Bonneville-Roussy, D. Stillwell, M. Kosinski, and J. Rust, "Age trends in musical preferences in adulthood: 1. Conceptualization and empirical investigation," *Musicae Scientiae*, vol. 21, no. 4, pp. 369–389, Feb. 2017.

[37] A. Bonneville-Roussy and T. Eerola, "Age trends in musical preferences in adulthood: 3. Perceived musical attributes as intrinsic determinants of preferences," *Musicae Scientiae*, vol. 22, no. 3, pp. 394–414, Sep. 2018.

[38] L. Harrison and P. Loui, "Thrills, chills, frissons, and skin orgasms: Toward an integrative model of transcendent psychophysiological experiences in music," *Frontiers in Psychology*, vol. 5, p. 790, 2014.

[39] L. Ferreri and A. Rodriguez-Fornells, "Music-related reward responses predict episodic memory performance," *Experimental Brain Research*, vol. 235, pp. 3721–3731, Dec. 2017.

[40] J. Lingham and T. Theorell, "Self-selected "favourite" stimulative and sedative music listening – how does familiar and preferred music listening affect the body?" *Nordic Journal of Music Therapy*, vol. 18, no. 2, pp. 150–166, Sep. 2009.

[41] F. Perrin, M. Castro, B. Tillmann, and J. Luauté, "Promoting the use of personally relevant stimuli for investigating patients with disorders of consciousness," *Frontiers in Psychology*, vol. 6, p. 1102, 2015.

[42] M. H. Thaut and W. B. Davis, "The Influence of Subject-Selected versus Experimenter-Chosen Music on Affect, Anxiety, and Relaxation," *Journal of Music Therapy*, vol. 30, no. 4, pp. 210–223, Dec. 1993.

[43] V. N. Salimpoor, I. van den Bosch, N. Kovacevic, A. R. McIntosh, A. Dagher, and R. J. Zatorre, "Interactions between the nucleus accumbens and auditory cortices predict music reward value," *Science (New York, N.Y.)*, vol. 340, no. 6129, pp. 216–219, Apr. 2013.

[44] S. O. Ali and Z. F. Peynircioğlu, "Intensity of Emotions Conveyed and Elicited by Familiar and Unfamiliar Music," *Music Perception*, vol. 27, no. 3, pp. 177–182, Feb. 2010.

[45] P. J. Rentfrow, L. R. Goldberg, and D. J. Levitin, "The Structure of Musical Preferences: A Five-Factor Model," *Journal of personality and social psychology*, vol. 100, no. 6, pp. 1139–1157, Jun. 2011.

[46] A. Lamont and A. Greasley, "Musical preferences," in *The Oxford Handbook of Music Psychology*, S. Hallam, I. Cross, and M. Thaut, Eds., 1st ed., Oxford University Press, Dec. 2008, pp. 263–281.

[47] E. Lex, D. Kowald, and M. Schedl, "Modeling Popularity and Temporal Drift of Music Genre Preferences," in *Transactions of the International Society for Music Information Retrieval*, vol. 3, Mar. 2020, pp. 17–30.

[48] T. Eerola, J. Vuoskoski, and H. Kautiainen, "Being Moved by Unfamiliar Sad Music Is Associated with High Empathy," *Frontiers in Psychology*, vol. 7, 2016.

[49] J. Vuoskoski and T. Eerola, "Can sad music really make you sad? Indirect measures of affective states induced by music and autobiographical memories.," *Psychology of Aesthetics, Creativity, and the Arts*, vol. 6, no. 3, pp. 204–213, 2012.

[50] J. Vuoskoski, W. Thompson, D. Mcilwain, and T. Eerola, "Who Enjoys Listening to Sad Music and Why?" *Music Perception*, vol. 29, no. 3, pp. 311–317, Feb. 2012.

[51] T. Eerola, H.-R. Peltola, and J. Vuoskoski, "Attitudes Toward Sad Music Are Related to Both Preferential and Contextual Strategies," *Psychomusicology: Music, Mind, and Brain*, vol. 25, no. 2, pp. 116–123, 2015.

[52] S. Garrido and E. Schubert, "Adaptive and maladaptive attraction to negative emotions in music," *Musicae Scientiae*, vol. 17, no. 2, pp. 147–166, Jun. 2013.

[53] M. B. Oliver, "Exploring the Paradox of the Enjoyment of Sad Films," *Human Communication Research*, vol. 19, no. 3, pp. 315–342, 1993.

[54] F. H. Rauscher, G. L. Shaw, and C. N. Ky, "Music and spatial task performance," *Nature*, vol. 365, p. 611, Oct. 1993.

[55] S. M. Carr and N. S. Rickard, "The use of emotionally arousing music to enhance memory for subsequently presented images," *Psychology of Music*, vol. 44, no. 5, pp. 1145–1157, 2016.

[56] S. Silva, F. Belim, and S. L. Castro, "The Mozart Effect on the Episodic Memory of Healthy Adults Is Null, but Low-Functioning Older Adults May Be an Exception," *Frontiers in Psychology*, vol. 11, p. 538 194, Nov. 2020.

[57] S. Bottiroli, A. Rosi, R. Russo, T. Vecchi, and E. Cavallini, "The cognitive effects of listening to background music on older adults: Processing speed improves with upbeat music, while memory seems to benefit from both upbeat and downbeat music," *Frontiers in Aging Neuroscience*, vol. 6, p. 284, 2014.

[58] L. Ferreri, J.-J. Aucouturier, M. Muthalib, E. Bigand, and A. Bugaiska, "Music improves verbal memory encoding while decreasing prefrontal cortex activity: An fNIRS study," *Frontiers in Human Neuroscience*, vol. 7, p. 779, 2013.

[59] L. Ferreri, E. Bigand, and A. Bugaiska, "The positive effect of music on source memory," *Musicae Scientiae*, vol. 19, no. 4, pp. 402–411, Dec. 2015.

[60] W.-J. He, W.-C. Wong, and A. N.-N. Hui, "Emotional Reactions Mediate the Effect of Music Listening on Creative Thinking: Perspective of the Arousal-and-Mood Hypothesis," *Frontiers in Psychology*, vol. 8, p. 1680, 2017.

[61] S. Eschrich, T. F. Münte, and E. O. Altenmüller, "Unforgettable film music: The role of emotion in episodic long-term memory for music," *BMC Neuroscience*, vol. 9, p. 48, May 2008.

[62] M. M. Bradley, M. K. Greenwald, M. C. Petry, and P. J. Lang, "Remembering pictures: Pleasure and arousal in memory," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 18, no. 2, pp. 379–390, 1992.

[63] E. A. Kensinger and S. Corkin, "Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words?" *Memory & Cognition*, vol. 31, pp. 1169–1180, Dec. 2003.

[64] A. J. Cohen, "Music as a source of emotion in film," in *Music and emotion: Theory and research*, P. N. Juslin and J. A. Sloboda, Eds., New York, NY, US: Oxford University Press, 2001, pp. 249–272.

[65] S. K. Marshall and A. J. Cohen, "Effects of Musical Soundtracks on Attitudes toward Animated Geometric Figures," *Music Perception*, vol. 6, no. 1, pp. 95–112, 1988.

[66] M. G. Boltz, "The cognitive processing of film and musical soundtracks," *Memory & Cognition*, vol. 32, pp. 1194–1205, Oct. 2004.

[67] J. Tamminen, K. Rastle, J. Darby, R. Lucas, and V. J. Williamson, "The impact of music on learning and consolidation of novel words," *Memory*, vol. 25, no. 1, pp. 107–121, Jan. 2017.

[68] A. Racette and I. Peretz, "Learning lyrics: To sing or not to sing?" *Memory & Cognition*, vol. 35, pp. 242–253, Mar. 2007.

[69] W. T. Wallace, "Memory for music: Effect of melody on recall of text," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 20, no. 6, pp. 1471–1485, 1994.

[70] T. Nguyen and J. A. Grahn, “Mind your music: The effects of music-induced mood and arousal across different memory tasks,” *Psychomusicology: Music, Mind, and Brain*, vol. 27, no. 2, pp. 81–94, 2017.

[71] P. Janata, S. T. Tomic, and S. K. Rakowski, “Characterisation of music-evoked autobiographical memories,” *Memory*, vol. 15, no. 8, pp. 845–860, Nov. 2007.

[72] A. M. Belfi, B. Karlan, and D. Tranel, “Music evokes vivid autobiographical memories,” *Memory*, vol. 24, no. 7, pp. 979–989, Aug. 2016.

[73] M. El Haj, L. Fasotti, and P. Allain, “The involuntary nature of music-evoked autobiographical memories in Alzheimer’s disease,” *Consciousness and Cognition*, vol. 21, no. 1, pp. 238–246, Mar. 2012.

[74] K. Nader, “Memory traces unbound,” *TRENDS in Neurosciences*, vol. 26, no. 2, pp. 65–72, 2003.

[75] C. Forcato, V. L. Burgos, P. F. Argibay, V. A. Molina, M. E. Pedreira, and H. Maldonado, “Reconsolidation of declarative memory in humans,” *Learning & Memory (Cold Spring Harbor, N.Y.)*, vol. 14, no. 4, pp. 295–303, Apr. 2007.

[76] M. Kindt, M. Soeter, and B. Vervliet, “Beyond extinction: Erasing human fear responses and preventing the return of fear,” *Nature Neuroscience*, vol. 12, pp. 256–258, Mar. 2009.

[77] M. P. Walker, T. Brakefield, J. A. Hobson, and R. Stickgold, “Dissociable stages of human memory consolidation and reconsolidation,” *Nature*, vol. 425, pp. 616–620, Oct. 2003.

[78] A. Hupbach, R. Gomez, and L. Nadel, “Episodic Memory Reconsolidation: An Update,” in *Memory Reconsolidation*, C. M. Alberini, Ed., Academic Press, 2013, pp. 233–247.

[79] L. Nyberg, A. R. McIntosh, R. Cabeza, R. Habib, S. Houle, and E. Tulving, “General and specific brain regions involved in encoding and retrieval of events: What, where, and when,” *Proceedings of the National Academy of Sciences*, vol. 93, no. 20, pp. 11 280–11 285, Oct. 1996.

[80] E. Tulving, “Episodic Memory: From Mind to Brain,” *Annual Review of Psychology*, vol. 53, no. 1, pp. 1–25, Feb. 2002.

[81] A. Hupbach, O. Hardt, R. Gomez, and L. Nadel, “The dynamics of memory: Context-dependent updating.,” *Learning & memory*, vol. 15, no. 8, pp. 574–579, 2008.

[82] A. Hupbach, R. Gomez, and L. Nadel, "Episodic memory reconsolidation: Updating or source confusion?" *Memory*, vol. 17, no. 5, pp. 502–510, Jul. 2009.

[83] ——, "Episodic memory updating: The role of context familiarity," *Psychonomic Bulletin & Review*, vol. 18, no. 4, pp. 787–797, Aug. 2011.

[84] K. R. Tay, "Episodic Memory Reconsolidation and Strengthening," Doctor of Philosophy, University of Birmingham, Sep. 2018.

[85] L. A. Warrenburg, "Choosing the Right Tune: A Review of Music Stimuli Used in Emotion Research," *Music Perception*, vol. 37, no. 3, pp. 240–258, Feb. 2020.

[86] T. Eerola and J. Vuoskoski, "A comparison of the discrete and dimensional models of emotion in music," *Psychology of Music*, vol. 39, no. 1, pp. 18–49, Jan. 2011.

[87] *Audacity*, 2017.

[88] M. M. Bradley and P. J. Lang, "Affective Norms for English Words (ANEW): Instruction Manual and Affective Ratings," *Technical Report C-1, The Center for Research in Psychophysiology, University of Florida*, p. 49, 1999.

[89] P. J. Lang and M. M. Bradley, "International Affective Picture System (IAPS): Technical Manual and Affective Ratings," *NIMH Center for the Study of Emotion and Attention*, 1997.

[90] Z. Chen and N. Cowan, "Core verbal working-memory capacity: The limit in words retained without covert articulation," *Quarterly Journal of Experimental Psychology*, vol. 62, no. 7, pp. 1420–1429, Jul. 2009.

[91] G. A. Miller, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information," *Psychological Review*, vol. 63, no. 2, pp. 81–97, 1956.

[92] E. A. Kensinger and D. L. Schacter, "Amygdala Activity Is Associated with the Successful Encoding of Item, But Not Source, Information for Positive and Negative Stimuli," *Journal of Neuroscience*, vol. 26, no. 9, pp. 2564–2570, Jan. 2006.

[93] ——, "Reality monitoring and memory distortion: Effects of negative, arousing content," *Memory & Cognition*, vol. 34, no. 2, pp. 251–260, 2006.

[94] H. Roediger and K. McDermott, "Creating False Memories: Remembering words not presented in lists," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 21, no. 4, pp. 803–814, Jul. 1995.

[95] L. Postman and B. J. Underwood, “Critical issues in interference theory,” *Memory & Cognition*, vol. 1, pp. 19–40, Mar. 1973.

[96] B. Rasch and J. Born, “About Sleep’s Role in Memory,” *Physiological Reviews*, vol. 93, no. 2, pp. 681–766, Apr. 2013.

[97] J. W. Peirce *et al.*, “PsychoPy2: Experiments in behavior made easy,” *Behavior Research Methods*, vol. 51, no. 1, pp. 195–203, Feb. 2019.

[98] H. J. Eysenck and S. B. G. Eysenck, *Manual of the eysenck personality inventory*. London: University of London Press, 1964.

[99] J. J. M. García, R. Iodice, J. Carro, J. A. Sánchez, F. Palmero, and A. M. Mateos, “Improvement of autobiographic memory recovery by means of sad music in Alzheimer’s Disease type dementia,” *Aging Clinical and Experimental Research*, vol. 24, no. 3, pp. 227–232, Jun. 2012.

[100] A. Clerico, A. Tiwari, R. Gupta, S. Jayaraman, and T. H. Falk, “Electroencephalography Amplitude Modulation Analysis for Automated Affective Tagging of Music Video Clips,” *Frontiers in Computational Neuroscience*, vol. 11, p. 115, 2018.

[101] L. Schwabe and O. T. Wolf, “New Episodic Learning Interferes with the Reconsolidation of Autobiographical Memories,” *PLOS ONE*, vol. 4, no. 10, e7519, Oct. 2009.

[102] J. A. McGeoch, “Forgetting and the law of disuse,” *Psychological Review*, vol. 39, no. 4, pp. 352–370, 1932.

[103] ——, *The Psychology of Human Learning: An Introduction*. New York: Longmans, Green and Co., 1942.

[104] D. M. Clark, J. D. Teasdale, D. E. Broadbent, and M. Martin, “Effect of mood on lexical decisions,” *Bulletin of the Psychonomic Society*, vol. 21, no. 3, pp. 175–178, 1983.

[105] K. Fiedler, H. Pampe, and U. Scherf, “Mood and memory for tightly organized social information,” *European Journal of Social Psychology*, vol. 16, no. 2, pp. 149–164, 1986.

[106] M. Rinck, U. Glowalla, and K. Schneider, “Mood-congruent and mood-incongruent learning,” *Memory & Cognition*, vol. 20, no. 1, pp. 29–39, Jan. 1992.

[107] G. H. Bower, “Mood and memory,” *American Psychologist*, vol. 36, no. 2, pp. 129–148, 1981.

[108] M. D. Schulkind and G. M. Woldorf, “Emotional organization of autobiographical memory,” *Memory & Cognition*, vol. 33, no. 6, pp. 1025–1035, Sep. 2005.

[109] J. W. B. Elsey and M. Kindt, “Tackling maladaptive memories through reconsolidation: From neural to clinical science,” *Neurobiology of Learning and Memory*, vol. 142, no. Pt A, pp. 108–117, Jul. 2017.